

Tree Morphology

1. Bailey, J.D. and J.C. Tappeiner. 1998. Effects of thinning on structural development in 40- to 100-year-old Douglas-fir stands in western Oregon. *Forest-Ecology-and-Management* 108(1/2): 99-113.

Keywords: thinning
commercial thinning
regeneration
tree morphology

Abstract: The composition and structure of the understory was studied in thinned and unthinned Douglas fir/western hemlock (*Pseudotsuga menziesii*/*Tsuga heterophylla*) stands on 32 sites in western Oregon. These stands had regenerated naturally after timber was harvested between 1880 and 1940; they were thinned between 1969 and 1984. Commercially thinned stands had 8-60% of their volume removed 10-24 yr before the study (in 1993-95). Undisturbed old-growth Douglas fir stands were present for comparison on 20 of these paired sites. Conifer regeneration density and frequency were consistently greater in thinned than unthinned stands. For example, average seedling density in thinned stands (1433/ha) was significantly greater than in unthinned stands (233/ha), but very similar to that in old-growth stands (1010/ha). Seedling density and frequency were strongly related to the volume removed and to stand density index (and other measures of overstorey density) just after thinning. In thinned stands, the density of small trees (intermediate crown class overstorey trees and advanced regeneration) was 159/ha, significantly greater than in unthinned stands (90/ha), but not significantly different from that of old-growth (204/ha). The live crown ratio of these trees in thinned stands (66%) was greater than in unthinned (44%) and old-growth (48%) stands. Cover and stem density of shrubs was variable in all 3 stand types. There was significantly less tall shrub cover in unthinned stands than in either thinned or old-growth stands, which did not differ. Thinned stands had the most low shrub cover. Salal (*Gaultheria shallon*) and bracken fern (*Pteridium aquilinum*) cover was greater in thinned stands than in the other stand types, but there was no difference in sword fern (*Polystichum munitum*) and Oregon grape [*Berberis nervosa*] cover. Leaf area index in thinned stands (6.6) was not significantly different from that in unthinned (6.8) and old-growth stands (7.1); however, there was more leaf area in shrubs in the thinned stands. Thinning young Douglas-fir stands will hasten the development of multistorey stands by recruitment of conifer regeneration in the understory as well as by enabling the survival of small overstorey trees and growth of advanced understory regeneration. Thinning will also help develop the shrub layer by increasing tall shrub stem density and cover of some low shrubs.

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2. Barclay, H.J. and J.A. Trofymow. 2000. Relationship of readings from the LI-COR canopy analyzer to total one-sided leaf area index and stand structure in immature Douglas-fir. *Forest-Ecology-and-Management* 132(2/3): 121-126.

Keywords: fertilization
thinning
tree morphology

Abstract: Estimation of leaf area is important in predicting potential growth. This estimation is often done by means of a photometer, such as the LI-COR plant canopy analyser, but such instruments generally give biased estimates. Consequently, conversion factors are required to convert output from the photometer to the actual leaf area index (LAI). Foliar biomass was estimated in a 52-year-old Douglas fir (*Pseudotsuga menziesii*) stand at Shawnigan in British Columbia, Canada, which had been treated with 3 levels of thinning and 3 levels of fertilizer 28 years previously. The 4 treatment extremes (no thinning or fertilizing, no thinning and heavy fertilizing (448 kg N/ha as urea), heavy thinning (to 1/3 basal area) and no fertilizing, and heavy thinning and heavy fertilizing) were sampled for foliage. Projected leaf areas were calculated from these biomass samples using specific leaf areas derived in a previous biomass sampling. Total one-sided leaf area was then computed by dividing the projected leaf areas by 0.9 to allow for lateral leaf curvature. In addition, LAI-2000 readings were taken in the same plots and then factors were derived to convert LAI-2000 readings to total one-sided LAI. These conversion factors were found to vary strongly with quadratic mean diameter, stand density, mean diameter at breast height, mean height and stand basal area. The effect of live crown height was minimal. These should allow the prediction of the conversion factor based on 2 or 3 of these highly correlated factors.

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3. Beddows, D. 2002. Levels-of-growing-stock cooperative study in Douglas-fir: Report No. 16 - Sayward Forest and Shawnigan Lake. Pacific-Forestry-Centre, Canadian-Forest-Service Information-Report BC-X-393. viii + 67 p.

Keywords: thinning
growth
tree morphology

Abstract: Results from the two levels-of-growing-stock installations at Sayward Forest and Shawnigan Lake on Vancouver Island, British Columbia, Canada, are summarized. Volume growth at both the site-III Sayward Forest installation to age 51 and the site-IV Shawnigan Lake installation to age 52 has been strongly related to level of growing stock. Basal area growth followed a similar, though weaker, trend. Thinning has affected stand development through tree size distribution and live crown development. Periodic annual increments in volume at both installations are still two to three times the mean annual increment, indicating the potential for productivity gains as the treated stands age. Results to date from both installations are similar to results from other cooperative installations, generally differing from the more productive sites only in the rate and degree of response associated with a lower site quality.

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4. Binkley, D. and P. Reid. 1984. Long-term responses of stem growth and leaf area to thinning and fertilization in a Douglas-fir plantation. *Canadian-Journal-of-Forest-Research* 14(5): 656-660.

Keywords: fertilization
thinning

tree morphology
carbon allocation
growth

Abstract: Replicated thinning and nitrogen fertilization plots in a 53-year-old plantation in Washington State were examined for responses in stem growth, leaf area, and stem growth per unit leaf area. Although measurements occurred 20-30 yr after plot installation, substantial effects from the various treatments were still present. Thinning reduced leaf area of the stands but increased stem growth per unit leaf area, resulting in little difference in stem growth per ha over the 5-yr measurement period (1977-81). Fertilization increased both stand leaf area and stem growth per unit leaf area, and more than doubled 5-yr stem growth per ha. Consideration of the role of leaf area and stem growth per unit leaf area in determining stand treatment responses may account for much of the variation found among replicates of treatments or between studies on different sites.

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5. Birchler, T.M., R. Rose and D.L. Haase. 2001. Fall fertilization with N and K: effects on Douglas-fir seedling quality and performance. *Western-Journal-of-Applied-Forestry* 16(2): 71-79.

Keywords: nursery operations
nursery fertilization
growth
tree physiology
tree morphology
tree/stand health

Abstract: Coastal Douglas fir (*Pseudotsuga menziesii*) 1+1 seedlings from coastal Oregon, USA, were applied with two fertilizers ($\text{NH}_4\text{NO}_3+\text{K}_2\text{SO}_4$ and $(\text{NH}_4)_2\text{SO}_4+\text{KCl}$) at four rates (0, 80, 160, 320 kg N and K/ha) split over three application dates (September 19, October 13, November 1, 1996). Fertilizer type did not affect total Kjeldahl nitrogen (TKN) levels on any of the sampling dates. By January 10, TKN concentrations had increased 16, 30 and 34%, and chloride concentrations had increased 57, 77 and 112% relative to the seedlings without fertilizer, for 80, 160 and 320 kg N+K/ha treatments, respectively. Nitrate levels increased briefly after the first application of $\text{NH}_4\text{NO}_3+\text{K}_2\text{SO}_4$. Potassium levels remained relatively unchanged. Levels of most other nutrients, as well as foliar dry weight, increased between September 16 and January 10, but these increases were generally unrelated to the fertilizer treatments. Root growth potential and cold hardiness did not differ among treatments. Seedlings that received 160 or 320 kg N/ha broke bud an average of 3 days earlier than the seedlings without fertilizer. Chlorophyll fluorescence (F_v/F_m) of seedlings with fertilizer was consistently higher than that of seedlings without fertilizer on November 13 and December 30. These treatment differences were not reflected in seedling outplanting performance after one growing season.

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6. Birot, Y. and C. Christophe. 1983. Genetic structures and expected genetic gains from multitrait selection in wild populations of Douglas fir and Sitka spruce. I. Genetic variation between and within populations. *Silvae-Genetica* 32(5/6): 141-151.

Keywords: genetic tree improvement
genetic relationships
growth
tree phenology
tree morphology

Abstract: For Douglas fir, 371 open-pollinated progenies from 26 provenances ranging from N. to S. along the western foothills of the Cascade Mts., Washington, were tested. For Sitka spruce, 292 open-pollinated progenies from 21 provenances ranging from S. British Columbia to middle-Oregon were tested. Observations were made on growth, phenology and form from the nursery stage up to age 12. Classical patterns of geographic variation were observed for both species. Heritability and genetic correlations varied from one provenance to another, especially for Douglas fir, and also changed over time. Sitka spruce showed high additive effects, offering good prospects of future genetic gains. It was concluded that preliminary investigations on genetic parameters were necessary before setting up a breeding strategy.

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7. Blake, J.I., R. Linderman and D. Lavender. 1988b. Seedling vigor of Douglas fir and western hemlock in relation to ethylene exposure levels and ethane production during cold storage. *In* Proceedings: 10th North American Forest Biology Workshop, 'Physiology and genetics of reforestation', University of British Columbia, Vancouver, British Columbia, July 10-22, 1988. *Eds.* J. Worrall, J. Loo-Dinkins and D.P. Lester. pp. 235-242.

Keywords: nursery operations
tree morphology
tree phenology
tree/stand health

Abstract: The effects were examined of ethylene treatment on *Pseudotsuga menziesii* and *Tsuga heterophylla* 2-yr-old bare root seedlings lifted in October or December (in a nursery in Washington) and stored for 2 and 7 days. Seedlings exposed to 0.5 p.p.m. ethylene at +1 degrees C for 7 days exhibited reduced bud and root activity. These effects were apparently reversed at 5.0 p.p.m. In a second experiment, reducing ethylene concentrations with KMnO₄ during storage at +1 or +10 degrees C for 30 days did not affect foliage colour, but root and bud activity were generally enhanced. Ethylene concentrations in control bags ranged from 0.80 to 2.24 p.p.m. in October-lifted seedling bags and from 0.10 to 1.3 p.p.m. in December-lifted samples. The quantity of ethane in stored bags of *P. menziesii* seedlings was closely related to an increase in foliage discoloration. Little or no ethane was measured in *T. heterophylla* storage bags.

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8. Blake, J.I. and R.G. Linderman. 1992. A note on root development, bud activity, and survival of Douglas-fir, and survival of western hemlock and noble-fir seedlings, following exposure to ethylene during cold storage. *Canadian-Journal-of-Forest-Research* 22(8): 1195-1200.

Keywords: nursery operations
tree morphology
tree phenology
tree/stand health

Abstract: Three cold storage experiments were conducted with bare-root (2+0) Douglas fir (*Pseudotsuga menziesii*) seedlings from coastal Oregon and eastern Washington Cascade sources. The objectives were to determine the effects of ethylene at ambient and below-ambient (absorbed by KMnO₄ pellets) concentrations, and at 0.5 and 5 p.p.m. ethylene, during short-term storage on subsequent root development and bud activity, and to relate these results to survival in the field at sites in Washington and Oregon, after prolonged cold storage. Root numbers and lengths were measured 28 days after a 7-day storage period after lifting seedlings on 27 September and 1 December. In the coastal source, root numbers and lengths in the 5 p.p.m. ethylene treatment were, respectively, 46 and 49% greater in September, and 22 and 13% greater in December, than the controls. No comparable treatment effects were found for the Cascade source. Neither the KMnO₄ nor the 0.5 p.p.m. ethylene treatments affected root development in either seed source. For terminal buds in the controls, the number of days to 50% bud break was increased 2-8 days by a 30-day cold storage period compared with a 7-day period. For the coastal source, no increase in the time to 50% bud break was observed in the 5 p.p.m. ethylene treatment. Seedling survival was evaluated in the field for the same treatments following 4 months cold storage for the Douglas fir sources, coastal western hemlock (*Tsuga heterophylla*), and noble fir (*Abies procera*). Survival for the 5 p.p.m. ethylene treatment compared with the control was increased by 55% in the coastal Douglas fir source and by 13% in western hemlock. These results suggest that stimulated root development and bud activity may be partially responsible for the observed survival increase following cold storage at elevated ethylene levels.

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9. Bledsoe, C.S. and R.J. Zasoski. 1983. Effects of ammonium and nitrate on growth and nitrogen uptake by mycorrhizal Douglas-fir seedlings. *In* Tree root systems and their mycorrhizas. *Ed.* D. Atkinson. pp. 445-454.

Keywords: nursery operations
nursery fertilization
growth
tree physiology
tree morphology
tree/stand health

Abstract: In a greenhouse pot study, 1-yr-old mycorrhizal (inoculated with *Hebeloma crustuliniforme*) and non-mycorrhizal Douglas fir seedlings were grown in sandy forest soil amended with 10% of clay minerals (bentonite and/or kaolinite) and ammonium or nitrate fertilizer. Ht. growth, root and shoot DM and accumulation of nitrogen and P were greater in mycorrhizal than non-mycorrhizal seedlings,

especially in the nitrate treatment. Ammonium interacted with kaolinite to reduce survival which again was poorer in the absence of mycorrhiza.

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10. Brand, D.G. 1986b. Competition-induced changes in developmental features of planted Douglas-fir in southwestern British Columbia. *Canadian-Journal-of-Forest-Research* 16(2): 191-196.

Keywords: planting operations
tree morphology
tree physiology
growth

Abstract: From measurements in 1- to 5-yr-old plantations, developmental characteristics of Douglas fir were tested against a competition index based on measures of the brush canopy surrounding individual trees. The most promising characteristics for assessing competition were specific leaf area, the allometric relationship of ht. to b.a. and bud production on nodal shoots. Measures of foliar N and leaf internode length were less well correlated with the competition index. Comparing these results with those of laboratory studies indicated that, on the study sites, brush competition effects on planted trees are expressed through adaptation to reduced light intensity. Developmental variables relating to moisture and nutritional status were not as strongly related to the competition index. This may reflect reduced tree demand or secondary brush canopy effects.

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11. Brix, H. 1984. Effects of thinning and nitrogen fertilization on growth of Douglas-fir: relative contribution of foliage quantity and efficiency. *Canadian-Journal-of-Forest-Research* 13(1): 167-175.

Keywords: fertilization
thinning
growth
carbon allocation
tree morphology

Abstract: [See FA 43, 1948, 3839] On Vancouver Island, aboveground biomass and annual production over 7 yr was studied in relation to thinning and nitrogen fertilization at 24 yr old. Biomass yield of both treatments increased during the first 3-4 yr then decreased for fertilization but not with thinning. Treatments doubled biomass production of individual trees over the study period when applied separately and quadrupled it when combined. Annual biomass production per unit of foliage (E) increased during the first 3-4 yr, but was at or below control level after 7 yr. E accounted for 20, 37, and 27% of the stemwood dry matter response to thinning, fertilization and the combined treatments, respectively; the remainder was attributed to an increase in foliage biomass. Thinning, but not fertilization, influenced distribution of radial growth along the stem, increasing growth only below the top one-third of the stem. This pattern was related to crown development.

