

Genetic Tree Improvement

1. 1994. Annual Report - Forest Research Laboratory, Oregon State University. Forest Research Laboratory, Oregon State University. ii + 29 pp.

Keywords: genetic tree improvement
tree/stand protection
tree phenology
tree physiology

Abstract: Highlights of research conducted during 1993-1994 are presented, including: preliminary results of a 2-year (1992-94) field cold hardiness study of Douglas fir [*Pseudotsuga menziesii*] in Oregon, USA involving open pollinated progeny of 40 parents at a high and a low elevation; results of a progeny test on the frequency of second flushing of Douglas fir near Orleans, France; and variation in stable carbon isotope ratios (a measure of water use efficiency) among varieties and populations (coastal and Rocky Mountain) of Douglas fir.

2. 1997. PNWTIRC Annual Report 1996-97, Pacific Northwest Tree Improvement Research Cooperative. Oregon State University, Oregon, USA. ii + 29 p.

Keywords: genetic tree improvement
tree/stand protection
tree phenology
growth
wood quality
tree physiology

Abstract: The report describes highlights for 1996-97, current research (3 projects), student project updates (3 projects), planned Douglas fir [*Pseudotsuga menziesii*] seed orchards for the new millennium and other planned activities of the PNWTIRC, a research cooperative operating in the Pacific Northwest area of North America (USA and Canada). Details are included of publications and finances. Details of the 3 current research projects and the 3 student projects, which all concern Douglas fir, are presented as short papers including brief results: (1) Influence of second flushing on cold hardiness; (2) Seedling drought physiology study; and (3) Quantitative trait loci influencing cold hardiness; (4) Seedling cold hardiness; (5) Growth response of saplings to drought; and (6) Measurement study follow-up: age-age correlations in forking defects.

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3. 2000. Annual Report 1999/2000 - Pacific Northwest Tree Improvement Research Cooperative. Oregon State University, Oregon, USA. 31 p.

Keywords: genetic tree improvement
tree/stand protection
tree physiology
reproduction

Abstract: Includes highlights of 1998-1999; a note to the cooperative members from Tom Adams; Introduction; Current research on seedling drought physiology of Douglas fir [*Pseudotsuga menziesii*], field drought study - genetics of drought sensitivity in older trees, early testing revisited, miniaturized orchard study, pollen contamination study; activities planned for 2000-2001; list of staff publications and abstracts; and a summary of financial support for the fiscal year 1999-2000.

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4. Abdel-Gadir, A.Y. and R.L. Krahmer. 1993. Genetic variation in the age of demarcation between juvenile and mature wood in Douglas-fir. *Wood-and-Fiber-Science* 25(4): 384-394.

Keywords: genetic tree improvement
wood quality

Abstract: Variation in the age of demarcation between juvenile and mature wood based on wood density was studied in 180 Douglas fir (*Pseudotsuga menziesii*) trees. Ring density profiles were generated from X-ray densitometry of increment cores from each of 3 randomly selected trees from each of 30 wind-pollinated families (parent trees) grown in 2 replication blocks in Washington. The families represented 10 provenances (3 families per provenance) from Washington and Oregon. Two boundary points were determined: the age at which a significant change occurred in the slope of the density-age relationship (using piecewise regression techniques), and the age at which species average density was reached. The period of juvenile wood production ranged from 11 to 37 years among the trees sampled. Most of the variation was among trees-within-plots; however, significant differences among families-within-provenances indicated that the period of juvenile wood production for this population of Douglas fir was under appreciable genetic control.

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5. Abdel-Gadir, A.Y., R.L. Krahmer and M.D. McKimmy. 1993. Relationships between intra-ring variables in mature Douglas-fir trees from provenance plantations. *Wood-and-Fiber-Science* 25(2): 182-191.

Keywords: genetic tree improvement
wood quality
genetic relationships

Abstract: Relationships among a variety of densitometric characteristics of juvenile and mature wood from 360 trees growing in two plantations of Douglas fir (*Pseudotsuga menziesii*) in Oregon and Washington were examined. Variables included earlywood density (EWD) and width (EWW); latewood density (LWD), width (LWW), and proportion (LWP); average ring density (RD); and total ring width (RW). The RD components (EWD and LWD) had strong phenotypic and genetic correlations with their respective RW components (EWW and LWW). However, no phenotypic correlation existed between average RD and total RW, and genotypic correlation was weak. The relation between wood density and radial growth varied by plantation and genotype. It was shown that the potential exists for improving wood density in juvenile and mature wood by selection, with only a minor effect on radial growth. Selection during the juvenile period to improve mature wood quality would be

feasible for RD, EWD, LWW, and LWP. Further, selection to improve juvenile RW would not result in reduced wood density during maturity.

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6. Adams, T., T. Anekonda and C. Lomas. 1999. Annual Report 1998-99, Pacific Northwest Tree Improvement Research Cooperative. 33 p.

Keywords: genetic tree improvement
tree/stand protection
tree/stand health
growth
tree physiology

Abstract: Summaries are given of research projects on improvement of Douglas fir [*Pseudotsuga menziesii*] in the Pacific Northwest: seedling drought physiology; genetics of dark respiration and its relationship with drought hardiness; response of saplings to drought, as measured by growth ring variables; use of microsatellite marker loci to identify pollen contamination in seed orchards; and evaluation of miniaturized seed orchard designs.

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7. Adams, W.T., S.N. Aitken, D.G. Joyce, G.T. Howe and J. Vargas-Hernandez. 2001. Evaluating efficacy of early testing for stem growth in coastal Douglas-fir. *Silvae-Genetica* 50(3/4): 167-175.

Keywords: genetic tree improvement
nursery operations
growth
genetic relationships

Abstract: In a test to evaluate the ability to predict stem growth of families in the field from nursery performance (i.e., early testing), 67 open-pollinated families and 66 full-sib families of coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) were sown in two nursery conditions, each replicated as separate experiments: two bareroot nursery trials established in successive years in the same nursery, and two container-sown greenhouse trials sown in different greenhouses in the same year. First year heights in the seedling trials were compared to mean stem volumes of the same open-pollinated families in eight 15-year-old field progeny tests and the same full-sib families in eleven 12-year-old tests. Family mean nursery-field correlations (r_{xy}) were similar for all four seedling trials for both open-pollinated (OP) and full-sib (FS) families, and generally ranged between 0.30 and 0.40. Although low, it is shown that nursery-field correlations of this magnitude can be quite useful in tree improvement programmes. For example, based on the data in this study, it is estimated that a single stage of family selection for first year seedling height would be about 50% as effective in improving 15-year volume as direct selection for this trait in field tests. Early testing, however, is probably of more practical significance as a tool for culling families prior to out-planting field tests in two-stage selection schemes. It is estimated that 25% of the OP families in this study could have been culled in an early test (first stage selection), with gain in 15-year volume after subsequent field testing and selection of the

remaining families (second stage selection) being nearly the same as if all families had been field tested. Thus, early testing is an effective tool for reducing the size and cost of field progeny tests without sacrificing genetic gain.

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8. Adams, W.T. and D.G. Joyce. 1990. Comparison of selection methods for improving volume growth in young coastal Douglas-fir. *Silvae-Genetica* 39(5-6): 219-226.

Keywords: genetic tree improvement
growth

Abstract: Data from a Douglas fir (*Pseudotsuga menziesii*) open-pollinated progeny test in Oregon were used for evaluating methods of selection for bole volume. Tree height and bole diameter at breast height (DBH) were measured on 12 to 13-year-old individuals from 90 families at each of 3 plantations in the central Oregon coast range, and bole-volume estimates were derived with a quadratic volume equation. Four methods were compared for both parental and progeny selection: (1) indirect selection based on height, (2) indirect selection based on DBH, (3) direct selection based on volume, and (4) selection based on an index that included all 3 traits. Two-stage selection was also explored, where test trees are culled on the basis of DBH in the first stage; height is measured only on the remaining trees, so that final selections (the second stage) are based on volume. Estimated genetic gains in volume from progeny selection were 8-11% greater than those from parental selection. The relative efficiencies of the various selection methods, however, were similar for parental and progeny selection. The greatest estimated gains in single-stage selection, which were achieved with the multitrait index, were only 1% better than those from selections based on volume alone. Indirect selection based on DBH produced about 90% of the gain achieved by direct selection for volume, and indirect selection based on height was about 92-94% as efficient as direct selection. With 2-stage selection, up to two-thirds of the trees could be culled in stage 1 without significantly lower gains in bole volume than those expected if the height of all trees had been measured.

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9. Aitken, S.N. and W.T. Adams. 1996. Genetics of fall and winter cold hardiness of coastal Douglas-fir in Oregon. *Canadian-Journal-of-Forest-Research* 26(10): 1828-1837.

Keywords: genetic tree improvement
tree/stand protection
tree/stand health
tree physiology
genetic relationships

Abstract: Genetic variation in autumn cold hardiness was studied in two western Oregon breeding populations of coastal Douglas fir (*Pseudotsuga menziesii* var. *menziesii*), one on the west slope of the Cascade Mountains and the other in the Coastal Range. On six sampling dates (September, October and November 1992 and January, September and October 1993), shoot cuttings from 40 open-

pollinated families in each of two progeny test sites for each breeding zone were subject to artificial freezing at two test temperatures. Damage in each shoot was recorded as visible injury to needle, stem and bud tissue separately. Considerable family variation was found for cold injury scores in all tissues in early to mid autumn, but differences were often smaller or nonsignificant in late autumn and midwinter. Individual heritability estimates for needle cold injury were low (<0.40) and generally decreased in late autumn and midwinter. Family rankings for autumn cold hardiness, however, are expected to be relatively consistent over sites and years, although needles appear to display more family-by-site interaction than stems or buds. Genetic correlations between tissues in cold injury varied considerably and were sometimes weak, indicating that the evaluation of a single tissue is probably not adequate for assessing overall cold hardiness of genotypes. Autumn and winter cold hardiness seem to be largely under separate genetic control since genetic correlations between hardiness at these two stages were weak. This study confirms earlier results in Washington breeding populations and shows that coastal Douglas fir families can be effectively ranked for autumn cold hardiness by conducting artificial freeze tests on cut shoots in mid-autumn (October) and scoring damage to stems and at least one other tissue.

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10. Aitken, S.N. and W.T. Adams. 1997. Spring cold hardiness under strong genetic control in Oregon populations of *Pseudotsuga menziesii* var. *menziesii*. *Canadian-Journal-of-Forest-Research* 27(11): 1773-1780.

Keywords: genetic tree improvement
tree/stand protection
tree/stand health
tree phenology
tree physiology
genetic relationships

Abstract: Genetic variation in spring cold hardiness of shoots prior to bud break was studied in two Oregon breeding populations of *Pseudotsuga menziesii* var. *menziesii*, one on the west slope of the Cascade Mountains and the other in the Coast Range. In March and April 1993, and April 1994, shoot cuttings from 40 open-pollinated families in each of two progeny test sites in each breeding zone were subjected to artificial freezing. Visible cold damage to needle, stem, and bud tissues was recorded. Date of bud burst (all sites), and injury resulting from a 1992 natural frost event (one site), were also recorded. Spring cold injury varied widely among families. Individual heritabilities for spring cold injury scores averaged 0.76 in the Coastal zone and 0.42 in the Cascade zone. Genetic correlations among tissues, sites, sampling dates, and years, and between April cold injury and date of bud burst were high, in most cases over 0.80. Correlations were also strong between natural frost damage in 1992 and artificial cold injury scores in 1993. Artificial freeze testing stem tissues of cut shoots sampled in April from a single test site should effectively rank families in this region for spring cold hardiness.

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11. Aitken, S.N., W.T. Adams, N. Schermann and L.H. Fuchigami. 1996. Family variation for fall cold hardiness in two Washington populations of coastal Douglas-fir

(*Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco). *Forest-Ecology-and-Management* 80(1/3): 187-195.

Keywords: genetic tree improvement
tree/stand protection
tree/stand health
tree physiology
tree phenology
genetic relationships

Abstract: In order to assess the genetics of autumn (fall) cold hardiness in coastal Douglas fir (*Pseudotsuga menziesii* var. *menziesii*), shoot cuttings were collected in October from saplings (9-year-old trees) of open-pollinated families in two progeny tests in each of two breeding zones in Washington, one in the Coast range (80 families) and one on the west slope of the Cascade Mountains (89 families). Samples from over 5500 trees were subjected to artificial freezing and visually evaluated for needle, stem and bud tissue injury. The extent to which cold injury is genetically related to tree height and shoot phenology (timing of bud burst and bud set) was also evaluated. Significant family variation was found for all cold hardiness traits; however, individual heritability estimates were relatively low (ranging from 0.09 to 0.22). Significant family-by-test site interaction was detected for needle injury in the Cascade breeding zone, but not in the coastal zone. Genetic correlations (r_A) among needle, stem and bud tissues for cold damage were weak ($0.16 < r_A < 0.58$) indicating that genes controlling autumn cold hardening are somewhat different for different tissues. Timing of bud burst and bud set were only weakly correlated with cold injury ($r_A < 0.49$). Thus, bud phenology is a poor predictor of autumn cold hardiness in this species. There was no consistent relationship between tree height and cold injury in the coastal zone. In the Cascade zone, taller trees appeared to be more susceptible to cold injury, but the association was weak (mean $r_A = 0.38$, range 0.20-0.72).

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12. Anekonda, T.S., M.C. Lomas, W.T. Adams, K.L. Kavanagh and S.N. Aitken. 2002. Genetic variation in drought hardiness of coastal Douglas-fir seedlings from British Columbia. *Canadian-Journal-of-Forest-Research* 32(10): 1701-1716.