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12. Brix, H. 1993. Fertilization and thinning effect on a Douglas-fir ecosystem at Shawnigan Lake: a synthesis of project results. B.C. Ministry of Forests FRDA-Report 196. X + 64 p.

Keywords: fertilization
thinning
growth
tree morphology
tree/stand health
carbon allocation
wood quality
tree physiology
photosynthesis
economics

Abstract: Treatments were initiated in 1970-71 in a 24-year-old Douglas fir (*Pseudotsuga menziesii*) near Shawnigan Lake, Vancouver Island, British Columbia, to determine the effects of 3 intensities of thinning (removing none, one-third and two-thirds of basal area) and 3 levels of urea fertilizer (0, 224 and 448 kg N/ha) on the growth and biology of the trees. Subsidiary experiments were established during 1972-87 to examine the effects of high doses of urea (672-1344 kg N/ha), ammonium nitrate as an N source instead of urea, understory response to thinning and fertilizer, and responses to P and S fertilizer.

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13. Brix, H. and A.K. Mitchell. 1983. Thinning and nitrogen fertilization effects on sapwood development and relationships of foliage quantity to sapwood area and basal area in Douglas-fir. *Canadian-Journal-of-Forest-Research* 13(3): 384-389.

Keywords: fertilization
thinning
tree morphology
tree physiology

Abstract: A 24-yr-old stand in British Columbia was treated in 1971-72 with various intensities and combinations of N fertilization and thinning. For 5-9 yr after treatments, trees were sampled to determine effects on foliage quantity and sapwood characteristics at varying stem ht. together with their relationships. Sapwood width remained relatively constant up the stem where heartwood was present, but the number of annual rings it contained decreased with ht. The sapwood width at b.h. increased with stem diam.; treatments had little effect on % sapwood at b.h. The ratio of foliage mass to sapwood cross-sectional area changed for different portions of the crown and was lower when based on sapwood area at b.h. than at base of live crown. Significant linear relationships of foliage mass and area to sapwood area at b.h. were found, but relationships of foliage to b.a. were just as close for all

treatments; treatments significantly affected these relationships with control trees having the lowest regression slopes.

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14. Busse, M.D., G.O. Fiddler and A.W. Ratcliff. 2004. Ectomycorrhizal formation in herbicide-treated soils of differing clay and organic matter content. *Water, Air, and Soil Pollution* 152:23-34.

Keywords: release treatments
chemical release
growth
tree morphology
tree/stand health
soil properties
mycorrhizal response

Abstract: Herbicides are commonly used on private timberlands in the western United States for site preparation and control of competing vegetation. How non-target soil biota respond to herbicide applications, however, is not thoroughly understood. We tested the effects of triclopyr, imazapyr, and sulfometuron methyl on ectomycorrhizal formation in a greenhouse study. Ponderosa pine, Douglas-fir, and white fir seedlings were grown in four forest soils ranging in clay content from 9 to 33% and organic matter content from 3 to 17%, and treated with commercial formulations of each herbicide at 0, 1.0, and 2.0 times the recommended field rate. Many of the possible herbicide-soil combinations resulted in reduced seedling growth. Root development was particularly sensitive to the three herbicides, with an average of 51% fewer root tips compared to the control treatment. The ability of mycorrhizal fungi to infect the remaining root tips, however, was uninhibited. Mycorrhizal formation was high, averaging 91% of all root tips, regardless of herbicide, application rate, soil type, or conifer species. In agreement, soil microbial biomass and respiratory activity were unaffected by the herbicide treatments. The results show that these herbicides do not alter the capability of mycorrhizal fungi to infect roots, even at concentrations detrimental to seedling growth.

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15. Carter, R. and R. Scagel. 1989. The effects of stand density and fertilization on stand development in immature coastal Douglas-fir. B.C. Ministry of Forests FRDA-Report 094. i + 15 p.

Keywords: fertilization
thinning
growth
tree morphology

Abstract: The effects of urea fertilizer were studied in *Pseudotsuga menziesii* stands spaced to 500, 750 and 1000 stems/ha in coastal British Columbia.

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16. Carter, R.E., I.M. Miller and K. Klinka. 1986. Relationships between growth form and stand density in immature Douglas-fir. *Forestry-Chronicle* 62(5): 440-445.

Keywords: planting operations
wood quality
tree morphology
growth

Abstract: Spacing was found to affect stem and crown characteristics and branching at whorls 6-10 in 27-yr-old Douglas fir established at 3 spacings (1.8x1.8, 3.6x3.6 and 4.6x4.6 m) near Haney, British Columbia. Ht., d.b.h. and stem diam. at the base of the live crown increased significantly with spacing, while age and ht. at the base of the live crown decreased. Increased spacing resulted in significantly greater branch diam. at whorls 6-10 and, in some whorls, an increase in branch number. Swelling of the stem at branch whorls, the number of Lammas whorls, knottiness ratio and a subjective index of stem form (where higher index indicated poorer form) increased with spacing. The selection of initial spacing is discussed and it is concluded that intensive management practices, e.g. thinning and pruning, will be necessary in all regimes if clear wood is to be produced over short rotations.

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17. Chanway, C.P., R.A. Radley and F.B. Holl. 1991. Inoculation of conifer seed with plant growth promoting *Bacillus* strains causes increased seedling emergence and biomass. *Soil-Biology-and-Biochemistry* 23(6): 575-580.

Keywords: nursery operations
growth
tree morphology

Abstract: Seeds of lodgepole pine (*Pinus contorta*), Douglas fir (*Pseudotsuga menziesii*) and white spruce (*Picea glauca*) were collected from 3 sites in British Columbia. Inoculation with *Bacillus* strains L5 and L6 significantly increased the rate of seedling emergence of spruce but did not affect subsequent seedling growth. Pine root growth was promoted by strain L5 in sterilized, but not non-sterile, growth medium. Strain L6 promoted pine root growth in sterilized medium, but also caused significant increases in seedling emergence, shoot weight and height, root weight and surface area, and root collar diameter when tested in non-sterile peat-vermiculite medium. The positive effects due to a single inoculation of pine with strain L6 at sowing were not detectable after 12 weeks growth. However, root growth was stimulated after 16 weeks growth if seedlings were re-inoculated with strain L6 mid-way through the experiment. Shoot-growth promotion was also detected when 1-yr-old pine seedlings were planted in pots and inoculated with strain L6. Douglas fir seedlings grown from seed inoculated with strain L5 had increased root collar diameters, whereas those inoculated with strain L6 exhibited increased root surface area.

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18. Chen, J.M. and T.A. Black. 1992. Foliage area and architecture of plant canopies from sunfleck size distributions. *Agricultural-and-Forest-Meteorology* 60(3/4): 249-266.

Keywords: thinning
pruning
tree morphology

Abstract: A Poisson model is developed to describe sunfleck or gap size distributions beneath clumped plant canopies. This model is based on the assumption that foliage clumps are randomly distributed in space and foliage elements are randomly distributed within each clump. Using this model, the foliage clumping index, leaf area index (L), clump area index, element area index in each clump, and element and clump widths were successfully derived for two artificial canopies and a thinned and pruned Douglas-fir (*Pseudotsuga menziesii*) forest stand. It is shown that existing theories for deriving L from measurements of canopy gap fraction have limitations, and use of canopy architectural information derived from canopy gap size distribution can substantially improve the technique for indirectly measuring L of plant canopies.

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19. Cole, E.C. and M. Newton. 1987. Fifth-year response of Douglas-fir to crowding and nonconiferous competition. *Canadian-Journal-of-Forest-Research* 17(2): 181-186.

Keywords: release treatments
chemical release
growth
tree morphology

Abstract: Measurements were made in autumn 1982 in 5-yr-old plantations with trees spaced 17-123 cm apart, alone or with grass or red alder (*Alnus rubra*) on 3 site types in the Oregon Coast Range. Crowding and competition from both grass and alder reduced aboveground dry wt. per tree. Dry wt./ha was higher at higher tree densities, but this is expected to change with time as the larger trees at low densities form fully stocked stands. Grass showed the greatest effect on growth at the driest site. Although red alder decreased growth on all sites, the effect was most significant at the coastal site where light is most limiting and moisture least limiting. For the production of max. individual tree size, low stocking with control of competing vegetation is recommended.

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20. Coleman, M.D., C.S. Bledsoe and B.A. Smit. 1990. Root hydraulic conductivity and xylem sap levels of zeatin riboside and abscisic acid in ectomycorrhizal Douglas fir seedlings. *New-Phytologist* 115(2): 275-284.

Keywords: nursery operations
nursery fertilization
tree morphology
tree physiology
mycorrhizal response

Abstract: The hypothesis that root hydraulic conductivity (LP) of ectomycorrhizal root systems is greater than that of non-mycorrhizal systems, and different to that of vesicular-arbuscular (VA) mycorrhizas was tested in a greenhouse experiment, by measuring hydraulic qualities of roots while accounting for seedling size and P content. Plant growth substances (abscisic acid and zeatin riboside) expressed from roots during the experiments were also measured. Douglas fir (*Pseudotsuga menziesii*) seedlings inoculated with the ectomycorrhizal fungi *Laccaria bicolor* and *Hebeloma crustuliniforme*, and non-inoculated seedlings infected naturally with *Thelephora* were grown under 3 rates of P fertilization (1, 10 and 100 micro M P). After 9 months, seedling morphology, tissue P concn., LP and plant growth substance concn. in xylem sap were measured. Increased tissue P and decreased root/shoot ratio correlated with increased LP in each mycorrhizal treatment; when adjusted for the effect of these 2 factors, LP of *Laccaria* and *Hebeloma* seedlings was still lower than that of *Thelephora* seedlings. In a subsequent experiment, LP of seedlings with *Hebeloma* and *Rhizopogon vinicolor* mycorrhizas was compared with that of non-mycorrhizal seedlings (grown at 100 mM P) and no differences were found among treatments. The lack of an ectomycorrhizal effect on LP is quite different from the enhancement of host LP by VA mycorrhizas. Zeatin riboside concentrations of *Thelephora*- and *Hebeloma*-infected seedlings were similar, yet higher than with *Laccaria*. There was no relationship between plant growth substances and LP in ectomycorrhizal Douglas fir, despite lower zeatin riboside concentrations for *Laccaria*-inoculated plants.

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21. Colinas, C., D. Perry, R. Molina and M. Amaranthus. 1994b. Survival and growth of *Pseudotsuga menziesii* seedlings inoculated with biocide-treated soils at planting in a degraded clearcut. *Canadian-Journal-of-Forest-Research* 24(8): 1741-1749.

Keywords: planting operations
fertilization
growth
tree/stand health
tree morphology

Abstract: To determine the factors of transfer soils responsible for increased seedling survival and growth, planting holes, at a site in SW Oregon, were inoculated with forest, plantation, and clear-cut soils subjected to one of 8 treatments: (i) treated with fertilizer to test for effects of nutrients; treated with biocides to test for effects of (ii) grazers (microarthropods or nematodes), (iii) protozoa, (iv) fungi, or (v) bacteria; (vi) pasteurized; (vii) Tyndallized; or (viii) untreated. Douglas fir (*Pseudotsuga menziesii*) seedlings were planted in June 1990 and seedling growth and survival was assessed in December 1990. Survival was increased by inoculation with untreated plantation soils, but not if they were fertilized or treated with dimethoate + carbofuran (grazercide), fumagillin (protozoacide), or oxytetracycline + penicillin (bactericide). Addition of untreated forest soil did not increase survival. For all soils, survival was increased by captan (fungicide), pasteurization and Tyndallization. Untreated plantation and forest

soil transfers increased dry weights whereas neither did when treated with dimethoate + carbofuran. Dry weights of seedlings given clear-cut soil were increased by fertilization, pasteurization and Tyndallization of the soil; the latter two treatments also increased the number of short roots. It is hypothesized that stimulation of seedling growth by soil transfers was related to an increased rate of nutrient mineralization due to microbivorous soil animals contained within the transfer soils. Soil transfers may have enhanced seedling survival by at least two mechanisms: (i) by providing a safe site for beneficial rhizosphere organisms to proliferate, free from competing organisms that have proliferated in the clear-cut soil; and (ii) through volatile organic compounds, especially ethylene, that stimulated seedling root growth.

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22. Collier, R.L. and E.C. Turnblom. 2001. Epicormic branching on pruned coastal Douglas-fir. *Western-Journal-of-Applied-Forestry* 16(2): 80-86.

Keywords: pruning
thinning
wood quality
tree morphology

Abstract: The Stand Management Cooperative (SMC 1998) at the University of Washington, USA, conducted live crown reduction experiments in the Pacific Northwest regions of the USA, to better understand the dynamics of the response of coastal Douglas fir (*Pseudotsuga menziesii*) to pruning. A detailed report on how frequently epicormic branches occur, where they occur on the bole, whether or not their occurrence is related to stand density or the amount of crown removed, and how epicormic sprouting may affect log grade, is presented. The experiments include fifty-six 0.08 ha pruning plots in 18 installations in British Columbia, Oregon and Washington. As part of the monitoring process, a subset of 38 plots in 12 installations was examined for the occurrence and size of epicormic branches 4 years after the initial pruning treatments. Results showed that epicormic branching was most severe on the south and west sides of trees. When epicormic branching was severe, sprouts occurred both at nodes (or whorls) and along internodes. Less severe or moderate sprouting tended to originate mainly in nodes. The risk of epicormic branching is minimal as long as the pruning treatment does not reduce the live crown by more than 40% and the stand has 500 or more stems/ha. The highest risk of epicormic branching was found to be when the live crown is reduced by more than 40%, and the stand carries less than 500 stems/ha.

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23. Copes, D.L. 1980. Effect of root stock vigor on leader elongation, branch growth, and plagiotropism in 4- and 8-year-old Douglas-fir grafts. *Tree-Planters' Notes* 31(1): 11-14.

Keywords: genetic tree improvement
tree grafting
growth

tree morphology

Abstract: In treatment (a) 2-yr-old seedling rootstocks were planted in containers in 1969 and scions from Oregon and Washington plantations grafted on in April 1970. The grafted trees were moved to transplant beds in Nov. 1970 and finally to field positions in Oregon in Dec. 1979. In treatment (b), rootstocks of the same age were bare-root planted in Nov. 1970 and scions grafted in April 1974. Graft growth was examined in May 1978. Field-grafted trees (b) showed upright tree form, significantly greater leader growth p.a. and longer branches in the 1976 whorl. Some 61% of container-grafted trees (a) showed a noticeable lean from vertical compared with none of the field grafted trees.

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24. Copes, D.L. and N.L. Mandel. 2000. Effects of IBA and NAA treatments on rooting Douglas-fir stem cuttings. *New-Forests* 20(3): 249-257.

Keywords: nursery operations
tree morphology
tree/stand health

Abstract: The effectiveness of 6 indole-3-butyric acid (IBA) and four 1-naphthaleneacetic acid (NAA) concentrations, 4 combinations of IBA and NAA concentrations, and control were tested for their ability to enhance rooting frequency of Douglas-fir [*Pseudotsugamenziesii*] cuttings. Two IBA and one NAA treatments were also compared to the control for quality of root system. Between 1984 and 1998, six independent studies were conducted in mist or fog environments with the 14 clones. Auxin concentrations tested ranged from 0 to 123 mM IBA and 0 to 10 mM NAA. Auxin, clone and auxin by clone effects were significant in every study, although individual clone analyses showed only two clones to differ significantly for auxin. All auxin treatments except the 10 mM NAA treatment induced significantly greater rooting percentage than the control, but no single auxin, auxin concentration or combination of auxins was clearly superior in every study. The 10 mM NAA concentration was the only concentration tested that reduced rooting percentage to less than the control. Both NAA and IBA appeared to have broad ranges of root-enhancing activity. However, within the effective range of IBA evaluated, 24.6 or 49.3 mM produced the greatest rooting percentage in 4 of 5 studies testing IBA. NAA solutions with concentrations between 2.5 and 7.5 mM NAA generally resulted in similar rooting success. Rooting responses to increased IBA and NAA were both nonlinear; rooting decreased with both too little and too much auxin. Combinations of IBA and NAA in the same solution did not increase rooting percentage above what was achieved with one auxin. For root system quality, auxin treated cuttings in one study, had significantly better root systems than control, but there was no difference in the other study in which root quality was estimated.

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25. Curtis, R.O. and D.D. Marshall. 2002. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 14 - Stampede Creek: 30-year results. Pacific-Northwest-Research-Station,-USDA-Forest-Service Research-Paper PNW-RP-543. xi + 77 p.

Keywords: thinning
commercial thinning
growth
yield
tree morphology
tree/stand health

Abstract: Results of the Stampede Creek installation of the levels-of-growing-stock (LOGS) study in Douglas-fir (*Pseudotsuga menziesii*) are summarized. To age 63 (planned completion of 60 feet of height growth), volume growth on the site III natural stand has been strongly related to level of growing stock, but basal area growth-growing stock relations were considerably weaker. Marked differences in tree size distributions have resulted from thinning. Periodic annual volume increments at age 63 are two to three times greater than mean annual increment; this stand is still far from culmination. Results for this southwest Oregon installation are generally similar to those reported from other LOGS installations, although development has been slower than on the site II installations that make up the majority of the series.

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26. Donald, D.G.M. and D.G. Simpson. 1985. Shallow conditioning and late fertilizer application effects on the quality of conifer nursery stock in British Columbia. B.C.-Ministry-of-Forests Research-Note 99. viii + 36 p.

Keywords: nursery operations
nursery fertilization
tree/stand protection
tree morphology
tree/stand health
growth

Abstract: Eight trials on 2+0 stock of *Picea engelmannii*, *P. glauca*, *P. sitchensis*, *Pinus contorta* and *Pseudotsuga menziesii* (var. *glauca* and var. *menziesii*) in 4 nurseries were conducted to compare the effects of shallow conditioning (undercutting and wrenching at 10 cm deep) with those of the standard conditioning regime (undercutting and wrenching at 20 cm) on nursery performance, storage and field performance. The application of a complete NPK fertilizer 50 days before lifting was also evaluated. Shallow conditioning and late fertilizer application improved the root growth capacity at lifting, but could not replace cold exposure for hardening *Pseudotsuga menziesii*. Shallow conditioning had little effect on survival after planting and reduced initial ht. increment of all species. Application of fertilizer just before lifting improved the early growth of the trees without adversely affecting survival. Planting seedlings some 5 cm deeper than they stood in the nursery improved establishment.

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27. Drew, A.P. 1983. Optimizing growth and development of 2-0 Douglas-fir seedlings by altering light intensity. *Canadian-Journal-of-Forest-Research* 13(3): 425-428.

Keywords: nursery operations
tree/stand protection
growth
tree morphology
carbon allocation

Abstract: Seedlings were grown outdoors in Michigan in pots under 71% of full light the first growing season and full light the second. Another group of seedlings was given full light continuously for 2 yr. At the end of the 1st year, seedlings given initial shade had grown larger in total wt. (root + shoot) than those grown under full light. With removal of shading, the larger plants began to allocate increased dry matter to root development relative to their shoots. By the end of 2 yr, shoot/root ratios for the 2 groups were no different, yet the plants shaded in their 1st year were significantly heavier (dry wt.) By proper use of shading during development, larger 2+0 planting stock with good root development may be produced. Such stock, grown without the use of costly fertilizer, may be better suited to regeneration of droughty sites in the Pacific Northwest USA than the usual 2+0 planting stock, nursery grown under full light.

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28. Driessche, R.v.-d. 1983. Growth, survival, and physiology of Douglas-fir seedlings following root wrenching and fertilization. *Canadian-Journal-of-Forest-Research* 13(2): 270-278.

Keywords: nursery operations
nursery fertilization
tree/stand health
tree morphology
tree physiology
growth

Abstract: Seedlings at different nurseries on Vancouver Island were subjected to wrenching treatments during their 2nd year of growth using a fixed blade at 20-25 cm below the bed surface. In the first experiment, wrenching reduced water potential of trees on unirrigated loam soil by an av. of 300 kPa during Aug. and Sept. Wrenched trees lifted in Oct. and stored at 2 degrees C until May, showed 25% higher survival than unwrenched trees 1 yr after planting. Trees lifted in Dec. had uniformly high survival (98%) and showed no effect of wrenching. Wrenched trees from irrigated plots had lower shoot length relative growth rates (RGR) than unwrenched trees during the year after planting. In the second experiment, wrenching treatments were applied to seedlings, growing in a loamy sand, for different periods between 15 May and 11 Sept. as follows: (a) no wrenching, (b) early summer, (c) midsummer, (d) late summer and (e) all summer. Three fertilizer treatments (none, and 2 amounts of NPK) were applied to each wrenching treatment, and seedlings were lifted for storage at 2 degrees C in Oct. and Dec. Stored trees and freshly lifted trees were planted at 700 m alt. on 3 March. Wrenching increased root dry wt., particularly when additional fertilizer was applied, but had no measurable effect on cold hardiness or root growth capacity. Nevertheless, late summer wrenching increased survival 5 and 7% above control 1 and 2 yr after planting. Wrenching had little subsequent effect on new shoot growth of

planted trees during the 2 yr after planting. However, late-summer wrenched trees showed significantly more new shoot growth than all-summer wrenched trees. More fertilizer reduced cold hardiness and survival of cold-stored trees, but increased root growth capacity. Cold hardiness (measured by electrical impedance) was correlated with survival of cold-stored trees after planting ($r^2 = 0.82$). Root growth capacity, averaged over all fertilizer treatments was closely correlated with survival of stored and freshly lifted trees ($r^2 = 0.93$). Foliar nutrient concn. were reduced by wrenching, but fertilizing increased nutrient reserves within the seedling.

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29. Driessche, R.v.-d. 1984a. Response of Douglas fir seedlings to phosphorus fertilization and influence of temperature on this response. *Plant-and-Soil* 80(2): 155-169.

Keywords: nursery operations
nursery fertilization
growth
tree physiology
carbon allocation
tree morphology

Abstract: In pot experiments levels of P fertilizers equivalent to 300 kg/ha were adequate for maximum growth of Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) seedlings over 14-18 weeks, and resulted in available soil P levels of 80 ppm after 15 weeks' growth. Maximum growth in pots was obtained with shoot P concentrations of 0.18%-0.20%, with higher values at lower temperatures, but the optimum concentration for one-year-old (1-0) nursery seedlings was 0.16% P. Growth of seedlings was greatly restricted at a soil temperature of 5 degrees C and an air temperature of 12 degrees C. At a soil temperature of 10 degrees C and an air temperature of 14 degrees C seedling P requirement was greater than at soil and air temperatures of 20 degrees C. Monoammonium phosphate was more effective than calcium superphosphate in stimulating growth in pots and nursery beds. Triple superphosphate was also effective in the nursery. Diammonium phosphate, potassium dihydrogen phosphate and phosphoric acid had no advantages as P sources in the nursery. Available P levels of 100-130 ppm, in the loamy sand and sandy loam nurseries studied, and needle P concentrations of 0.18%, when sampled in October, were associated with maximum growth of two-year-old (2-0) seedlings. P fertilization decreased the root/shoot ratio, but did not alter the allometric relationship of shoot to root. Improving the P status from a low level increased the root growth capacity in 2-0 seedlings and P fertilization of potted seedlings increased the dry weight/height ratio. Uptakes per seed bed ha of 236 kg N, 31 kg P, 81 kg K and 73 kg Ca by 2-0 seedlings were comparable with, or greater than, uptake rates of agricultural crops. Recoveries of 6-11% of P from fertilizer were recorded in the nursery.

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30. Driessche, R.v.-d. 1984b. Seedling spacing in the nursery in relation to growth, yield, and performance of stock. *Forestry-Chronicle* 60(6): 345-355.

Keywords: nursery operations
growth
tree morphology
carbon allocation
tree physiology
tree/stand health

Abstract: In 3 experiments at nurseries in coastal British Columbia *Picea sitchensis*, *P. glauca*, *Pinus contorta* var. *latifolia*, *Thuja plicata* and coastal and interior varieties of *Pseudotsuga menziesii* were sown in May 1979, 1980 or 1982 and grown at spacings ranging from 0.5 to 12 cm. A 1-cm increase in spacing increased seedling dry wt. by 0.5-1.5 g and root collar diam. by 0.2-0.25 mm up to a spacing of about 8-10 cm. Above this, response was less. Ht. of 2-yr-old seedlings was increased slightly or even decreased by wider spacing. Height : diameter ratios decreased sharply and shoot : root dry wt. decreased or remained unchanged with wider spacing. The number of needle primordia in 2-0 *P. menziesii* buds increased up to a spacing of 2 cm, and the number of 1st and 2nd order branches were also increased by wider spacing. Increases in root growth capacity were associated with wider spacing in *T. plicata* and *Picea sitchensis*. In a test of 3 types of precision seeders, none produced anything like accurate seed placement. Irregularity was increased by 10-20% non-viable seed and winter mortality. Increased spacing of 2-5 cm between seedlings was justified by the yield of acceptable seedlings only when the culling standard was increased to a root collar diam. of about 6 mm. Three yr after planting out the survival of *P. glauca* was increased 11% by wider spacing. After 2 yr *P. sitchensis* survival was increased 13% by wider spacing. Both species grown at wider spacing maintained a ht. and diam. advantage over those from close spacing.

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31. Driessche, R.v.-d. 1987. Importance of current photosynthate to new root growth in planted conifer seedlings. *Canadian-Journal-of-Forest-Research* 17(8): 776-782.

Keywords: nursery operations
tree physiology
photosynthesis
tree morphology

Abstract: Reports are given of 6 experiments. Two-yr-old seedlings of Douglas fir and Sitka spruce, labelled with ^{14}C in Oct. and kept outdoors, contained ^{14}C in old roots but little in new roots when placed in a growth chamber in Jan. New roots were highly radioactive in seedlings labelled with ^{14}C after 12 days' growth in Jan., indicating that current photosynthate was the primary C source for new roots. These results agreed with an experiment in which the number and wt. of new roots on 1+1 Douglas fir transplants were directly related to light intensity. Net photosynthesis (P_n) of similar Douglas fir nursery stock after cold storage was inadequate to supply C for respiration and new root growth under 16-h photoperiods of 200 $\mu\text{E}/\text{m}^2 \text{ s}$, although new root growth occurred. This suggested that reserves contributed to respiration. Douglas fir seedlings began transpiration immediately after planting in moist soil. Two-yr-old lodgepole pine seedlings grown outdoors over winter with root systems maintained at ≤ 10 degrees C produced more new roots in spring than seedlings grown outdoors without heated roots or in a greenhouse; no relations were observed between new root growth and P_n .

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32. Driessche, R.v.-d. 1991a. Influence of container nursery regimes on drought resistance of seedlings following planting. I. Survival and growth. *Canadian-Journal-of-Forest-Research* 21(5): 555-565.

Keywords: nursery operations
tree/stand protection
growth
tree morphology
carbon allocation
tree/stand health

Abstract: In a 2 year study, Douglas fir (*Pseudotsuga menziesii*), lodgepole pine (*Pinus contorta*) and white spruce (*Picea glauca*) seedlings, grown in Styroblock containers in a container nursery from February to July 1988, were exposed to three temperatures and three levels of drought stress applied factorially during 18 July to 29 September 1988. Mean temperatures of 13, 16 and 20 degrees C were imposed in growth chambers, in a cooled plastic house, and in an ambient plastic house, respectively. Control, medium and severe levels of drought stress were imposed in a series of eight cycles, resulting in mean xylem pressure potentials of -0.32, -0.50 and -0.99 MPa, respectively. Seedlings were kept in the ambient plastic house until January 1989, when they were lifted and cold-stored until transplanting to covered 0.5-m deep sand beds, which provided hygric, mesic, and xeric conditions for testing all species and treatments. At the end of nursery growth, an increase in nursery temperature increased height and height : diameter ratio in all species and shoot:root dry weight ratio in Douglas fir and lodgepole pine. Increase in temperature also increased the number of seedlings with large well-formed buds in white spruce, but reduced the number in Douglas fir. Drought stress reduced height and dry weight in all species and bud length in lodgepole pine. After 9 weeks in sand beds, low nursery temperature increased survival (19% for lodgepole pine and white spruce grown in the xeric bed), except for Douglas fir grown in the xeric bed. Nursery drought stress also increased survival (16% for Douglas fir and lodgepole pine in the xeric bed), but had little effect on white spruce. Low temperature and drought stress treatments that increased survival also reduced height and dry weight of lodgepole pine and white spruce after one growing season in sand beds. Survival showed significant negative correlations with height, dry weight and height:diameter and shoot : root weight ratios. Low nursery temperature continued to affect growth 16 weeks after planting, increasing relative growth rate and allometric ratio (K) of Douglas fir and reducing K of white spruce.

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33. Entry, J.A., K. Cromack, Jr., R.G. Kelsey and N.E. Martin. 1991. Response of Douglas-fir to infection by *Armillaria ostoyae* after thinning or thinning plus fertilization. *Phytopathology* 81(6): 682-689.

Keywords: thinning
fertilization
tree/stand protection
growth
tree morphology
carbon allocation

tree/stand health
tree physiology

Abstract: Second-growth stands of Douglas-fir (*Pseudotsuga menziesii*) were thinned to a 5- x 5-m spacing (TT); additional plots were thinned and fertilized once with 360 kg of N (as urea)/ha (TF). An unthinned, unfertilized stand (UT) served as a control. Ten years after treatment, trees were inoculated with 2 isolates of *A. ostoyae*. Trees receiving the TF and TT treatments produced greater diameter growth, leaf area, and wood production/leaf area per year than did those under the UT treatment. Rates of infection by *A.ostoyae* were highest in trees that received the TF and lowest in trees that received the TT treatment. Conc'n of sugar, starch and cellulose in root bark tissue were highest in trees receiving the TF treatment and lowest in trees receiving TT treatment. Conc'n of lignin, phenolics and protein-precipitable tannins were highest in root bark from TT trees and lowest in root bark from TF trees. Biochemical parameters of root bark tissue were regressed with incidence of infection; coefficients of determination (r^2) ranged from 0.07 (starch) to 0.57 (phenolic compounds). Ratios of the energetic costs of phenolic and of lignin degradation to the energy available from sugars (Epd:Eas and Eld:Eas) were correlated with incidence of infection ($r^2 = 0.77$ and 0.70 , respectively). It is concluded that thinning combined with fertilization may predispose *P. menziesii* trees to infection by *A. ostoyae* by lowering conc'n of defensive compounds in root bark and increasing the energy available to the fungus to degrade them.