Keywords: genetic tree improvement
tree/stand protection
growth
tree/stand health
genetic relationships
tree physiology

Abstract: Genetic variation in drought hardiness traits and their genetic correlations with growth potential and recovery traits were investigated in 39 full-sib families of coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) from southwestern British Columbia, Canada. Seedlings of these families were grown in raised nursery beds and subjected to three moisture regimes each in the second (well-watered or control, mild, and moderate drought) and third (control, severe drought, and recovery from second-year moderate drought) seasons. Traits assessed included drought hardiness (foliage damage, cavitation of xylem tracheids, xylem hydraulic conductivity, and height and diameter growth

increment) in the drought treatments, growth potential (total height and diameter) in the control treatment, and height and diameter growth increments in the recovery treatment. Xylem cavitation in the growth ring produced in a particular year was nearly three times greater under the moderate drought and four times greater under the severe drought than in the control treatment. Xylem hydraulic conductivity of seedlings in the severe drought treatment was 40% lower than conductivity of seedlings under the control treatment. Mean foliage damage in seedlings subjected to severe drought (third season) was much greater (33%) than in seedlings subjected to mild or moderate drought (second season). Families differed significantly in most drought hardiness traits, with individual tree heritabilities averaging 0.19. Thus, much potential exists for identifying drought-hardy families at the seedling stage and using this information for deployment or breeding purposes. In addition, most hardiness traits were strongly intercorrelated (genetic correlations often exceeded $|0.80|$) indicating that these traits are controlled largely by the same set of genes and that selection for hardiness based on one trait will increase hardiness as reflected in the other traits as well. Genetic correlations were only moderate (0.49) between hardiness traits measured in different years, perhaps due to the large difference in severity of the drought applied in the two seasons. Although injury to seedlings, as reflected in foliage damage and xylem cavitation, was relatively low under the moderate drought of the second season, it did result in reduced growth increment the following (recovery) year. Growth potential under favourable moisture regimes was nearly uncorrelated with drought hardiness, suggesting that drought hardiness could be improved in this southwestern British Columbia breeding population without negatively impacting growth potential in favourable moisture conditions.

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13. Aubry, C.A., W.T. Adams and T.D. Fahey. 1998. Determination of relative economic weights for multitrait selection in coastal Douglas-fir. *Canadian-Journal-of-Forest-Research* 28(8): 1164-1170.

Keywords: genetic tree improvement
yield
wood quality
economics

Abstract: Relationships between tree traits and tree value for lumber production were investigated. For the purposes of estimating relative economic weights for use in multitrait selection in coastal Douglas fir (*Pseudotsuga menziesii* var. *menziesii*), tree height, diameter at breast height, and branch diameter were measured on 164 trees (ages 36-66 yr) sampled from 11 intensively managed stands with a wide range of site attributes, growing conditions, ages and stocking histories in western Washington and Oregon. Increment cores from a subsample (92) of these trees were assayed by X-ray densitometry to determine wood density. Bole volume was derived by summing the log volumes of all logs from each tree. Value of lumber recovered from each tree was determined in a separate mill study using both visual and machine stress rated (MSR) grading rules. Multiple linear regression was used to relate tree value to the growth and wood quality traits. Stem volume and branch diameter significantly influenced tree value under visual grading, with relative economic weights of 0.06 and -5.22 cm, respectively. Wood density significantly influenced tree value under MSR grading (relative economic weights: 0.06, -6.69 cm, and 0.06 kg/m³, respectively), where lumber strength is measured more accurately. These regression coefficients can be used directly as economic weights in selection indices in the development of advanced breeding programmes for Douglas fir.

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14. Barclay, H.J. and Y.A. El-Kassaby. 1988. Selection for cone production in Douglas-fir adversely affects growth. *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. 149-151.

Keywords: genetic tree improvement
genetic relationships
growth
reproduction

Abstract: Cone production and radial growth increment were studied for 8 years in a Douglas fir (*Pseudotsuga menziesii*) seed orchard on Vancouver Island, British Columbia, in 365 trees representing 29 open-pollinated (half-sib) families. Genetic correlations for the two traits were compared for each of the 8 years. Six of the correlations were significantly negative, while the remaining two were significantly positive. The predominantly negative correlation between cone production and growth indicates that selection for one of these two characters will effectively select against the other. The practice of selecting for high cone-producing trees in seed orchards may also be expected to yield slower-growing trees.

[Non-OSU Link](#)

15. 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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16. 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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17. Copes, D.L. 1983. Failure of grafted Douglas-fir planted at Monterey, Calif. *Tree-Planters' Notes* 34(3): 9-10.

Keywords: genetic tree improvement
tree grafting
growth
tree/stand health
tree phenology

Abstract: Trees were grafted onto established rootstocks (grown from rooted cuttings from Oregon or seedlings from California) in Oregon in April 1979, and in Dec. 109 of these were transplanted to a site on the Monterey Peninsula, California. Grafts were examined in July 1981. More than 30% of the transplanted grafts had died of early incompatibility and the cumulative 1980 and 1981 leader growth of the survivors averaged 12 cm. Identical grafts in Oregon showed 2-10% death due to incompatibility and av. leader growth of 1-2 m. It is suggested that the atypical unreliable budflush and reduced leader elongation in Monterey was due to winter temperatures that were not cool enough to satisfy bud dormancy requirements. It had been hoped to establish seed orchards out of range of pollen contamination from local Douglas fir stands.

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18. Copes, D.L. 1989. Bark scoring problem grafts in five Douglas-fir seed orchards: a case history. *Pacific-Northwest-Research-Station,-USDA-Forest-Service. Research-Note PNW-RN-487.* 12 p.

Keywords: genetic tree improvement
tree grafting
tree/stand health

tree physiology

Abstract: Grafted seed orchards of Douglas fir (*Pseudotsuga menziesii*) often suffer tree losses caused by delayed graft incompatibility. Bark scoring (to improve translocation across the graft union) was performed in April, June and August 1983 and 1985 on 379 trees, 5-16 yr old, in 5 seed orchards in western Oregon. Cuts were made with a small chainsaw every 3.1 to 4.3 cm across the defective union. Effects of scoring were assessed in 1984 and 1986. Many trees showed improved vigour after treatment and annual mortality was only 1.6% when all defective grafts were treated. The greatest improvement in average compatibility occurred in trees treated in April, when the youngest grafts responded most favourably. Inherent and induced incompatibility was found, with brownline round the entire or part of the circumference of the union, respectively. Wound tissue in induced incompatible grafts was usually free of brownline, but brownline appeared in all wound tissue of inherently incompatible grafts. These latter grafts will require bark scoring every 2-3 yr to maintain a live cambium at the union.

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19. Copes, D.L. 1999. Breeding graft-compatible Douglas-fir rootstocks (*Pseudotsuga menziesii* (MIRB.) FRANCO). *Silvae-Genetica* 48(3/4): 188-193.

Keywords: genetic tree improvement
tree grafting
tree/stand protection
growth
tree phenology
tree/stand health
genetic relationships

Abstract: A study encompassing 24 years was conducted to determine if a breeding programme could produce highly graft-compatible rootstocks for *P. menziesii*. A total of 27 trees of apparent high graft compatibility were selected and crossed to produce 226 control-pollinated families. Seedlings were grown, field planted and grafted with test scions. Graft unions from field tests were evaluated anatomically for internal symptoms of incompatibility. Average compatibility of progeny from the 226 crosses was 90.6%, compared with 65% in native populations. Breeding values were calculated for each parent by the best linear prediction (BLP) procedure. Average compatibility resulting from crossing among the top 10 parents was estimated by breeding values as 95.4%. Field-test results of progeny from 34 crosses among the 10 most compatible parents showed 96% compatibility. In addition to field-tests for graft compatibility, nursery tests of seedlings from 124 crosses were evaluated for second-year vegetative bud flush and seedling height. It was possible, while maintaining adequately high levels of graft compatibility, to breed both for resistance to spring frost damage and for increased seedling height.

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20. Copes, D.L. and R.A. Sniezko. 1991. The influence of floral bud phenology on the potential mating system of a wind pollinated Douglas-fir orchard. *Canadian-Journal-of-Forest-Research* 21(6): 813-820.

Keywords: genetic tree improvement
tree phenology
reproduction
genetic relationships

Abstract: Reproductive bud phenology was recorded from 1983 to 1989 in a Douglas fir (*Pseudotsuga menziesii*) clonal orchard near Monmouth, Oregon. Potential outcross efficiency was calculated for 20 clones from dates of male and female bud opening and pollination mechanism information. Potential outcross efficiency was limited to a maximum of 58% (1983) to 87% (1987). Cool weather before bud opening of the earliest clones delayed and compressed the breeding period and resulted in a greater percentage of trees having synchronous periods of pollen release and receptive seed strobili. Length of breeding season among years averaged 20 days and ranged from 16 to 27 days. Differences in phenology significantly affected the breeding system because the overall breeding period of the orchard clones exceeded the 8-day receptive period of individual clones by two or three times, and often prohibited or limited potential outcrossing between the earliest and latest clones. Outcrossing was greatest in clones with intermediate phenology and least in the earliest clones. The breeding system appears to be an almost continuous series of overlapping breeding subpopulations. Each year's breeding subpopulations were different from those of other years because of (1) large shifts in rank order of bud opening by 10 to 20% of the clones and (2) differences in the length of breeding season. Average temperature during March was linearly associated with time of floral bud opening. Geneticists may be able to use average temperature of the 4-week periods prior to opening of the earliest floral buds as a tool to identify seed crops formed during years with compressed breeding seasons. Such seed crops are potentially more diverse than seed crops produced during years with extended breeding seasons.

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21. Crook, R.W. and W.E. Friedman. 1992. Effects of pollen tube number and archegonium number on reproduction in Douglas-fir: significance for seed orchard management. *Canadian-Journal-of-Forest-Research* 22(10): 1483-1488.

Keywords: genetic tree improvement
seed orchard management
reproduction
tree/stand health

Abstract: Analyses of the relations between pollen tube number or archegonium number and the number of fertilization events per ovule (fertilization number) in Douglas fir (*Pseudotsuga menziesii*) growing at a seed orchard near Centralia, Washington, indicated strong trends toward higher levels of simple polyembryony as both pollen tube number and archegonial number increased on a per seed basis. These relations have a significant bearing on the management of conifer seed orchards. Simple polyembryony has been proposed to be an effective means of increasing competition on a per seed basis in conifers and, potentially, the overall fitness of progeny. In conifers, supplemental mass pollination has the direct effect of increasing the number of pollen tubes per ovule. Clonal variation in average number of archegonia per ovule is also likely to exist among conifers. It is proposed that when used together, supplemental mass pollination and selection of clones with high archegonial averages may enhance the fitness of seed orchard progeny.

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22. El Kassaby, Y.A. 1995. Evaluation of the tree-improvement delivery system: factors affecting genetic potential. *Tree Physiology* 15:545-550.

Keywords: genetic tree improvement
nursery operations
seed orchard management
genetic relationships
reproduction

Abstract: Possible causes of the genetic erosion that occurs during the fragmented phases of the tree-improvement delivery system (a term used for the domestication process in forest trees) are reviewed. The impacts of intentional and unintentional directional selection during phenotypic selection, seed production (with its associated reproductive-phenology asynchrony, fecundity differential and varying propensity to inbreeding), seed processing and storage, and seedling production are evaluated. Allozyme analysis data were used to compare heterozygosity of first-generation seed orchards of western red cedar (*Thuja plicata*), Sitka spruce (*Picea sitchensis*) and Douglas fir (*Pseudotsuga menziesii*) with that of their corresponding natural populations. In general, genetic diversity and heterozygosity parameters of seed orchards are higher or similar to those observed in their natural-population counterparts. However, parental contribution to the resultant seed orchard seed crops is consistently asymmetrical, and this is a major cause of genetic erosion. In most cases, less than 20% of an orchard's clones contribute 80% of the cone crop, thus reducing the effective population size. Because seed germination of coniferous tree species is under strong maternal genetic control, the combined effects of differences in reproductive output and germination, as well as of management practices (e.g., simulated long-term storage of seed showed that loss of viability during storage is genotype specific), cause unintentional directional selection during seedling production. This review confirms the need for genetic monitoring of each phase of the tree-improvement delivery system, so that practical solutions can be developed to alleviate genetic erosion.

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23. El Kassaby, Y.A. 2000. Representation of Douglas-fir and western hemlock families in seedling crops as affected by seed biology and nursery crop management practices. *Forest Genetics* 7(4): 305-315.

Keywords: genetic tree improvement
nursery operations
genetic relationships
tree/stand health
reproduction

Abstract: The impact of container-nursery management practices on the genetic representation of seedling crops of Douglas fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) were evaluated. Two experiments, one for each species, were conducted in British Columbia, Canada, to determine the cumulative effects of seed-donor variation on germination parameters (percent and

speed) and their interaction with container-nursery practices of thinning and culling on the genetic representation of each seed-donor in the resultant seedling crops. The experimental work was conducted on seedlots that were represented with equal contribution of seeds from 15 seed orchard parents (families). In each experiment, a total of 25 920 seeds were sown in four different arrangements to compare the crop development under single-, two-, and three-seeds per cavity (seeds within cavity were selected randomly among the 15 families) and family blocks (seeds within block belonged to one family). This experimental design allowed determination of inter- and intra-family competition. Within each experiment, a total of 15 015 cavities were used and the identity of every seed within every cavity within each arrangement was maintained throughout the study. Families were compared based on: (1) changes in their rank order from seedling emergence (germination) to post-thinning and post-culling status, and (2) relative performance of each family from seed contribution to seedling production. Changes were observed in both assessments (i.e., rank and relative contribution). Path analysis was used to determine the percent contribution of each factor to seedling production. It was determined that seedling germination, germinant thinning, and seedling culling all affected seedling production, indicating the presence of several consecutive unintentional bottlenecks in the process. Family sowing with culling standards that recognize the growth differences among families in the nursery and single seed sowing after understanding the inter-/intra-family competition are recommended for seedling production to maintain seedling-crop family representation.

[OSU Link](#)

24. El Kassaby, Y.A., S. Barnes, C. Cook and D.A. MacLeod. 1993. Supplemental mass pollination success rate in a mature Douglas-fir seed orchard. *Canadian-Journal-of-Forest-Research* 23(6): 1096-1099.

Keywords: genetic tree improvement
seed orchard management
reproduction

Abstract: Supplemental mass pollination (SMP) success rate in a mature Douglas fir (*Pseudotsuga menziesii*) seed orchard in British Columbia was studied with the aid of a unique electrophoretically detectable allozyme marker. Four SMP methods were tested during periods of maximum pollen release in 1990: operational applications of pollen (pollen applied once to a branch at average receptivity), and branch applications that were carried out during one, two, or three visits (a first pollen application at maximum receptivity and subsequent applications 2 and 4 days later) were conducted. No significant increase in seed-yield traits (total number of seeds per cone, number of filled seeds per cone and seed efficiency) was observed between wind-pollinated and SMP-treated cones. However, multiple branch visits showed significant increases in SMP success rate (18%) when compared with the operational visit (8%) or the one branch visit (9%) results. No significant increase in SMP success rate was obtained when the number of branch visits was increased from two (17.8%) to three (17.9%). It was concluded that operational SMP has the potential to improve the genetic value of the treated Douglas fir crops even under high pollen load. The degree of improvement is dependent directly on SMP fertilization success and indirectly on the genetic value differential between the supplemented and the orchard's ambient pollen, the frequency of application, and the quality (i.e. viability) of the pollen applied.