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34. Gagnon, J., C.G. Langlois, D. Bouchard, F.I. Tacon and F. Le Tacon. 1995. Growth and ectomycorrhizal formation of container-grown Douglas-fir seedlings inoculated with *Laccaria bicolor* under four levels of nitrogen fertilization. *Canadian Journal of Forest Research* 25:1953-1961.

Keywords: nursery operations
nursery fertilization
growth
carbon allocation
tree physiology
tree morphology
mycorrhizal response
soil properties

Abstract: Container-grown Douglas fir (*Pseudotsuga menziesii*) seedlings were inoculated at the time of sowing with a *Laccaria bicolor* mycelial suspension produced in a fermentor. They were grown in a peat moss-vermiculite substrate under four levels of N fertilization (7.2, 14.4, 21.6 and 28.7 mg/seedling per season (N1, N2, N3 and N4, respectively)) to determine the N level suitable for both ectomycorrhizal development and seedling growth. After 18 weeks in the greenhouse, seedlings inoculated with *L. bicolor* had 44%, 32%, 44% and 5% of their short roots mycorrhizal when fertilized with N1, N2, N3 and N4, respectively. Only when they were fertilized with N4 did the *L. bicolor* seedlings have significantly greater shoot height than the controls. For the other growth parameters, they were not significantly different from control seedlings for any of the N levels. After 18 weeks, regardless of the level of N, seedlings inoculated with *L. bicolor* had significantly lower N concentrations (%) and contents (mg/seedling) than the uninoculated ones. Consequently, for the same production of biomass,

the mycorrhizal seedlings had taken up less N than the nonmycorrhizal ones. The efficiency of applied N, expressed in terms of produced biomass, decreased when the N fertilization increased; mycorrhizal and nonmycorrhizal seedlings did not tend to be different. The efficiency of the absorbed N also decrease with the level of applied N, but less rapidly, and tended to be greater for the mycorrhizal seedlings than for the nonmycorrhizal ones. Therefore, the mycorrhizal infection improved the utilization of the absorbed N. N3 was the best of the four N levels used, since it was the only one that maximized both the ectomycorrhizal formation and the growth of the seedlings. In other words, a total seedling N concentration of 1.6% and a substrate fertility of 52 p.p.m. N are appropriate to optimize both the ectomycorrhizal development and the growth of Douglas fir seedlings.

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35. Gardner, E.R. 1990. Fertilization and thinning effects on a Douglas-fir ecosystem at Shawnigan Lake: 15-year growth response. Canadian-Forest-Service, Pacific and Yukon Region Information-Report BC-X-319. ix + 42 p.

Keywords: fertilization
thinning
growth
yield
tree morphology
tree/stand health

Abstract: Responses after 15 yr to 3 rates of nitrogen (urea), applied at 0, 224 or 448 kg N/ha to a 24-yr-old Douglas fir (*Pseudotsuga menziesii*) stand in the very dry maritime region of British Columbia, were analysed on the basis of per hectare, individual tree, crop tree and tree size class. Thinned and unthinned plots were measured.

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36. Greene, S.E. and W.H. Emmingham. 1986. Early lessons from commercial thinning in a 30-year-old Sitka spruce-western hemlock forest. Pacific-Northwest-Research-Station,-USDA-Forest-Service Research-Note PNW-RN-448. 14 p.

Keywords: thinning
commercial thinning
growth
tree/stand health
tree morphology

Abstract: Three commercial thinning treatments were applied to a 30-yr-old stand of *Picea sitchensis* and *Tsuga heterophylla* with *Pseudotsuga menziesii* that had been precommercially thinned at 15 yr old on the Oregon coast. Data were collected to determine the effects of thinning on diam. and ht. growth, the amount of damage and subsequent decay in remaining trees and relations between leaf area and volume production.

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37. Grier, C.C., K.H. Lee and R.M. Archibald. 1984. Effect of urea fertilization on allometric relations in young Douglas-fir trees. *Canadian-Journal-of-Forest-Research* 14(6): 900-904.

Keywords: fertilization
growth
carbon allocation
tree morphology

Abstract: Twenty three yr old trees growing on a class III site in Washington State were fertilized with 225 kg/ha N in March 1980. Trees were measured before fertilizing and after 1980-83 growing seasons and destructively sampled after 2 growing seasons (in Nov.-Dec. 1981 and Jan. 1982). Logarithmic regression equations using stem diam. to predict tree biomass components were not significantly ($p = 0.05$) different between fertilized and control trees for total foliage, total branch, dead branch, stembark, or stemwood. New foliage and new twig components, however, were higher in fertilized trees than in control trees. Analysis of data from this and earlier studies suggests that fertilizing will increase leaf biomass per tree relative to control trees on sites having low nitrogen availability; however, this response will decrease with increasing nitrogen availability. Regression equations based on regional analysis of unfertilized trees yield estimates of foliage biomass for average trees on average sites. If N fertilizing brings the site above average in terms of nitrogen availability then these regression equations will underestimate foliage biomass. However, on sites that are initially very nitrogen deficient, N fertilizing will bring the site closer to average in terms of nitrogen availability, resulting in more accurate predictions of foliage biomass for fertilized stands than for control stands.

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38. Grotta, A.T., B.L. Gartner and S.R. Radosevich. 2004. Influence of species proportion and timing of establishment on stem quality in mixed red alder-Douglas-fir plantations. *Canadian-Journal-of-Forest-Research* 34(4): 863-873.

Keywords: planting operations
tree morphology
wood quality

Abstract: The relationships among stand structure, Douglas-fir (*Pseudotsuga menziesii*) branch characteristics, and red alder (*Alnus rubra*) stem form attributes were explored for 10- to 15-year-old trees growing in mixed Douglas-fir-red alder plantations in Oregon, USA. Treatments included a range of species proportions, and red alder was either planted simultaneously with Douglas-fir or after 5 years. Both replacement effects (total stand density held constant) and additive effects (stand density doubled) of competition were considered. When the two species were planted simultaneously and red alder proportion was low, red alder trees had low crown bases and much stem defect (lean, sweep, and multiple stems). Douglas-fir grew slowly when the two species were planted simultaneously. When red alder planting was delayed, species proportion did not affect red alder stem form, and height to the base of the Douglas-fir live crown decreased with increasing red alder proportion. Doubling Douglas-fir

density increased the height to the base of the Douglas-fir live crown; however, doubling stand density by adding red alder did not affect Douglas-fir crown height. Douglas-fir lumber coming from mixed stands may be inferior because of the changes in knot characteristics associated with these different patterns of crown recession. In stands with a low proportion of red alder, red alder product recovery may be compromised because of the stem defects described above.

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39. Haase, D.L. and R. Rose. 1993. Soil moisture stress induces transplant shock in stored and unstored 2+0 Douglas-fir seedlings of varying root volumes. *Forest-Science* 39(2): 275-294.

Keywords: nursery operations
tree/stand protection
growth
tree morphology

Abstract: Transplant shock was induced by applying a range of soil water contents (6, 12, 18 or 24%) to unstored and cold-stored 2-yr-old (2 + 0) bareroot Douglas fir (*Pseudotsuga menziesii*) seedlings graded by root volume. Moisture stress had the greatest influence on morphological characteristics that express transplant shock. Seedling terminal shoot growth, stem diameter growth, and needle length increased with increased soil moisture content. In addition, number of needles per centimeter on the terminal shoot greatly increased with increasing drought stress. Under high drought stress, seedlings with relatively high root volumes tended to exhibit reduced early growth, but later showed significantly increased overall growth regardless of soil water content. In every case, seedlings grown in the driest soil had the lowest dry weight components. Similarly, seedlings with the smallest initial root volumes had the lowest dry weights, and those with the largest root volumes had the greatest dry weights. The results indicate that drought stress is a cause of transplant shock, and that increased seedling root volume may enable seedlings to avoid shock following outplanting to a specific site.

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40. Haase, D.L. and R. Rose. 1994. Effects of soil water content and initial root volume on the nutrient status of 2+0 Douglas-fir seedlings. *New-Forests* 8(3): 265-277.

Keywords: nursery operations
tree/stand protection
tree physiology
growth
tree morphology

Abstract: Two-year-old bareroot Douglas fir (*Pseudotsuga menziesii*) seedlings from a NW Oregon provenance were graded on the basis of four root-volume categories - 5 to 8, 9 to 10, 11 to 13, and 14 to 20 cm³ - and transplanted into pots and subjected to one of four moisture-stress treatments (6, 12, 18, and 24% soil water content) for 16 weeks. Macronutrient concentrations and contents of both old (i.e. nursery-grown) and new (i.e. grown during moisture stress treatment) foliar tissue were

determined. A reduction in soil water content resulted in high concn of phosphorus, potassium, and particularly nitrogen in both old and new foliar tissue. This was attributed to reduced growth, translocation, metabolic activity, and nutrient requirement in response to moisture stress. Seedlings with relatively greater root volumes exhibited higher nutrient concn and contents, as well as increased growth. Thus, increased total root biomass per unit of soil area with increasing seedling root volume may have resulted in greater nutrient use, supply, uptake, and storage. It is suggested that relations between initial root volume and water stress can be applied to nursery cultural practices in order to increase seedling adaptation to a specific stress.

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41. Hobbs, S.D., S.G. Stafford and R.L. Slagle. 1987. Undercutting conifer seedlings: effect on morphology and field performance on droughty sites. *Canadian-Journal-of-Forest-Research* 17(1): 40-46.

Keywords: nursery operations
tree morphology
growth
tree/stand health

Abstract: One-yr-old barerooted Douglas fir and ponderosa pine seedlings in an Oregon nursery were subjected during Feb.-June 1980 to 5 undercutting treatments that varied by number and depth of cuts and seedling phenology at time of treatment. Eight morphological variables were measured in Jan. 1981 before planting the seedlings at 2 sites in Oregon. Seedling survival and growth was recorded annually for 4 yr. All treatments significantly reduced shoot growth in the nursery, but changes in root system morphology depended on treatment severity and species. Treatment effects were generally more pronounced in ponderosa pine than in Douglas fir. Discriminant analysis showed that seedlings responded similarly in all undercutting treatments relative to control seedlings that were not undercut. No effects of undercutting were apparent after 4 yr in the field.

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42. Jacobs, D.F., R. Rose and D.L. Haase. 2003a. Development of Douglas-fir seedling root architecture in response to localized nutrient supply. *Canadian-Journal-of-Forest-Research* 33(1): 118-125.

Keywords: nursery operations
nursery fertilization
tree morphology
tree physiology
growth

Abstract: Three months following sowing, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings were transplanted into pots with controlled-release fertilizer (CRF) applied at rates of 0, 8, 16, and 24 g/2200 cm³ soil as a single uniform layer beneath the root system. Seedlings were destructively harvested periodically, and roots were divided into vertical segments above (S1), within (S2), and below (S3) the fertilizer layer. Two months following transplant, the number of active root tips was positively

correlated with CRF rate in S1 and negatively correlated with rate in S2 and S3. At 6 months, root penetration into S3 was severely restricted at 16 and 24 g. This was attributed to detrimental changes in soil osmotic potential in S2. Fertilizer improved seedling growth at 8 g after 6 months compared with controls but was inhibitory at 24 g. Photochemical quantum yield was higher in all CRF treatments compared with controls 3 months following transplant, which corresponded with rapid initial CRF nutrient release. Despite improvements in nutrient release technology with CRF, high application rates may result in excessive concentrations of fertilizer nutrients in media, which can restrict root penetration and negatively affect seedling growth. Conservative application rates and improvements in CRF technology will help reduce the potential for adverse effects on seedling development.

[OSU Link](#)

[Non-OSU Link](#)

43. Jacobs, D.F., R. Rose, D.L. Haase and P.D. Morgan. 2003b. Influence of nursery soil amendments on water relations, root architectural development, and field performance of Douglas-fir transplants. *New-Forests* 26(3): 263-277.

Keywords: nursery operations
fertilization
tree physiology
tree morphology
growth
carbon allocation
soil properties
tree/stand health

Abstract: This experiment evaluated the influence of manure, peat, and vermiculite incorporated at low and high rates (0.0118 and 0.0236 m³/m²) and under two soil moisture regimes on Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedling (1+0 for 1+1) xylem water potential (Phi xylem), whole-plant growth, root architectural development, and subsequent field performance under fertilized and non-fertilized conditions. Trends in soil moisture retention were observed (high manure > high peat > control) but there were no differences in Phi xylem. Root length in the wetter soil moisture experiment was initially (three months) greatest for seedlings in high vermiculite and least in high manure but there were no differences among treatments at lifting (eight months). Mean height was greatest for seedlings grown in vermiculite and peat (wetter nursery experiment) after two field seasons. Field fertilization (35 g/seedling) with controlled-release fertilizer in the planting hole stimulated height growth initially, but decreased height and diameter growth during the second growing season. Dramatic improvements associated with the use of nursery soil amendments were not realized, but the failure to identify negative effects, a potential reduction in disease incidence, and improvement of nursery soil physical and chemical properties may justify their use.

[OSU Link](#)

[Non-OSU Link](#)

44. Joseph, G. and R.G. Kelsey. 1999. Growth of Douglas-fir and ponderosa pine seedlings with foliar applications of methanol and ethanol. *Western-Journal-of-Applied-Forestry* 14(4): 183-185.

Keywords: nursery operations
growth
tree morphology
tree/stand health

Abstract: Ethanol and methanol have been reported to enhance the growth and development of several agricultural and horticultural species. To test whether methanol or ethanol stimulated growth of coast Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) or ponderosa pine (*Pinus ponderosa*) in the nursery, seedlings were sprayed with concentrations of 1 to 10% (v/v) on the foliage twice a week for 13 wk during the growing season. Foliar applications of methanol and ethanol neither significantly stimulated nor inhibited growth, and signs of damage at these concentrations were lacking.

[OSU Link](#)

[Non-OSU Link](#)

45. Jozsa, L.A. and G.R. Middleton. 1994. A discussion of wood quality attributes and their practical implications. Forintek Canada Corp. 42 p.

Keywords: planting operations
wood quality
tree morphology

Abstract: Wood quality is defined as the suitability of wood for a particular end-use. Wood anatomy and tree growth are discussed in terms of macroscopic and microscopic features of a tree examined in cross section. End-use requirements are described in terms of lumber grading. The following wood quality attributes are introduced, defined and discussed in terms of their practical implications for wood processing and wood products: wood density, density variation, juvenile wood/mature wood distribution, proportion of heartwood/sapwood, fibre length, fibril angle, compression wood, knots, grain and extractives. The potential for influencing tree growth characteristics (e.g. wood density, branch size) and wood quality (structural and appearance lumber grades) through stand stocking control is discussed.