[OSU Link](#)

[Non-OSU Link](#)

25. El Kassaby, Y.A., K. Chaisurisri, D.G.W. Edwards and D.W. Taylor. 1993. Genetic control of germination parameters of Douglas-fir, Sitka spruce, western redcedar, and yellow-cedar and its impact on container nursery production. *In* Dormancy and barriers to germination. Proceedings of an international symposium of IUFRO Project Group P2.04-00 (Seed problems), Pacific Forestry Centre, Victoria, British Columbia, Canada. Ed. D.G.W. Edwards. pp. 37-42.

Keywords: genetic tree improvement
nursery operations
genetic relationships
reproduction

Abstract: The genetic control of germination parameters (germination capacity, peak value, and germination value) in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), Sitka spruce (*Picea sitchensis* (Bong.) Carr.), western redcedar (*Thuja plicata* Donn), and yellow-cedar (*Chamaecyparis nootkatensis* (D.Don) Spach.) was studied using wind-pollinated seeds collected from several seed orchards. The extent of genetic control over these parameters was assessed through the determination of broad-sense heritabilities. The impact of genetic control of these parameters on the expected genetic diversity of container nursery seedling crops is evaluated.

[OSU Link](#)

[Non-OSU Link](#)

26. El Kassaby, Y.A. and C. Cook. 1994. Female reproductive energy and reproductive success in a Douglas-fir seed orchard and its impact on genetic diversity. *Silvae-Genetica* 43(4): 243-246.

Keywords: genetic tree improvement
genetic relationships
reproduction

Abstract: The relationship between reproductive energy and reproductive success and its impact on clonal female gamete contribution were studied in a clonal *Pseudotsuga menziesii* seed orchard. The effect of among- vs. within-clonal variation on seed-cone crop (energy) and filled-seed yield (success) was determined by partitioning their respective variance components. Clonal gametic representations were expressed using Griffin's [Australian Forest Research (1982) 12, 295-302] parental-balance curves and Crow and Kimura's [An introduction to population genetic theory (1970) New York, USA; Harper and Row Publishers] effective population number. Seed-cone and filled-seed yields produced similar parental-balance curves and female effective population numbers. Although similar parental-balance curves and female effective population numbers were produced, the actual clonal gametic representation differed when the contribution of any set of specific clones were considered. It was concluded that parental-balance curves and female effective population numbers provide a static description of the genetic representation and do not illustrate the dynamics of clonal reproductive outputs.

[OSU Link](#)

[Non-OSU Link](#)

27. El Kassaby, Y.A. and R. Davidson. 1990. Impact of crop management practices on the seed crop genetic quality in a Douglas-fir seed orchard. *Silvae-Genetica* 39(5-6): 230-237.

Keywords: genetic tree improvement
seed orchard management
genetic relationships

Abstract: The impact of 2 crop management practices, supplemental-mass-pollination (SMP) and overhead cooling, on levels of pollen contamination and outcrossing was assessed in a 13-year-old seedling Douglas fir (*Pseudotsuga menziesii*) seed orchard with the aid of 6allozyme loci. A 2 x 2 factorial arrangement of SMP/no SMP and cooling/no cooling was applied to 4 genetically similar blocks of trees. The 4 treatment combinations used were spatially and temporally isolated by buffer blocks and 9-day reproductive bud phenology delay, respectively. The study led to the following conclusions: (1) no contamination was observed when cooling and/or SMP was used, (2) no inbreeding was observed when cooling and SMP were used concurrently and (3) SMP was effective in reducing consanguineous mating, but not to the level achieved by cooling and SMP combined. In addition, the results obtained from the control block (i.e. no cooling and no SMP) indicated that (1) isolation zones are effective in reducing contamination, and (2) randomization of trees within seed orchard blocks is associated with a high outcrossing rate.

[OSU Link](#)

[Non-OSU Link](#)

28. El Kassaby, Y.A. and Y.S. Park. 1993. Genetic variation and correlation in growth, biomass, and phenology of Douglas-fir diallel progeny at different spacings. *Silvae-Genetica* 42(6): 289-297.

Keywords: genetic tree improvement
nursery operations
genetic relationships
growth
carbon allocation
tree phenology

Abstract: Parents of coastal Douglas fir (*Pseudotsuga menziesii*) selected from natural stands on sites ranging from 0 to 450 m altitude on Vancouver Island and in southeastern British Columbia were crossed and the resulting 104 full-sib families evaluated for 3 years after germination. The full-sib families were produced by a disconnected diallel mating scheme, consisting of 7 sets of 6-parent partial diallels, grown under 2 spacing treatments in a nursery. The objectives of the study were to determine the extent of genetic control of growth traits, biomass distribution and allocation strategies, and vegetative phenology. Spacing had a significant effect on 6 of the 11 traits studied. Significant GCA variance was found for all traits except 1-year height. Individual tree narrow-sense heritability varied from 0.06 to 0.69 for root dry weight and vegetative phenology, respectively. Spacing x family interaction variance was significant for only 2 traits. Two harvest indices, based on total and above-ground dry weights, were used to assess dry matter allocation strategy and to explore potential usefulness in tree breeding. Both indices had similar heritability estimates and their genetic correlation was high (0.91), indicating that use of an index based on above ground dry weight is a good surrogate for that based on total dry weight. Genetic correlations among growth and biomass traits were generally high, while those correlations with the harvest indices were variable.

[OSU Link](#)

[Non-OSU Link](#)

29. El Kassaby, Y.A., J. Parkinson and W.J.B. Devitt. 1986. The effect of crown segment on the mating system in a Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seed orchard. *Silvae-Genetica* 35(4): 149-155.

Keywords: genetic tree improvement
seed orchard management
genetic relationships
reproduction

Abstract: The mating system in a mixed clonal/seedling Douglas fir seed orchard was studied by analysing 6 polymorphic allozyme loci. Trees were subjected to cooling treatment to retard bud development and compact the pollination period. The outcrossing rates of upper and lower crown levels and northern and southern crown aspects were estimated and compared for clonal and seedling material separately using single and multilocus methods. Single locus estimates of outcrossing rate ranged from 0.645 to 0.999 and were significantly heterogeneous. No significant differences between the multilocus estimates were observed between crown levels or aspects for either the clonal or seedling material. For all comparisons, the unweighted or weighted single locus means were lower than those obtained by the multilocus method, indicating the presence of other types of consanguineous mating in addition to selfing. In general, higher outcrossing rates were observed in the clonal trees than in those derived from seedlings. The implications of these results for seed orchard management are discussed.

[OSU Link](#)

[Non-OSU Link](#)

30. El Kassaby, Y.A. and K. Ritland. 1986. The relation of outcrossing and contamination to reproductive phenology and supplemental mass pollination in a Douglas-fir seed orchard. *Silvae-Genetica* 35(5/6): 240-244.

Keywords: genetic tree improvement
seed orchard management
tree phenology
genetic relationships
economics
reproduction

Abstract: A study was made using allozyme markers of outcrossing and contamination rates in relation to reproductive phenology and supplemental mass pollination in a Douglas fir seed orchard in British Columbia, Canada. Supplemental mass pollination was applied only to the intermediate reproductive phenology class, which showed a high outcrossing rate and no contamination. Both early and late reproductive phenology classes showed significant contamination, but the outcrossing rate for the former was significantly higher than for the latter. These results show that interpretation of seed crop genetic quality based on outcrossing alone could be misleading. The rate and source of contamination, reproductive phenology and crop size should also be considered. The practicability and economics of supplemental mass pollination in avoiding both selfing and contamination are discussed. It was concluded that waterspray cooling and/or supplemental mass pollination of early and late reproductive phenology classes in moderate or good cone-crop years would be an effective management practice. The option of aborting small cone crops in mature orchards is also discussed.

[OSU Link](#)

[Non-OSU Link](#)

31. El Kassaby, Y.A. and A.J. Thomson. 1996. Parental rank changes associated with seed biology and nursery practices in Douglas-fir. *Forest Science* 42:228-235.

Keywords: genetic tree improvement
nursery operations
reproduction
genetic relationships
tree/stand health

Abstract: The impact of container-nursery management practices on the genetic composition of seedling crops was evaluated in an experimental study in a seed orchard in British Columbia. The study was designed to determine the cumulative effects of: (1) differences in parental reproductive output in bulk seedlots; (2) parental variation in germination parameters (percentage and speed); and (3) the interaction of these parameters with container-nursery practices of thinning and culling, and their effect on the genetic representation of parents in the resultant seedling crops. Results from the experimental study were compared with predictions of a stochastic simulation designed to estimate the consequences of differential parental seed contribution, and seed germination percentage and germination speed on indicators of crop performance. The experimental study was conducted on a Douglas-fir (*Pseudotsuga menziesii*) bulk seedlot that was representative of the differential seed contributions from 19 seed orchard parents. The nursery study included a total of 42 000 seeds. Seeds were sown at three seeds per cavity. Within the 14 000 cavities used, the identity of every seed was maintained throughout the study. Comparisons of parents were made based on: (1) changes in their rank order from sowing to postthinning and postculling status; and (2) relative performance from seed contribution to seedling production. Changes were observed in both assessments. Path analysis was used to determine the percentage contribution of each factor to seedling production. It was determined that germination, thinning, and culling contributed 66, 20, and 14%, respectively, to seedling production, indicating the presence of three consecutive bottlenecks in the process. Single seed or individual family sowing in the nursery was recommended for seedling production to maintain genetic diversity.

[OSU Link](#)

[Non-OSU Link](#)

32. Fashler, A.M.K. and Y.A. El-Kassaby. 1987. The effect of water spray cooling treatment on reproductive phenology in a Douglas-fir seed orchard. *Silvae-Genetica* 36(5-6): 245-249.

Keywords: genetic tree improvement
seed orchard management
tree/stand protection
genetic relationships
reproduction
tree/stand health

Abstract: The effectiveness of reproductive bud cooling on genetic efficiency in a Douglas fir seed orchard in British Columbia, Canada, was tested by comparing the reproductive bud phenology in 3 cooled and 3 uncooled years. The cooling system was found to affect 2 major elements affecting seed orchard genetic efficiency, namely pollen contamination levels and panmictic equilibrium, as well as

insect infestation, frost damage, seed yield and management effectiveness. Based on these results, a permanent irrigation/cooling system is recommended for Douglas fir seed orchards.

[OSU Link](#)

[Non-OSU Link](#)

33. Fernando, D.D., J.N. Owens and P.v. Aderkas. 1998. In vitro fertilization from co-cultured pollen tubes and female gametophytes of Douglas fir (*Pseudotsuga menziesii*). *Theoretical-and-Applied-Genetics* 96(8): 1057-1063.

Keywords: genetic tree improvement
reproduction

Abstract: A previous attempt on in vitro fertilization (IVF) in conifers resulted in pollen tube penetration of female gametophytes, but because of the rapid decline in egg viability, no further interaction occurred. It is reported that, for the first time, IVF has been achieved in conifers. Using Douglas fir (*Pseudotsuga menziesii*), a two-step process is described which involved induction of pollen tubes in culture followed by introduction of isolated female gametophytes at the tips of growing pollen tubes. Pollen tubes penetrated the introduced isolated female gametophytes at various places, but a number of tubes entered the egg cell through the neck cells similar to the in vivo condition. Under current culture conditions, longevity of pollen tubes and eggs was improved resulting in the release of sperms, fusion of gametes, and initial formation of the proembryo. Continued plasmolysis of the egg limited the number of successful gametic interactions. IVF has been accomplished in flowering plants in several ways, but the gametophyte-gametophyte IVF system described in here is unique. IVF offers a novel breeding technology that takes advantage of the sexual reproductive route. When coupled with hybridization and genetic transformation, IVF could result in the development of stable novel genotypes of economically superior trees.

[OSU Link](#)

[Non-OSU Link](#)

34. Fernando, D.D., J.N. Owens, P.v. Aderkas and T. Takaso. 1997. In vitro pollen tube growth and penetration of female gametophyte in Douglas fir (*Pseudotsuga menziesii*). *Sexual-Plant-Reproduction* 10(4): 209-216.

Keywords: genetic tree improvement
reproduction

Abstract: Pollen tube and female gametophyte interactions in Douglas fir (*Pseudotsuga menziesii*) were examined in vitro. Formation of pollen tubes in Douglas fir occurred on a modified MS medium in which concentrations of H₃BO₃ and Ca(NO₃)₂ were altered and supplemented with sucrose and polyethylene glycol. Addition of 100 micro g/ml H₃BO₃ and 300 micro g/ml Ca(NO₃)₂ resulted in optimum pollen viability. Lack of H₃BO₃ inhibited pollen tube formation. Addition of H₃BO₃ and Ca(NO₃)₂ significantly increased pollen tube formation within one week in culture. Using a medium supplemented with mannitol, viability of Douglas fir pollen can be sustained for 7 weeks in culture, about the same length of time as in vivo. However, pollen tubes are not formed. This suggests that the factors responsible for tube formation reside in the external environment of the pollen. Culture of female

gametophytes to examine egg viability and longevity had not been done previously. Egg viability in culture is short-lived, and therefore the window to study and manipulate events of fertilization in Douglas fir is very limited. In spite of this, about 7% of the female gametophytes that were co-cultured became penetrated by pollen tubes. In vitro archegonial penetration has been repeatedly achieved, but pollen tubes also penetrated other parts of the female gametophytes. Pollen tubes also penetrated non-viable eggs. Most female gametophytes were not penetrated because of pollen tube branching and swelling, failure of tubes to orient towards the female gametophytes, or premature pollen tube death due to plasmolysis. This report outlines the first attempt towards in vitro fertilization in conifers.

[OSU Link](#)

[Non-OSU Link](#)

35. Fu, Y., A.D. Yanchuk and G. Namkoong. 1999. Spatial patterns of tree height variations in a series of Douglas-fir progeny trials: implications for genetic testing. *Canadian-Journal-of-Forest-Research* 29(6): 714-723.

Keywords: genetic tree improvement
growth

Abstract: Conventional statistics and geostatistical techniques were used to examine spatial variation patterns of tree heights at ages 6-12 years in a series of Douglas fir (*Pseudotsuga menziesii*) progeny trials conducted on 66 test sites over southern coastal British Columbia. Large variations in tree height were observed over the years within and among the 66 test sites. The estimated proportions of the within-site variance explained by family, row, column, patchiness and within-plot were on average 11, 7, 5, 12 and 47%, respectively, plus 7% due to unknown factors, and the applied blocking removed about 5% of the within-site variance. Significant gradients in row and column directions were observed in more than 44 test sites, and the estimated slopes ranged in average from 0.33 to 1.52 cm/plot. Patch sizes varied greatly over the test sites and ranged in average from 5.21 to 6.47 plots, indicating that the average patch size for these trials was 18 m across. Temporal variations were large for family variance but not much for those variance proportions explained by row, column and patchiness. More gradients and larger patch sizes were found with older trees. The implications of these results are discussed in relation to forest genetic testing.