[OSU Link](#)

[Non-OSU Link](#)

46. Kershaw, J.A., Jr. and D.A. Maguire. 1996. Crown structure in western hemlock, Douglas-fir, and grand fir in western Washington: horizontal distribution of foliage within branches. *Canadian-Journal-of-Forest-Research* 26(1): 128-142.

Keywords: fertilization
tree morphology

Abstract: Horizontal distribution of foliage within individual branches was explored for western hemlock (*Tsuga heterophylla*), Douglas fir (*Pseudotsuga menziesii*) and grand fir (*Abies grandis*), three major tree species in the Pacific Northwest. Weibull, beta, normal, and Johnson's SB distributions were assessed for their ability to conform to the empirical foliage distributions. Moment-based parameter recovery and parameter prediction methodologies were applied. On the basis of the rank of individual branch chi

superscript 2-values, the beta distribution performed best under parameter recovery, while Johnson's SB distribution was best in terms of total sum of chi superscript 2-values. Overall, few differences between the four distributions were observed. A system of moment-based parameter prediction equations was developed from branch dimensional and positional measures. The prediction equations showed that the ratio of relative distances from the stem to mean foliage density increased with increasing branch size. This relative increase was enhanced with increasing depth into crown for western hemlock, but not for Douglas fir or grand fir. Again, the beta distribution, based on predicted moments, followed most closely the empirical distributions on the basis of the ranks of chi superscript 2-values. The normal distribution was the best in terms of total sum of chi superscript 2-values. As expected, moment-based parameter recovery produced smoothed distributions that followed more closely the observed empirical distributions; however, parameter prediction provides a methodology for predicting distributions when empirical moments are not available. No significant ($p > 0.05$) differences in horizontal foliage distribution were found between sites or fertilizer (0 or 225 kg N/ha as urea) treatments.

[OSU Link](#)

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47. Knowe, S.A. 1994a. Effect of competition control treatments on height-age and height-diameter relationships in young Douglas-fir plantations. *Forest-Ecology-and-Management* 67(1-3): 101-111.

Keywords: release treatments
chemical release
manual release
growth
tree morphology

Abstract: Height-age and height-diameter models for plantations of young Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) were examined in relation to vegetation management treatments. The models were developed from 10 years of measurements in a competition release study installed on six sites in the Coast Ranges of Oregon and Washington. Analysis of height growth patterns for dominant trees indicated significant differences between the total vegetation control treatment and operational release treatments or no treatment. The resulting height-age function depicted exponential growth patterns for the total vegetation control treatment and nearly linear patterns for the operational release treatment and no treatment. The height-diameter function was compatible with dominant height growth and quadratic mean diameter prediction functions. Different height-diameter curve shapes were associated with total vegetation control and the operational release and no treatments. The resulting function implied that Douglas fir trees of a given diameter and age were slightly taller when underinterspecific competition, especially for trees with smaller diameters. The height-age and height-diameter functions may be used in conjunction with diameter distribution or stand table projection models developed for these data to predict dynamics and stand structure in young Douglas fir plantations.

[OSU Link](#)

[Non-OSU Link](#)

48. Knowe, S.A. 1994b. Incorporating the effects of interspecific competition and vegetation management treatments in stand table projection models for Douglas-fir saplings. *Forest-Ecology-and-Management* 67(1-3): 87-99.

Keywords: release treatments
chemical release
growth
tree morphology

Abstract: A stand table projection system based on individual-tree and stand-level models for young Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) plantations was developed from and evaluated with remeasurement data from xeric sites in the Siskiyou Mountains of SW Oregon (established in a competition gradient study), and mesic sites in the Coast Ranges of Oregon and Washington (established in a treatment efficacy study). A projection equation was developed for relative tree size, defined as the ratio of individual-tree diameter at 15 or 30 cm above ground level (depending on the study location) to quadratic mean diameter. The relative size projection equation for the Coast Ranges study included the effect of total vegetation control, which indicated that diameters of Douglas fir receiving total vegetation control tended to become more uniform over time in the Coast Ranges. An additional equation was developed to project quadratic mean diameter so that individual-tree diameters could be estimated from projected relative size. The effect of vegetation management treatments on projected quadratic mean diameters in the Siskiyou study was expressed as an interaction between proportion of cover removed by treatments (intensity) and dominant height of Douglas fir at time of treatment relative to current dominant height. In 1- and 2-yr projection periods, the stand table projection system performed similarly to a diameter distribution prediction system based on a Weibull distribution function. However, the difference between projected and predicted diameter distributions became more pronounced as the projection period increased to 5 years.

[OSU Link](#)

[Non-OSU Link](#)

49. Knowe, S.A., T.B. Harrington and R.G. Shula. 1992. Incorporating the effects of interspecific competition and vegetation management treatments in diameter distribution models for Douglas-fir saplings. *Canadian-Journal-of-Forest-Research* 22(9): 1255-1262.

Keywords: release treatments
manual release
chemical release
growth
tree morphology

Abstract: A parameter recovery procedure for the Weibull distribution function, based on diameter percentiles, was modified to incorporate the effects of competing vegetation in young Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) plantations. The procedure was tested using data from sites in the Coast Ranges of Oregon and Washington and in the Siskiyou Mountains of SW Oregon. The Coast Ranges study was conducted in 2- to 3-yr-old plantations needing release from woody shrub (mainly *Rubus spectabilis* and *R. parviflorus*) and broadleaved tree (*Alnus rubra* and *Acer macrophyllum*) competition. Release treatments were an untreated control, manual cutting, triclopyr ester applied aerially, glyphosate applied aerially, and a total vegetation control treatment consisting of annual

broadcast applications of hexazinone and spot treatments of glyphosate and triclopyr. The Siskiyou Mountains study was conducted in 1- to 2-yr-old plantations on sites covered by tanoak (*Lithocarpus densiflorus*). Tanoak sprout clumps were left unthinned or were thinned to 50, 25 and 0% of the pretreatment cover. Four percentiles (0, 25th, 50th, 95th) of the cumulative probability distribution were predicted as functions of quadratic mean diameter and age. In the Siskiyou study, cover and total vegetation control affected quadratic mean diameter and all four percentiles; intensity of the vegetation treatments affected the 0 and 25th percentiles, and the interaction between intensity and timing of treatment affected mean diameter. In the Coast Ranges study, only quadratic mean diameter was affected by cover of woody vegetation, while quadratic mean diameter and the 25th percentile were significantly affected by total vegetation control. The predicted distributions showed decreasing variance with increasing cover, particularly in the Siskiyou Mountains. In the Coast Ranges study, the coefficient of variation increased with increasing cover, indicating that the variance of stem diameters was affected by average size. On xeric sites in the Siskiyou Mountains, high diameter variability in plots with total vegetation control suggests that interspecific competition may inhibit the expression of microsite variation.

[OSU Link](#)

[Non-OSU Link](#)

50. Knowe, S.A. and W.I. Stein. 1995. Predicting the effects of site preparation and protection on development of young Douglas-fir plantations. *Canadian-Journal-of-Forest-Research* 25(9): 1538-1547.

Keywords: site preparation
release treatments
tree/stand protection
growth
tree morphology
tree/stand health
stand conditions

Abstract: Diameter prediction models based on the Weibull distribution function and stand-table projection models based on changes in relative diameter were developed for 2- to 10-year-old Douglas fir (*Pseudotsuga menziesii*) plantations in Oregon. Both modelling approaches incorporated the effects of site preparation, animal protection, and competing vegetation. The diameter distribution approach is appropriate when information on initial diameters is not available. The stand-table projection approach may be applied when tree diameters in a plantation are measured two or more growing seasons after planting. At young ages, the stand-table approach provided more accurate representation of observed diameter distributions than the diameter distribution approach. At age 10 the two methods provided comparable diameter distributions. The equations derived for predicting survival, height growth of dominant trees, height-diameter relationships, and the development of woody vegetation over time will facilitate the study and comparison of stand structure and dynamics after various site-preparation and animal protection treatments.

[OSU Link](#)

[Non-OSU Link](#)

51. Lopushinsky, W. and T.A. Max. 1990. Effect of soil temperature on root and shoot growth and on budburst timing in conifer seedling transplants. *New-Forests* 4(2): 107-124.

Keywords: planting operations
tree morphology
tree phenology
tree physiology

Abstract: Results are presented of studies of tree seedling morphological responses to a wide range (0-30 degrees C) of soil temperatures and the effects of soil temperature on needle water potential and stomatal conductance in ponderosa pine (*P. ponderosa*). Bare-root 2-year-old seedlings from high-altitude seed sources in the Cascade Mountains (Washington and Oregon states) were used for the morphological study. Root growth in Douglas fir (*Pseudotsuga menziesii*), Pacific silver fir (*Abies amabilis*), noble fir (*Abies procera*), lodgepolepine (*Pinus contorta*) and ponderosa pine began when soil temperature exceeded 5 degrees C. Root growth increased rapidly after 10 degrees C and attained maximum values at 20 degrees C. At 30 degrees C, no root growth occurred in the firs; in the pines, root growth was 30 to 39% of maximum. Maximum shoot growth also occurred at 20 degrees C. In ponderosa pine, height growth of seedlings from a high-altitude source was unaffected by cold soil, but in low-altitude seedlings it was reduced. Budburst in Douglas fir and the pines was delayed up to 11 days by cold soil, whereas in silver fir and noble fir, it was only slightly delayed. Prior to new root growth in ponderosa pine, xylem pressure potentials and stomatal conductances during the afternoon indicated reduced stomatal opening at all soil temperatures, whereas 23 days later, stomata were open to a greater degree when temperatures exceeded 10 degrees C. Implications of these results are briefly discussed: although root growth was initiated at soil temperatures of 5 degrees C, this does not imply that seedlings should not be transplanted until soils reach that temperature.

[OSU Link](#)

[Non-OSU Link](#)

52. Lu, S., K.G. Mattson, J.B. Zaerr and J.D. Marshall. 1998. Root respiration of Douglas-fir seedlings: effects of N concentration. *Soil-Biology-and-Biochemistry* 30(3): 331-336.

Keywords: nursery operations
nursery fertilization
growth
carbon allocation
tree morphology
tree physiology
mycorrhizal response

Abstract: Six-month-old Douglas-fir (*Pseudotsuga menziesii*) seedlings were grown at three N concentrations and with controlled root temperatures in Oregon, USA. Measurements of root respiration were conducted on undisturbed root systems by passing humidified air with 1000 micro l/litre CO₂ through root boxes onto an infrared gas analyser. The effects of N on soil respiration were sought by examining total root respiration rate per seedling, specific root respiration rate/g root dry wt, and root dry wt after N fertilization. Total respiration rates of seedlings grown at 50 mg N/litre concentration were significantly higher than those grown at 10 or 200 mg N/litre. Seedlings grown at N concentration of 200 mg/litre had significantly smaller roots than those grown at the two lower N concentrations. The specific respiration rate increased as N concentration was increased from 10 to 50 mg N/litre, but remained constant as N was further increased from 50 to 200 mg/litre. The increase of total respiration rate with the increase in N concentration from 10 to 50 mg/litre was

attributed to the increase in specific respiration, whereas the subsequent decrease in total respiration with the increase in N concentration from 50 to 200 mg/litre was attributed to the decrease in root dry wt. The depression of soil respiration after the addition of N fertilizers to relatively fertile soil may be explained by reduced root and mycorrhizal mycelial growth.

[OSU Link](#)

[Non-OSU Link](#)

53. Maguire, D.A. and W.S. Bennett. 1996. Patterns in vertical distribution of foliage in young coastal Douglas-fir. *Canadian-Journal-of-Forest-Research* 26(11): 1991-2005.

Keywords: thinning
precommercial thinning
tree morphology

Abstract: Variation in foliage distribution was analysed on trees and plots in a series of even-aged Douglas fir (*Pseudotsuga menziesii*) stands scheduled for management under a wide range of silvicultural regimes in British Columbia, Washington and Oregon. Branch-level foliage mass and foliage area equations were developed from a sample of 138 branches. These equations were applied to 27 trees on which the diameter and height of all live primary branches were measured, allowing estimation of both the total amount of foliage and its vertical distribution. A beta -distribution was fitted to data describing the vertical distribution of foliage on each tree, and the resulting parameter estimates were modelled as functions of tree height, diameter at breast height, crown length, and relative height in the stand. Foliage area distribution tended to be shifted downward relative to foliage mass because of the expected increase in specific leaf area with depth into the crown. Similarly, the relative foliage distribution in terms of both mass and area was shifted downward as the tree became more dominant, or as relative height in the stand increased. In contrast, foliage on trees of similar relative height was shifted upward in response to the lower stand densities imposed by precommercial thinning. On the stand level, relative vertical distribution of foliage in the canopy was more peaked than would be implied by assuming a constant leaf area/sapwood area ratio throughout the composite tree crowns. Between-stand variation in vertical foliage distribution was dictated by differences in stand top height, height to crown base, and number of trees per hectare.

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[Non-OSU Link](#)

54. Marshall, D.D. and R.O. Curtis. 2002. Levels-of-growing-stock cooperative study in Douglas-fir: report no. 15 - Hoskins: 1963-1998. *Pacific-Northwest-Research-Station,-USDA-Forest-Service Research-Paper PNW-RP-537*. 80 p.

Keywords: thinning
commercial thinning
growth
yield
tree/stand health
tree morphology

Abstract: The cooperative levels-of-growing-stock (LOGS) study in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) was begun to study the relations between growing stock, growth, cumulative wood production, and tree size in repeatedly thinned stands. This report summarizes results from the Hoskins installation through age 55. Growing stock has been allowed to accumulate for 19 years since the last treatment thinning was applied in this high site class II natural stand. Volume and diameter growth were strongly related to growing stock. Basal area growth-growing stock relations were considerably weaker. Differences in tree size and volume distribution were considerable. Culmination of mean annual increment has not occurred for any of the treatments, although the control has culminated for total stem cubic volume and is near culmination for merchantable cubic volume. Only small differences are seen in growth percentages between thinning treatments. Results demonstrate potential flexibility in managing Douglas-fir to reach a range of objectives.

[OSU Link](#)

[Non-OSU Link](#)

55. McDonald, P.M. and G.O. Fiddler. 1996. Development of a mixed shrub-tanoak-Douglas-fir community in a treated and untreated condition. Pacific-Southwest-Research-Station, USDA-Forest-Service Research-Paper PSW-RP-225. iv + 16 p.