[OSU Link](#)

[Non-OSU Link](#)

36. Gonzalez, J.S. and J. Richards. 1988. Early selection for wood density in young coastal Douglas-fir trees. *Canadian-Journal-of-Forest-Research* 18(9): 1182-1185.

Keywords: genetic tree improvement
wood quality

Abstract: Selection age for wood density in vigorous coastal Douglas-fir (*Pseudotsuga menziesii*) on Vancouver Island was determined by examining the strength of the correlation between total-stem wood density of 50-yr-old trees and the b.h. density when the trees were 5-30 yr old (b.h. age), and the efficiency in terms of gain per year of tree improvement effort by selecting at ages 5-30, relative to selecting at age 50. The linear regression and rank correlation between total-stem and b.h. densities

improved as age increased from 5 to 15 yr, but showed no significant improvement from 15 to 30 yr. Densities of early-growth rings fluctuated considerably and their exclusion from the calculation of b.h. density enhanced the linear regression with total-stem density. Efficiency estimates in terms of gain per year showed an opt. value at age 15, but the estimates for ages 10-14 were nearly as efficient.

[OSU Link](#)

[Non-OSU Link](#)

37. Hermann, R.K. and D.P. Lavender. 1999. Douglas-fir planted forests. *New-Forests* 17(1/3): 53-70.

Keywords: genetic tree improvement
nursery operations
planting operations
site preparation
release treatments
fertilization
thinning
pruning
tree/stand protection
growth
yield

Abstract: A combination of superior wood quality and high productivity has made Douglas fir (*Pseudotsuga menziesii*) one of the premier timber trees in the world. As such, it is grown as a plantation species in several countries in Europe and South America, and in New Zealand and Australia, as well as throughout its extensive natural range in western North America. Decades of experience with the silviculture of young stands have demonstrated that practices such as planting, the use of genetically improved seedlings, precommercial and commercial thinning, and fertilizing may dramatically increase the yield of industrial products over that of natural forests. Further, such silviculture is compatible with the production of desired amenities. Vigorous implementation of such practices wherever Douglas fir is cultivated will increase the world's timber resources, and be an effective strategy for reducing the pressure, occasioned by the world's rapidly increasing population, to harvest the fragile tropical and boreal forests.

[OSU Link](#)

[Non-OSU Link](#)

38. Jermstad, K.D., D.L. Bassoni, K.S. Jech, N.C. Wheeler and D.B. Neale. 2001a. Mapping of quantitative trait loci controlling adaptive traits in coastal Douglas-fir. I. Timing of vegetative bud flush. *Theoretical-and-Applied-Genetics* 102(8): 1142-1151.

Keywords: genetic tree improvement
tree phenology

Abstract: Thirty-three unique quantitative trait loci (QTLs) affecting the timing of spring bud flush have been identified in an intraspecific mapping population of coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) in a field experiment conducted in several sites in Washington

and Oregon, USA, during 1995-98. Both terminal and lateral bud flush were measured over a 4-year period on clonal replicates at two test sites, allowing for the repeated estimation of QTLs. QTLs were detected on 12 linkage groups and, in general, each explained a small proportion of the total phenotypic variance and were additive in effect. Several QTLs influenced the timing of bud flush over multiple years, supporting earlier evidence that the timing of bud flush through developmental stages was under moderate to strong genetic control by the same suite of genes through developmental stages. However, only a few QTLs controlling the timing of bud flush were detected at both test sites, suggesting that geographic location plays a major role in the phenology of spring growth. A small number of QTLs with year and site interactions were also estimated.

[OSU Link](#)

[Non-OSU Link](#)

39. Jermstad, K.D., D.L. Bassoni, N.C. Wheeler, T.S. Anekonda, S.N. Aitken, W.T. Adams and D.B. Neale. 2001b. Mapping of quantitative trait loci controlling adaptive traits in coastal Douglas-fir. II. Spring and fall cold-hardiness. *Theoretical-and-Applied-Genetics* 102(8): 1152-1158.

Keywords: genetic tree improvement
tree/stand protection
genetic relationships
tree physiology
tree phenology

Abstract: Quantitative trait loci (QTLs) affecting fall and spring cold hardiness (cold resistance) were identified in a three-generation outbred pedigree of coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* [*Pseudotsuga menziesii*]) in a field experiment conducted in Washington and Oregon, USA, during 1996-97. Eleven QTLs controlling fall cold hardiness were detected on four linkage groups, and 15 QTLs controlling spring cold hardiness were detected on four linkage groups. Only one linkage group contained QTLs for both spring and fall cold hardiness, and these QTLs tended to map in close proximity to one another. Several QTLs were associated with hardiness in all three shoot tissues assayed in the spring, supporting previous reports that there is synchronization of plant tissues during de-acclimatization. For fall cold hardiness, co-location of QTLs was not observed for the different tissues assayed, which was consistent with previous reports of less synchronization of hardening in the fall. In several cases, QTLs for spring or fall cold hardiness mapped to the same location as QTLs controlling spring bud flush. QTL estimations, relative magnitudes of heritabilities, and genetic correlations based on clonal data in this single full-sib family, supports conclusions about the genetic control and relationships among cold hardiness traits observed in population samples of Douglas-fir in previous studies.

[OSU Link](#)

[Non-OSU Link](#)

40. Johnson, G.R. 1997. Site-to-site genetic correlations and their implications on breeding zone size and optimum number of progeny test sites for coastal Douglas-fir. *Silvae-Genetica* 46(5): 280-285.

Keywords: genetic tree improvement
genetic relationships

Abstract: Type B genetic correlations were used to examine the relationship among geographic differences between sites and their site-to-site genetic (Type B) correlations. Examination of six local breeding zones in Oregon indicated that breeding zones were, for the most part, not too large because few environmental variables were correlated with Type B genetic correlations. The data also were used to examine expected gains from using combinations of sites in selection indices. Even though additional sites always increased the expected genetic gain, the marginal increase was only minimal if 3 or 4 sites were already in the index. The trend was consistent over all 6 breeding zones.

[OSU Link](#)

[Non-OSU Link](#)

41. Johnson, G.R. 2002. Genetic variation in tolerance of Douglas fir to Swiss needle cast as assessed by symptom expression. *Silvae-Genetica* 51(2/3): 80-86.

Keywords: genetic tree improvement
tree/stand protection
tree/stand health
growth
genetic relationships

Abstract: The incidence of Swiss needle cast (caused by *Phaeocryptopus gaeumannii*) on Douglas fir (*Pseudotsuga menziesii*) has increased significantly in recent years on the Oregon coast. Genetic variation in symptoms of disease infection, as measured by foliage traits, was assessed in two series of progeny trials to determine whether these "crown health" indicators were under genetic control and correlated with tolerance (tolerance being continued growth in the presence of high disease pressure). Foliage traits generally had lower heritabilities than growth traits and were usually correlated with diameter growth. Foliage traits of crown density and colour appeared to be reasonable indicators of disease tolerance. In the absence of basal area data, assessing crown density and colour can help screen for families that show tolerance to the disease.