Keywords: release treatments
manual release
chemical release
tree/stand health
growth
tree morphology
stand conditions
economics

Abstract: On a medium site in northern California, a tanoak (*Lithocarpus densiflorus*)-mixed shrub community in a Douglas fir plantation was given several treatments (manual release two and three times, a combination chainsaw and cut surface herbicide (Garlon 3A [triclopyr]) treatment, two foliar herbicides (2,4-D or Garlon 4), and a tank mix of the two herbicides) to study its development in both a natural (control) and treated condition. The herbicides were each applied twice. Survival of planted Douglas fir (*Pseudotsuga menziesii*) seedlings was recorded for 11 years and growth was quantified for 9 years after the last treatment application. In addition to Douglas fir, data are presented individually for the two most abundant species (tanoak and snowbrush, *Ceanothus velutinus* var. *hookeri*), for greenleaf manzanita (*Arctostaphylos patula*), and for the hardwood tree and shrubs combined. At the study's end in 1992, combined vegetation in the control had a mean density of 1800 plants/acre, foliar cover of 23 700 ft²/acre, and height of 11.2 ft. In contrast, combined tree and shrubs in the most effective treatment for controlling them (cut and spray Garlon 3A) had a mean density of 150 plants/acre, foliar cover of 150 ft²/acre and height of 5.9 ft at study end. Because competition for site resources was low, Douglas fir seedlings developed best in this treatment. Mean Douglas fir diameter was 4.6 inches at 12 inches above mean ground line, height averaged more than 21 ft, and mean foliar cover was 39 850 ft² at the end of the study. The cost was \$227 per acre.

[OSU Link](#)

[Non-OSU Link](#)

56. McDonald, P.M. and G.O. Fiddler. 1999. Ecology and development of Douglas-fir seedlings and associated plant species in a Coast Range plantation. Pacific-Southwest-Research-Station, USDA-Forest-Service Research-Paper PSW-RP-243. ii + 18 p.

Keywords: release treatments
manual release
chemical release
stand conditions
growth
tree morphology
economics

Abstract: On an average site in northern coastal California, USA, a tanoak (*Lithocarpus densiflorus*)-mixed shrub community was given several treatments (manual release one, two, and three times; a combination chainsaw and cut surface chemical treatment; two foliar chemicals; and a tank mix of the two chemicals) to study its development over an 11-year period (1981-91) in both a broadcast-burned (untreated control) and released (treated) condition. The chemicals were 2,4-D, Garlon [triclopyr] 3A, and Garlon 4, each applied two times. The site had been planted with 2+0 seedlings of Douglas fir (*Pseudotsuga menziesii*) in 1979. In addition to Douglas-fir, data are presented individually for the four most abundant and well distributed species (tanoak, hairy manzanita (*Arctostaphylos columbiana*), huckleberries (*Vaccinium ovatum* and *V. parviflorum*), and rhododendron (*Rhododendron macrophyllum*)), and for these plus two more of the tallest and most abundant (but poorly distributed) species (snowbush (*Ceanothus velutinus*), elderberry (*Sambucus mexicana*)) combined. In 1991, combined shrubs in the control had a mean density of 4733 plants per acre, foliar cover of 16 800 ft² per acre, and height of 9.5 feet. In contrast, combined shrubs in one of the most effective treatments for controlling them (2,4-D) had a mean density of 2000 plant per acre, foliar cover of 2600 ft² per acre and height of 5.5 feet at the end of the study. Here, mean Douglas-fir diameter was 4.0 inches at 12 inches above mean ground line, height averaged 18.7 feet, and mean foliar cover was 34 800 ft² per acre. The cost (including chemical) was \$77 per acre. The biological and economical data in this paper provide the ecosystem manager, wildlife biologist, and fuels manager with knowledge on how to attain plant communities with different density and development potentials, and the cost of creating them.

[OSU Link](#)

[Non-OSU Link](#)

57. Minore, D., H.G. Weatherly and P.G. Cunningham. 1993. Sowing at 1.5-cm (0.6-inch) depth produces heaviest Douglas-fir roots in small containers. *Tree-Planters' Notes* 44(3): 122-124.

Keywords: nursery operations
tree morphology
growth
reproduction

Abstract: Sowing seeds of Douglas fir (*Pseudotsuga menziesii*) at five depths in Leach Super Cells indicated that the only benefit of deep sowing in small containers occurred at a depth of 1.5 cm. Sowing at this depth produced heavier roots without a significant reduction in seedling emergence. Sowing at greater depths significantly reduced seedling emergence and growth.

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[Non-OSU Link](#)

58. Mitchell, S.J. 2000. Stem growth responses in Douglas-fir and Sitka spruce following thinning: implications for assessing wind-firmness. *Forest-Ecology-and-Management* 135(1/3): 105-114.

Keywords: thinning
tree morphology
carbon allocation
growth

Abstract: Diagnosing the stand hazard component of windthrow risk requires evaluation of the 'acclimation' of trees to wind loads. Height-diameter ratio is a commonly used indicator of relative wind-firmness. A sample of coastal Sitka spruce (*Picea sitchensis*) and interior Douglas fir (*Pseudotsuga menziesii*) trees, representing a range of initial slenderness, were sampled from stands in British Columbia, Canada, which had very high densities (about 6000 and 23,000 stems/ha, respectively) prior to thinning. Annual height increment, radial increment, allocation of radial increment along the bole, and height-diameter ratio were reconstructed using stem analysis. Thinning treatments affected growth responses compared to trees in control (unthinned) stands: temporary reduced height increment, increased radial increment and increased basal allocation contributed to a reduction in height-diameter ratio. This reduction was most pronounced in trees which were initially more slender. The reverse-S pattern of height-diameter ratio adjustment and the patterns of growth allocation suggest a period of acclimative growth during which the trees re-equilibrate with post-thinning wind loads. Observing the rate of stem form adjustment could be useful in diagnosing wind-firmness when scheduling multiple thinning entries in high-density stands.

[OSU Link](#)

[Non-OSU Link](#)

59. Mohammed, G.H., K.R. Patel and W.E. Vidaver. 1989. The control of adventitious root production in tissue-cultured Douglas-fir. *Canadian-Journal-of-Forest-Research* 19(10): 1322-1329.

Keywords: nursery operations
reproduction
growth
tree morphology

Abstract: Rooting percentage and root number in tissue-cultured Douglas fir (*Pseudotsuga menziesii*) were examined to assess the influence of rooting substrate, the concentrations of sucrose and boron in the rooting medium, shoot height, and shoot generation. Peat/perlite was a better substrate than agar, producing 70% compared with 0% rooted shoots, respectively. On peat/perlite, cell divisions were organized and were associated with tracheid nests, whereas on agar proliferation was neither organized nor restricted to the nests. An optimum sucrose concentration of 4% was found for the production of nodular or rooted shoots. At 4% sucrose and 3 mg/litre boric acid, 100% of the shoots rooted, and the mean root number was 11. Rooting percentage and root number were significantly greater with shoots that were 3 cm tall rather than 2 or 1 cm tall. Shoot responses were more rapid in third and fourth

generation shoots, with at least 80% rooted or nodular after 4 weeks, compared with only 36% from the second generation.

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[Non-OSU Link](#)

60. O'-Hara, K.L. 1988. Stand structure and growing space efficiency following thinning in an even-aged Douglas-fir stand. *Canadian-Journal-of-Forest-Research* 18(7): 859-866.

Keywords: thinning
commercial thinning
growth
tree morphology
carbon allocation

Abstract: The growth of individual trees from four thinning treatments in a 64-yr-old *Pseudotsuga menziesii* stand in western Washington was analysed to determine desirable residual stand structures after thinning. Dominant and codominant trees had the highest individual tree stem vol. growth rates over the previous 5 yr and accounted for most stand vol. growth in thinned and unthinned stands. Two measures of growing space, crown projection area and sapwood b.a. (a surrogate for leaf area), were used to measure how efficiently individual trees used their growing space. Crown classes were useful in characterizing growing space efficiency (vol. growth per unit of growing space) only in the unthinned treatment. In thinned treatments, tall trees with medium-sized crowns were most efficient, while in the unthinned treatment tall trees with relatively large crowns were most efficient. A large crown in an unthinned stand was comparable in size to a medium-sized crown in a thinned stand. Results suggest growing space is not limiting individual tree growth in thinned stands and that thinning to a particular stand structure is more appropriate than thinning to a particular stand density.

[OSU Link](#)

[Non-OSU Link](#)

61. O'-Hara, K.L. 1989. Stand growth efficiency in a Douglas fir thinning trial. *Forestry-Oxford* 62(4): 409-418.

Keywords: thinning
commercial thinning
growth
carbon allocation
tree morphology

Abstract: Stand growth efficiency (ratio of periodic stand volume growth to sapwood basal area) was measured over 5 yr (1980-84) in a long term Douglas fir (*Pseudotsuga menziesii*) thinning trial (established in 1957 at 36-yr-old, with 5 thinnings over 23 yr) in coastal Washington, USA. Sapwood basal area - as a surrogate for leaf area - and volume growth were estimated in two fifth-hectare plots from each of three thinning treatments, and from a single fifth-hectare control plot. Stand growth increased with increasing sapwood basal area. No distinct pattern of stand growth efficiency with sapwood basal

area was evident. Large differences in efficiency between plots of the same treatment were found and were attributed to differences in stand structure, or the arrangement of tree sizes.

[OSU Link](#)

[Non-OSU Link](#)

62. Perry, D.A., C. Choquette and P. Schroeder. 1987. Nitrogen dynamics in conifer-dominated forests with and without hardwoods. *Canadian-Journal-of-Forest-Research* 17(11): 1434-1441.

Keywords: release treatments
soil properties
tree morphology

Abstract: In studies on the E. slopes of the Oregon Coast Range, contents of N and C in the surface 12 cm of mineral soil, N in leaf litterfall, anaerobic N mineralization rates in the soil and forest floor, and root and N accretion to sand traps placed in surface soil layers were studied in stands dominated by Douglas fir trees, from which the broadleaved component had been partially or completely removed during thinning 3 yr earlier. Contrary to expectations, stands without broadleaved species had more N in mineral soil, a greater rate of anaerobic soil N mineralization and a lower soil C : N ratio than stands with broadleaved species. These variables did not differ between thinned and unthinned mixed stands. From litterfall and sand trap data, it is suggested that N was redistributed in the coniferous system after removal of the broadleaved species.

[OSU Link](#)

[Non-OSU Link](#)

63. Peterson, M. and J.R. Sutherland. 1989. Grey mould control by seedling canopy humidity reduction through under-bench ventilation and styroblock aeration. B.C. Ministry of Forests FRDA-Report 077. 15 p.

Keywords: nursery operations
growth
tree/stand health
tree morphology

Abstract: The potential for grey mould control on Douglas-fir seedlings was investigated using under-bench ventilation and aerated styroblocks. Twenty-five percent of all ventilated styroblock seedlings were infected with *Botrytis cinerea* while 75% of the control seedlings showed signs of infection. The reduced incidence of grey mould in the ventilated treatments was attributed to a more rapid drying of the seedling canopy following watering. The lowest frequency of ideal conditions for *B. cinerea* infection by spore germination was observed in the seedling canopy of the treatment receiving unheated, forced air ventilation.

[OSU Link](#)

[Non-OSU Link](#)

64. Reukema, D.L. and J.H.G. Smith. 1987. Development over 25 years of Douglas-fir, western hemlock, and western redcedar planted at various spacings on a very good site in British Columbia. Pacific-Northwest-Research-Station,-USDA-Forest-Service Research-Paper PNW-RP-381. ii + 46 p.

Keywords: planting operations
pruning
growth
yield
tree morphology

Abstract: Five spacing trials were established during 1957-67 at the University of British Columbia Research Forest, covering a range of spacings from 1 to 5 m and of experimental designs (49-tree-plot, 0.2-ha plot, rectangularity, Nelder and variable block trials). Results showed that initial spacing is among the most important factors influencing stem and crown development, and stand growth and yield for Douglas fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*) and western redcedar (*Thuja plicata*). Top heights were initially taller at closer spacings, but are now similar at all spacings. Av. ht. is now shorter at close spacing. Decreases in heights to dead and live crowns and increases in diam. of lower stem, taper and crown size occurred as spacing increased. B.a. and stand vol. increased as spacing decreased until onset of density-related mortality. It is concluded that initial wide spacings with rectangularities up to 2:1 (e.g. 6x3 m) will result in efficient production of large trees of high value and satisfactory quality. Pruning of widely spaced trees to enhance lower stem quality is strongly recommended.

[OSU Link](#)

[Non-OSU Link](#)

65. Ritchie, G.A., J.W. Keeley and P.A. Ward. 1997. Effects of shade and root confinement on the expression of plagiotropic growth in juvenile-origin Douglas-fir rooted cuttings. *Canadian-Journal-of-Forest-Research* 27(7): 1142-1145.

Keywords: nursery operations
growth
tree morphology

Abstract: The purpose of this experiment was to determine why juvenile-origin Douglas fir (*Pseudotsuga menziesii*) rooted cuttings, which remain plagiotropic (branch-like) when grown in containers in shaded greenhouses, become orthotropic (vertical) after they are transplanted to an outdoor environment. Plagiotropic rooted cuttings (mean angle from vertical = 45-50 degrees) from three full-sib families were transplanted into an outdoor nursery in Olympia, Washington, and subjected to four treatments consisting of a factorial of (1) shaded or unshaded and (2) bareroot or confined roots. After two growing seasons, treatments had significantly affected plant size and biomass in the order unshaded-bareroot > shaded-bareroot > unshaded-confined > shaded-confined, but plants in all treatments had become nearly orthotropic. It is concluded that neither shading nor root confinement is, but other greenhouse environmental conditions are, responsible for the persistence of plagiotropic growth.

[OSU Link](#)

[Non-OSU Link](#)

66. Ritchie, G.A., Y. Tanaka and S.D. Duke. 1992. Physiology and morphology of Douglas-fir rooted cuttings compared to seedlings and transplants. *Tree-Physiology* 10(2): 179-194.

Keywords: nursery operations
tree phenology
tree physiology
growth
tree morphology
carbon allocation

Abstract: Cuttings of Douglas fir (*Pseudotsuga menziesii*) from three open-pollinated families were rooted in two types of tray and then grown for 1.5 years in a nursery in Washington State. During their second winter they were sampled periodically and tested for cold hardiness, dormancy status, root growth potential and various morphological characteristics. Two-year-old seedlings and transplants were tested concurrently for comparison. Rooted cuttings, seedlings and transplants cold hardened at similar rates during early winter, achieving the same level of midwinter hardiness (LT50 = -18 degrees C) in early January. However, rooted cuttings remained hardier later into spring than did seedlings or transplants. Rooted cuttings exhibited deeper dormancy in early winter than seedlings or transplants but these differences disappeared after January. Root growth potentials of all three stock types remained above threshold values established for transplants throughout winter. Rooted cuttings had greater stem diameter, higher stem diameter : height ratio, and greater root weight than either seedlings or transplants. This may reflect lower growing densities for rooted cuttings. Root : shoot ratios of rooted cuttings were greater than for seedlings and similar to those of transplants. Rooted cuttings also had deeper and coarser root systems, which probably reflected lack of wrenching at the nursery.

[OSU Link](#)

[Non-OSU Link](#)

67. Rose, R., J.F. Gleason and M. Atkinson. 1993. Morphological and water-stress characteristics of three Douglas-fir stocktypes in relation to seedling performance under different soil moisture conditions. *New-Forests* 7(1): 1-17.

Keywords: nursery operations
tree phenology
tree physiology
growth
tree morphology

Abstract: Phenology, morphology, frost hardiness and response to moisture stress were examined for three Douglas fir (*Pseudotsuga menziesii*) stocktypes grown from the same seed lot in a nursery near Olympia, Washington, USA. The types were mini-plugReg. transplants(MPT), 1+1 bareroot transplants (1+1), and 2+0 bareroot seedlings (2+0). In the late summer and autumn before lifting, 2+0 seedlings set bud before 1+1 seedlings and 1+1 seedlings before MPT seedlings. The 2+0 seedlings appeared slowest to acquire frost hardiness and seemed to deharden most rapidly in

spring. Although 2+0 seedlings were taller than the MPT stocktype, MPT and 2+0 seedlings were relatively similar in other morphological respects, but 1+1 seedlings were much larger. All stocktypes were potted on 20 January 1989, placed in a greenhouse, and subjected to 39%, 18%, 16%, or 6% soil water-content (% dry weight) until the end of the experiment in mid-July 1990. The largest decrease in pre-dawn xylem water potential occurred with 16% and 6% soil water content; pre-dawn xylem water potential averaged over the three stocktypes generally declined 219% from low to high soil moisture stress. The 1+1 seedlings used more water than the other two stocktypes, and at maximum soil moisture stress, plant moisture stress increased in the order MPT < 2+0 < 1+1. During the 6-month greenhouse experiment, the larger 1+1 stocktype showed the most absolute growth, but the smaller stocktypes grew more on a relative scale. Growth of the stocktypes appeared to be related to differences in morphology and water-use patterns as the seedlings competed for available water within each pot. The results show that MPT seedlings, a new stocktype, performed as well as the more traditionally used 2+0 and 1+1 seedlings and that stocktype selection is important in reforestation efforts.

[OSU Link](#)

[Non-OSU Link](#)

68. Rose, R. and D.L. Haase. 2000. The use of coir as a containerized growing medium for Douglas-fir seedlings. *Native-Plants-Journal* 1(2): 107-111.

Keywords: nursery operations
growth
carbon allocation
tree physiology
tree morphology
soil properties

Abstract: In response to environmental concerns and the need for peatland conservation, alternative growing media for conifer seedling production must be investigated. Douglas-fir (*Pseudotsuga menziesii*) seedlings were grown in 6 media; components included peat moss, peat moss amended with sawdust, and 2 sources of coir (coconut fibre) mixed with and without peat moss. Coir had higher pH, P, K, and Na and lower Ca and N than peat moss and a peat moss-sawdust mixture. Bulk densities of coir and coir-based media were lower than those in peat moss and a peat moss-sawdust mixture. After 21 weeks, seedlings grown in coir-based media were significantly smaller and had lower foliar N and Ca than those grown in peat moss. Because of coir's many favourable qualities, further research is recommended using culturing regimes specific to the substrate's nutrient properties.

[OSU Link](#)

[Non-OSU Link](#)

69. Rose, R., J.S. Ketchum and D.E. Hanson. 1999. Three-year survival and growth of Douglas-fir seedlings under various vegetation-free regimes. *Forest-Science* 45(1): 117-126.

Keywords: release treatments
chemical release
growth

tree morphology
tree/stand health
stand conditions

Abstract: Responses of Douglas-fir (*Pseudotsuga menziesii*) seedlings were studied for 3 yr (1993-96) following eight vegetation-control treatments in three western Oregon clearcuts. The objectives were to determine seedling growth response to different areas of spot vegetation control and to determine the relative influence of early woody and herbaceous competition on seedling growth. Herbicide treatment areas varied in size from those receiving no control to full control (9.3 m²). Controlled areas were maintained free of herbaceous vegetation for 2 yr and all woody vegetation was controlled for 3 yr. Two additional treatments, complete control of woody vegetation only and complete control of herbaceous vegetation only, were also examined. On two sites (Summit and Marcola), seedling growth parameters were maximized at or near full vegetation control with a tree spacing of 3 m x 3 m. On the third site (Pedee), maximum growth response occurred between 5 and 6 m² of control. Herbaceous vegetation control resulted in increased seedling growth at all sites while woody vegetation control yielded increased seedling growth only at the Pedee site. Cumulative 3 yr herbaceous cover accounted for 68% and 41% of the variability in stem volume at Summit and Marcola, respectively. Adding cumulative 3 yr woody cover to the model accounted for an additional 18% and 49% of the variability in stem volume at Summit and Marcola, respectively. At Pedee, neither herbaceous nor woody cover significantly influenced 3 yr stem volume, suggesting that factors other than vegetation cover were responsible for differences measured.

[OSU Link](#)

[Non-OSU Link](#)

70. Roth, B.E. and M. Newton. 1996b. Survival and growth of Douglas-fir relating to weeding, fertilization, and seed source. *Western-Journal-of-Applied-Forestry* 11(2): 62-69.

Keywords: planting operations
fertilization
release treatments
chemical release
growth
tree physiology
tree morphology
tree/stand health

Abstract: The goal of this study was to quantitatively evaluate the individual and interactive effects of weed control, nitrogen fertilizer, and seed source on Douglas fir (*Pseudotsuga menziesii*) survival and growth in plantations on a range of sites and growing conditions in western Oregon. Weed control with hexazinone (broadcast application after planting) was the dominant factor influencing seedling survival and growth and accounted for 49% of the explained variation in seedling volume after 2 years. Nitrogen fertilizer (urea) had no effect when used in conjunction with weed control and a negative effect when used without weed control. Seedlings from a seed orchard source were significantly larger in diameter and volume than those from a wild local source after two growing seasons, but second-year heights were similar for the two seedling types. Initial seedling size was positively correlated with growth rate.

[OSU Link](#)

[Non-OSU Link](#)

71. Scagel, C.F., R.G. Linderman and R.K. Scagel. 2000. Ten-year growth and survival of Douglas-fir seedlings treated with plant growth regulating substances at transplant. *Canadian-Journal-of-Forest-Research* 30(11): 1778-1787.

Keywords: nursery operations
growth
tree/stand health
tree morphology

Abstract: Commercially available plant growth regulators (PGRs) or moisture retention gels, applied to the roots of Douglas fir (*Pseudotsuga menziesii*) before planting, can modify IAA levels in roots, root growth responses, and tree survival. Two different 1+0 stock types (PSB313B and PSB323, interior and coastal Douglas fir, respectively, the latter having a larger root mass) were treated with IBA, ethephon (Ethrel), alginate, or a combination of IBA and alginate. New root growth and IAA levels in roots were measured 2 weeks after planting, and aboveground growth and tree survival were monitored over 10 growing seasons after planting in May 1988 on a site clear felled in winter 1988 in British Columbia, Canada; no site preparation was carried out. Treatment with IBA or the combination of IBA and alginate increased IAA conjugate and free IAA levels in roots, root growth, and tree survival. Alginate treatment alone increased new root growth and tree survival, but did not increase free IAA levels in roots. Ethephon treatment increased free IAA levels and root growth, but had no effect on IAA conjugates or tree survival. A cost analysis suggested that use of certain PGRs or alginate decreased the cost required to attain target stocking and increased tree size. The results suggest that application of PGRs or other root-promoting materials to the roots of Douglas fir before planting has the potential to be a cost-beneficial method for increasing root growth and tree survival.

[OSU Link](#)

[Non-OSU Link](#)

72. Schneider, W.G., S.A. Knowe and T.B. Harrington. 1998. Predicting survival of planted Douglas-fir and ponderosa pine seedlings on dry, low-elevation sites in southwestern Oregon. *New-Forests* 15(2): 139-159.

Keywords: site preparation
mechanical preparation
prescribed fire
tree/stand health
tree morphology
stand conditions

Abstract: Four equations were developed by logistic regression for predicting the probability of Douglas fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) survival for the first (0-1) and first to third (1-3) growing seasons after applying mulching, radial scalping (removal of all vegetation and a thin layer of soil in a 1-m radius area around each tree), or artificial shading (shade cards) treatments in plantations in SW Oregon. Most of the sites had been burned by wildfire or prescribed fire before

planting. Variables describing conifer size, levels of competing vegetation, presence of silvicultural treatments, site factors, and climate factors were collected from 13 sites up to 6 yr after planting and examined as potential predictors of survival. Age, stem diameter, a competition index for shrubs, severity of growing season at time of treatment, average annual precipitation, aspect, and slope angle were predictors of Douglas fir survival during 0-1 and 1-3 growing seasons after treatment; the presence of silvicultural treatments was also a predictor only during the first growing season after treatment. Age, aspect, and slope angle were predictors of ponderosa pine survival over both 0-1 and 1-3 growing seasons after treatment; height-diameter ratio, competition indices for herbs, shrubs, and hardwoods, silvicultural treatment, severity of growing season at time of treatment, and average annual precipitation were also predictors only during the first growing season after treatment; crown width was a predictor of survival only during 1-3 growing seasons after treatment. When significant in the models (equations), predicted probability of survival increases with treatments, less severe weather conditions, diameter, crown width, age, and precipitation; probability decreases with increasing height-diameter ratio and competition indices for herbs, shrubs, and hardwoods.

[OSU Link](#)

[Non-OSU Link](#)

73. Shainsky, L.J., M. Newton and S.R. Radosevich. 1992. Effects of intra- and inter-specific competition on root and shoot biomass of young Douglas-fir and red alder. *Canadian-Journal-of-Forest-Research* 22(1): 101-110.

Keywords: planting operations
growth
tree morphology
carbon allocation
tree physiology

Abstract: Two-year-old seedlings of Douglas fir (*Pseudotsuga menziesii*) and red alder (*Alnus rubra*) were planted in Oregon in 1985 at densities of 1, 2, 4, 8 and 16 trees/m² in a two-way density matrix composed of 5 monoculture densities and 25 mixtures of all possible pairwise combinations of monoculture densities. Roots and shoots were harvested after the fourth growing season. Response surfaces for root, shoot and total biomass per tree were generated within the matrix. Regression analysis quantified the effect of each species' density on biomass components. Alder overtopped the Douglas fir in all mixed stands. Alder density influenced the root and shoot biomass of both species more than Douglas fir density did, the greatest reduction in root biomass of Douglas fir taking place at an alder density of ≤ 1 tree/m². Douglas fir density interacted with red alder density to influence all biomass components. Douglas fir density effects were inconsistently significant across alder densities. While increasing the density of each species reduced root and shoot biomass per tree, allocation of biomass to roots and shoot was not affected by competition, nor were the allometric equations relating biomass to stem diameter and stem volume index. Foliar concentrations of N and P in the Douglas fir understory are reported.

[OSU Link](#)

[Non-OSU Link](#)

74. Sorensen, F.C. 1997. Effects of sib mating and wind pollination on nursery seedling size, growth components, and phenology of Douglas-fir seed-orchard progenies. *Canadian-Journal-of-Forest-Research* 27(4): 557-566.

Keywords: genetic tree improvement
nursery operations
growth
tree/stand health
tree morphology
tree phenology

Abstract: Polymix outcross (X), full-sib (FS), and wind-pollination (WP) families were produced on 25 seed trees and 10 half-sib families on 10 of the same trees in a *Pseudotsuga menziesii* var. *menziesii* seedling seed orchard in Oregon. Seedlings were raised at 2 sowing densities for 2 years in the nursery, and inbreeding depression (ID) in seedling size related to inbreeding effect on growing season length and growth rate. Seedling mortality was light and not affected by inbreeding. Mean ID for 2-year size traits was 6% (height) and about 8% (diameter) per 10% increase in F, the inbreeding coefficient, and was linear with the increase in F over the range of F used. Both amount of ID and its fit to linearity differed greatly among seed trees. Elongation season was significantly and slightly shorter for FS than for X families; second-year relative elongation rate was nonsignificantly larger for FS than for X families. Inbred families had nonsignificantly larger within-plot variance and significantly larger coefficients of within-plot variance than X families. Sowing density was not a significant factor except in diameter and height/diameter ratio. Results are discussed in terms of plant growth habit and possible gene action. WP compared with X families were significantly shorter by 3.8% and significantly smaller in diameter by 4.6%, with much variation among family groups. About half of the height difference could be explained by seed weight; the remainder could have been due to pollen contamination or natural inbreeding. Progenies of the two pollen types did not differ for phenological traits, even though the seed orchard was in a drier, more inland location than the parent-tree locations. Progenies of WP had nonsignificantly larger within-plot variance than X progenies.

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75. St-Clair, J.B. 1994b. Genetic variation in tree structure and its relation to size in Douglas-fir. II. Crown form, branch characters, and foliage characters. *Canadian-Journal-of-Forest-Research* 24(6): 1236-1247.

Keywords: genetic tree improvement
carbon allocation
tree morphology
wood quality
genetic relationships

Abstract: Genetic variation and covariation among traits of tree size (volume, basal area, diameter at breast height and height) and structure were assessed in 1991 in an 18-year-old Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) genetic test in the Coast Range of Oregon. Considerable genetic variation was found for relative crown width, stem increment per crown projection area, leaf area and branch weight relative to crown size, branch diameter and length adjusted for stem size, branch stoutness, cross-sectional area of branches per crown length and needle size. Little genetic variation was

found for branch numbers per whorl, branch angle and specific leaf area. At both the phenotypic and genetic level, large trees growing in relatively small spaces had tall, narrow crowns, high leaf areas per crown projection area or branch length, greater partitioning to leaves versus branches, and stouter branches. Thus, large, efficient trees were those that invested more in the photosynthetic machinery of leaf area and the branch biomass necessary to support that leaf area, but distributed that leaf area over a greater vertical distance. Unfortunately, these traits were also associated with increased branchiness, and selection for these traits would be accompanied by reductions in harvest index and wood quality.

[OSU Link](#)

[Non-OSU Link](#)

76. St-Clair, J.B. and R.A. Sniezko. 1999. Genetic variation in response to shade in coastal Douglas-fir. *Canadian-Journal-of-Forest-Research* 29(11): 1751-1763.

Keywords: genetic tree improvement
growth
tree morphology
carbon allocation
tree phenology

Abstract: Tree improvement programmes have generally relied on testing families in open light environments. With increased interest in multiaged silvicultural systems, some people have questioned whether families selected in the open are appropriate for planting in the shade. Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) families from two climatically distinct seed sources in the Coast Range (NW Oregon) and Siskiyou Mountains (SW Oregon) were grown for 2 years under four levels of shade. The response to shade differed for several traits between the two populations and among families within populations. The magnitude of variation associated with the interaction, however, was small compared with the overall effects of genetic selection or of shade. Families selected based on performance in an open light environment resulted in nearly the same response to selection when grown under shade as families selected based on performance in the shade. It is concluded that seedlings from families selected in an open light environment are appropriate for use in the low-light environments of alternative silvicultural systems and that use of such genetically selected stock may compensate for the less favourable growing conditions. Genetic selection may contribute importantly to meeting multiple objectives, including the production of significant amounts of wood as well as the efficient and timely creation of large stand structures needed for other forest values.

[OSU Link](#)

[Non-OSU Link](#)

77. Stein, W.I. 1984. Wrenching Douglas-fir seedlings in August: immediate but no lasting effects. *Pacific-Northwest-Forest-and-Range-Experiment-Station,-USDA-Forest-Service Research-Paper PNW-RP-317*. 12 p.

Keywords: nursery operations
tree morphology
growth
carbon allocation

tree/stand health

Abstract: Seedlings in a nursery in Oregon were wrenched in their 2nd growth season in 1976. Wrenched and unwrenched seedlings were sampled at intervals from Aug. 1976 until Jan. 1977, and measured. The entire bed was lifted in Jan. and 100 treated and 100 control seedlings were planted out. After 24 days (Aug.), the number of lateral roots, shoot length, and root dry wt. were significantly smaller in wrenched seedlings. Shoot/root ratio was also smaller and remained so until early Oct. By late Oct., shoot length and the number of lateral roots were significantly greater in wrenched seedlings. During the first 5 yr after planting out, there were n.s.d. between wrenched and unwrenched trees in survival and growth, which were both good.

[OSU Link](#)

[Non-OSU Link](#)

78. Stein, W.I. 1988. Nursery practices, seedling sizes, and field performance. *In*: Proceedings, combined meeting of the Western Forest Nursery Associations; 1988 August 8-11; Vernon, British Columbia. *Tech Coord.* T.D. Landis. Rocky Mountain Forest and Range Experiment Station, USDA Forest Service General Technical Report RM-GTR-167. 15-18 pp.

Keywords: nursery operations
growth
tree morphology
tree/stand health

Abstract: Highlights are presented from a large cooperative study in Oregon to determine the combined effects of nursery cultural practices on the size and field performance of 2+0 Douglas fir [*Pseudotsuga menziesii*] seedlings. Seedlings were grown in 3 nurseries using seed from 7 sources; field plantings were made over 3 yr on 28 sites in SW Oregon. Seedbed density had more effect than irrigation frequency, undercutting or wrenching on seedling size, and survival and growth 4 yr after planting.

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79. Steinfeld, D., D. Davis, S. Feigner and K. House. 2002. Fall versus spring transplanting of container seedlings: a comparison of seedling morphology. *In* National Proceedings: Forest and Conservation Nursery Associations 1999, 2000, and 2001, USDA-Forest-Service Rocky-Mountain-Research-Station RMRS-P-24. 196-200 pp.

Keywords: nursery operations
growth
tree/stand health
tree morphology

Abstract: In a study in Oregon, USA, containerized seedlings of Engelmann spruce (*Picea engelmannii*), sugar pine (*Pinus lambertiana*), Douglas-fir (*Pseudotsuga menziesii*), western redcedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*) transplanted in the early fall and later in the early spring

were compared for differences in stem diameter, height, root area, and shoot area. Fall-transplanted *Pseudotsuga menziesii* and the *Thuja plicata* showed an increase in stem diameter of 13 (2.0 mm) and 4% (0.4 mm), respectively. Fall-transplanted seedlings developed larger root systems - *Picea engelmannii* by 18%, *Pinus lambertiana* by 48%, *Pseudotsuga menziesii* by 58%, and *Tsuga heterophylla* by 47%.

[Non-OSU Link](#)

80. Thompson, G. 1995. Nitrogen fertilization requirements of Douglas-fir container seedlings vary by seed source. *Tree-Planters' Notes* 46(1): 15-18.

Keywords: nursery operations
nursery fertilization
growth
carbon allocation
tree morphology

Abstract: Growth of container-grown Douglas fir (*Pseudotsuga menziesii*) from different seed sources from western Washington, northern Idaho and western Montana was evaluated following application of 100, 150, or 200 p.p.m. nitrogen during the rapid growth phase. The optimum level of N varied between seed sources for height, stem diameter, and bud growth, as well as for root shoot ratio. Target seedling specifications were met adequately for the westernmost sources at 100 and 150 p.p.m. N, whereas eastern sources required 150 or 200 p.p.m. Nitrogen levels should thus be tailored to individual Douglas fir seed sources to maximize the number of shippable seedlings per lot.

[OSU Link](#)

[Non-OSU Link](#)

81. Thomson, A.J. and H.J. Barclay. 1984. Effects of thinning and urea fertilization on the distribution of area increment along the boles of Douglas-fir at Shawnigan Lake, British Columbia. *Canadian-Journal-of-Forest-Research* 14(6): 879-884.

Keywords: fertilization
thinning
tree morphology
growth

Abstract: Assessments were made using radial growth measurements made 6 and 9 yr after treatment. Within treatments, av. area increment per tree was linearly related to d.b.h. and this relation was used to evaluate the effects of treatment on growth rate. Fertilizing had the greatest effect on av. area increment, and for a particular fertilization regime, thinning increased the response. Thinning modified the distribution of growth over the bole of all trees and increased butt flare, especially in smaller trees. The effect declined from the 4- to 6-yr measurement period to the 7- to 9-yr measurement period. Fertilizing had no consistent effect on growth distribution. The regression methods used in this study provided a more sensitive measure of form changes than previous methods, were independent of size distribution, and facilitated extrapolations and evaluation of temporal trends.

[OSU Link](#)

[Non-OSU Link](#)

82. Turner, J. and S.J. Mitchell. 2003. The effect of short day treatments on containerized Douglas-fir morphology, physiology and phenology. *New-Forests* 26(3): 279-295.

Keywords: nursery operations
growth
tree morphology
tree physiology
photosynthesis
tree phenology

Abstract: The effect of short day treatments ('blackout') on Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) container seedlings at the time of lift and following cold storage was investigated. Variables measured included height, root collar diameter (RCD), root growth capacity (RGC), photosynthetic efficiency after -18 degrees C freezing (PEF), and days to terminal bud break (DBB). From one to four blackout dormancy induction treatments were started on three dates (July 12, July 26, and August 10) with 10 or 20 d between multiple blackouts. Increasing the number of blackout treatments resulted in lower RCD, lower DBB in the late winter/early spring, and higher PEF in the early fall. Later blackout start dates decreased PEF in the early fall, and increased overall height and late fall RGC as compared to earlier blackout start dates. Nurseries growing Douglas-fir seedlings from coastal Pacific Northwest provenances should be aware that blackout regimes can decrease RGC in the late fall, and cause quicker dormancy release in the early spring. Coastal Douglas-fir can be lifted and planted in the early fall, when RGC and DBB are relatively high. If planting between February and April is necessary, seedlings given blackout should be cold stored in January to maintain an adequate level of dormancy, RGC and PEF.

[OSU Link](#)

[Non-OSU Link](#)

83. Velazquez-Martinez, A., D.A. Perry and T.E. Bell. 1992. Response of aboveground biomass increment, growth efficiency, and foliar nutrients to thinning, fertilization, and pruning in young Douglas-fir plantations in the central Oregon Cascades. *Canadian-Journal-of-Forest-Research* 22(9): 1278-1289.

Keywords: fertilization
thinning
pruning
growth
carbon allocation
tree physiology
tree morphology

Abstract: The effect of thinning and silvicultural practices (multinutrient fertilization and/or pruning) on total aboveground biomass increment and growth efficiency was studied over three consecutive 2-year periods (1981-1987) in young Douglas fir (*Pseudotsuga menziesii*) plantations in the central Oregon Cascades. Plantations were 21-27 yr old in 1987. Plots were heavily thinned (leaving 300 trees/ha),

moderately thinned (leaving 604 trees/ha) or left unthinned (leaving 3459 trees/ha) in 1981. Fertilizer (N, P, K, Ca, S and Fe) was applied with slow-release tabs. Net above-ground biomass annual increment over the 6-year period averaged 14.5, 7.8, and 5.5 t/ha for the high-, medium-, and low-density plots, respectively. Growth efficiency, after dropping sharply between leaf area indexes (LAI) of 1 and 6, remained relatively constant up to the highest measured LAI of 17. Consequently, above-ground biomass increment continued to increase at LAIs well above that at which the Beer-Lambert law predicts maximum light should be absorbed. Foliage analyses indicated that thinning improved N, K and Mg nutrition and increased the translocation of K from 1-yr-old foliage to support new growth. However, fertilizer application increased foliar N and P contents only when coupled with pruning, suggesting that trees favour total leaf area over individual needle nutrition. Indications of K and Mg limitations in this study are supported by other recent studies of Douglas fir.

[OSU Link](#)

[Non-OSU Link](#)

84. Vogt, K.A., D.J. Vogt, E.E. Moore, W. Littke, C.C. Grier and L. Leney. 1985. Estimating Douglas-fir fine root biomass and production from living bark and starch. *Canadian-Journal-of-Forest-Research* 15(1): 177-179.

Keywords: fertilization
tree morphology
tree physiology

Abstract: A potential indirect technique for determining fine root biomass and production is reported. Data from 4 permanent Douglas fir plots in Washington State given different fertilizer treatments showed a direct correlation between the starch content of a 1-cm wide band of living bark at b.h. per hectare and fine root biomass per hectare ($r^2 = 0.85$). Starch content was determined in bark samples from 5 trees in each plot and estimates of the volume of 1-cm wide bands of bark at b.h. were made from measurements of d.b.h. and total bark thickness of every tree in each plot. Fine root biomass was determined in soil cores obtained with a post hole digger (inner diam. 15.3 cm); traditional small core methods could not be used because of the high gravel and rock content of the soil.

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85. Wagner, R.G. and S.R. Radosevich. 1991a. Interspecific competition and other factors influencing the performance of Douglas-fir saplings in the Oregon Coast Range. *Canadian-Journal-of-Forest-Research* 21(6): 829-835.

Keywords: site preparation
prescribed fire
growth
tree morphology

Abstract: Regression models describing total height, stem diameter, stem volume index, and crown volume index of individual 4- to 9-year-old saplings of Douglas fir (*Pseudotsuga menziesii*) were developed from a retrospective analysis of two site preparation experiments (with/without prescribed

burning). Measurements of 787 Douglas fir saplings were taken at nine sites during July and August 1984. The variables included in the models were age, interspecific competition index, height, animal damage (browsing and clipping), use of prescribed burning, and slope angle and azimuth. The models, which integrate environmental and morphological factors that can influence the performance of Douglas fir saplings into one set of equations, accounted for 64-73% of the variation in individual tree size. Interspecific competition and amount of animal damage were negatively correlated with tree size. Tree age, 1st-year height, and the use of prescribed burning were positively correlated with tree size. When factors were held constant, trees were largest on steep southeast slopes. The models indicated that tree age, competing vegetation, animal damage, and initial seedling size had a dominant influence on the performance of Douglas fir saplings, while prescribed burning and topography were of relatively minor importance.

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[Non-OSU Link](#)

86. Walker, R.B., S.P. Gessel and R.E. Miller. 1994. Greenhouse and laboratory evaluation of two soils derived from volcanic ash. *Northwest-Science* 68(4): 250-258.

Keywords: fertilization
growth
tree/stand health
carbon allocation
tree morphology
tree physiology

Abstract: This study assessed the mineral nutrient status of two soils derived from volcanic ash in SW Oregon. The study was initiated because conifers in some of the field plots on such soils had failed to give an expected yield response to the application of nitrogen fertilizer. Soil pot tests were carried out using both Romaine lettuce (*Lactuca sativa*) and Douglas fir (*Pseudotsuga menziesii*) seedlings, with a wide range of fertilizer treatments. Heavy phosphorus fertilization was necessary for satisfactory growth of lettuce, which also showed a 26% response to sulfur addition. With Douglas fir, pot tests showed no response to nitrogen alone, but gave a statistically significant response to phosphorus fertilization together with nitrogen (seedlings were non-mycorrhizal), and some suppression of yield with sulfur additions. There was a favourable effect of sulfur fertilization on foliar colour, and a chlorosis in younger foliage probably attributable to iron deficiency. Most of the tissue analyses showed low concentrations of magnesium (<0.05%), and also of calcium (<less or =>0.08%), iron (<70 mg/kg), boron (mostly 20 mg/kg) and copper (<less or =>2.6 mg/kg) in the younger foliage. Thus there is an implication from the field trials, and evidence from the greenhouse and laboratory study, that elements besides nitrogen need to be added to provide proper nutrition on these volcanic ash soils. The information can aid in guiding further fertilizer trials in forests on volcanic ash derived soil in SW Oregon and elsewhere.

[OSU Link](#)

[Non-OSU Link](#)

87. Wilson, J.S. and P.J. Baker. 2001. Flexibility in forest management: managing uncertainty in Douglas-fir forests of the Pacific Northwest. *Forest-Ecology-and-Management* 145(3): 219-227.

Keywords: planting operations
thinning
yield
tree morphology
economics
tree/stand health

Abstract: Long planning horizons generate substantial uncertainty in forest management, making management flexibility, the ability to choose between multiple options or opportunities, a desirable attribute of managed forests. Flexibility in forest management reflects both the relative rigidity of intervention requirements and the potential range of development pathways for a stand. The wind stability of Pacific Northwest Douglas-fir (*Pseudotsuga menziesii*) plantations is used to demonstrate the concept of management flexibility. Dense Douglas-fir plantations develop high height to diameter ratios in the dominant trees making them unstable and prone to wind damage. The management of these plantations is inflexible, because without early and timely thinning, the stands do not contain stable trees that could be expected to survive long rotations or late thinnings. A combination of reduced planting densities and site-specific management reduces both the necessity and rigidity of intervention requirements (e.g., thinning) and expands the number of potential developmental pathways for these stands. The cost of greater management flexibility is reduced efficiency of wood volume production; however, greater adaptability to changing markets, labour conditions, and management objectives may be more important for many forest owners. While this approach to management is complex, it frees owners and managers from rigid management requirements and allows for a wider range of future stand conditions.

[OSU Link](#)

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88. Wilson, J.S. and C.D. Oliver. 2000. Stability and density management in Douglas-fir plantations. *Canadian-Journal-of-Forest-Research* 30(6): 910-920.

Keywords: planting operations
thinning
tree/stand protection
tree morphology
tree/stand health

Abstract: Limited tree size variation in Douglas fir (*Pseudotsuga menziesii*) plantations in coastal Oregon, Washington, and British Columbia makes them susceptible to developing high height to diameter ratios (H/D) in the dominant trees. The H/D of a tree is a relative measure of stability under wind and snow loads. Experimental plot data from three large studies were used to evaluate the impact of initial planting densities and thinning on plantation H/D values. The H/D predictions from the experimental plot data match spacing trial results closely but are substantially different from distance-independent growth model predictions. The results suggest that plantation H/D values can be lowered and stability promoted through reduced planting densities or early thinning; however, later thinnings may not be effective in promoting stability, since they do not appear to lower H/D values. Higher initial planting densities shorten the time period during which thinning can be expected to effectively lower future H/D values. Time-sensitive thinning requirements in dense plantations make

their management inflexible. The flexibility with which a stand can be managed describes the rigidity of intervention requirements and/or potential range of stand development pathways.

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