[OSU Link](#)

[Non-OSU Link](#)

42. Johnson, G.R., R.A. Snieszko and N.L. Mandel. 1997. Age trends in Douglas-fir genetic parameters and implications for optimum selection age. *Silvae-Genetica* 46(6): 349-358.

Keywords: genetic tree improvement
growth
genetic relationships

Abstract: Trends in genetic variation in Douglas fir (*Pseudotsuga menziesii*) were examined over 51 progeny test sites throughout western Oregon. Narrow sense heritabilities for height and diameter showed an increasing trend to age 25, the oldest age examined. Before age 10, height heritabilities were relatively unstable. Type B site-site genetic correlations increased slowly with age for height and remained relatively stable for diameter. Age-age correlations were used to develop an equation to predict age-age correlations by using the log of the age ratios (LAR). Optimum selection age was calculated for a 60-year rotation by using two measures of efficiency: gain per year and discounted gain.

The optimum selection age for height tended to be 2 to 3 years earlier than for diameter. Gain per year was maximized at age 10 for height and age 13 for diameter.

[OSU Link](#)

[Non-OSU Link](#)

43. Johnson, G.R., N.C. Wheeler and S.H. Strauss. 2000. Financial feasibility of marker-aided selection in Douglas-fir. *Canadian-Journal-of-Forest-Research* 30(12): 1942-1952.

Keywords: genetic tree improvement
economics

Abstract: The paper addresses the financial feasibility of using molecular marker-aided selection (MAS) as a tool to supplement phenotypic selection during population improvement of quantitative traits, which is the predominant focus for the breeding of Douglas fir (*Pseudotsuga menziesii*) and most other tree species. The land area required for a MAS programme to break even (i.e., have equal costs and benefits) was estimated using computer simulation for coastal Douglas fir in the Pacific Northwest USA. The selection efficiency obtained when using an index that included the phenotype and the marker score was compared with that obtained using only the phenotype. It was assumed that MAS was restricted to within-family selection, that the rotation age was 50 years, and that growth rate (heritability, $h^2 = 0.25$), tree form ($h^2 = 0.25$), and (or) wood density ($h^2 = 0.45$) were the objects of improvement. Several population quantitative trait loci (QTL) models, selection population sizes, and interest rates were considered. When large selection population sizes were employed (500 trees per family) MAS gave considerable increases in efficiency of within-family selection; however, results showed that the combination of small selection population sizes (100 trees per family) and many QTL of moderate effect could lead to losses in gain from MAS compared with phenotypic selection. For many reasonable selection scenarios and the simplified assumptions in the model used, the land base required for breeding programmes to break even is smaller or near to the limit of those in place under operational breeding programmes in the region. Considerably more research is needed to predict reasonably whether MAS would be cost-effective in practice. However, before some of the basic research needed to implement MAS can be done, organizations need to establish large blocks of full-sib families to allow for QTL identification.

[OSU Link](#)

[Non-OSU Link](#)

44. Johnson, R. 1998. Breeding design considerations for coastal Douglas-fir. Pacific-Northwest-Research-Station, USDA-Forest-Service General-Technical-Report PNW-GTR-411. iii + 34 p.

Keywords: genetic tree improvement
seed orchard management
genetic relationships

Abstract: The basic principles of designing forest tree breeding programmes are reviewed for Douglas fir (*Pseudotsuga menziesii*) in the Pacific Northwest (USA). Breeding populations are discussed given current and future breeding zone sizes and seed orchard designs. Seed orchard composition is discussed for potential genetic gain and maintaining genetic diversity in the forest. Mating and field testing designs

are described and compared. Recommendations of the Breeding Zone Evaluation and Restructuring Cooperatives Working Group of the Northwest Tree Improvement Cooperative are presented.

[OSU Link](#)

[Non-OSU Link](#)

45. Kastner, W.W., Jr., S.M. Dutton and D.M. Roche. 2001. Effects of Swiss needle cast on three Douglas-fir seed sources on a low-elevation site in the northern Oregon Coast Range: results after five growing seasons. *Western-Journal-of-Applied-Forestry* 16(1): 31-34.

Keywords: genetic tree improvement
tree/stand protection
growth
tree/stand health

Abstract: Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) seedlings grown from three seed sources were evaluated for 5 years for their relative tolerance to Swiss needle cast (caused by the ascomycete *Phaeoxypoptopus gaeumannii*), on a high-disease-hazard site located approximately 3 miles northeast of Tillamook, Oregon, USA. The seed sources were: (1) seed collected from trees showing an apparent degree of tolerance to Swiss needle cast in natural stands in the coastal fog belt, (2) open-pollinated seed orchard seed collected from random single-pair crosses of parent trees in natural stands outside of the coastal fog belt, but west of the Oregon Coast Range summit, whose progeny demonstrated an apparent degree of disease tolerance in coastal Douglas-fir progeny test sites, and (3) standard reforestation seed purchased from a commercial vendor. There were no significant differences among seed sources in basal diameter and total height for all five growing seasons. Needle retention varied among seed sources over the 5-year period, but current-year needle retention did not vary significantly after the fifth growing season, and retention of 1- and 2-year-old needles was relatively low for all seed sources. The intense disease pressure on this site may have overwhelmed expression of disease tolerance among seed sources. We do not recommend planting Douglas-fir on such high-hazard sites.

[OSU Link](#)

[Non-OSU Link](#)

46. Kaya, Z. 1992. The effects of test environments on estimation of genetic parameters for seedling traits in 2-year-old Douglas-fir. *Scandinavian-Journal-of-Forest-Research* 7(3): 287-296.

Keywords: genetic tree improvement
nursery operations
genetic relationships
growth
tree phenology

Abstract: The effects of test environments (dry versus wet) on the estimation of genetic parameters in seedling traits were studied in 160 open-pollinated families of Douglas fir (*Pseudotsuga menziesii*) from southwestern Oregon. Seedlings from four populations were grown in two test nursery environments between which a water potential difference of -9 bars was created over two growing seasons, by

withholding water for 4 and 8 wk, respectively. Estimated genetic variances in most growth and phenology traits were considerably higher for seedlings grown in the wet environment than for those in the dry. Estimated genetic correlations between the same traits measured in different test environments indicated that most seedling traits studied for two growing seasons were genetically stable in both environments, suggesting that genotype environment interaction in these traits are weak. However, it is emphasized that the effect of test environment on estimation of genetic parameters in seedling traits, especially in adaptive seedling traits, should be evaluated very carefully when early evaluation of genetic entries is practised in Douglas-fir, since these traits (budburst timing, lammas growth and free growth) appear to be plastic in character.

[OSU Link](#)

[Non-OSU Link](#)

47. Kaya, Z. 1993. Genetic variation in shoot growth components and their correlations in *Pseudotsuga menziesii* var. *menziesii* seedlings. *Scandinavian-Journal-of-Forest-Research* 8(1): 1-7.

Keywords: genetic tree improvement
genetic relationships
growth

Abstract: Stem-unit measurements could be useful for early selection if these dimensions were highly heritable and strongly correlated with traits of commercial interest, such as height growth. Height increments and the number and length of stem segments were measured in the first and second growth period in predetermined and free growth of Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) seedlings from 40 families in each of 2 populations from southwestern Oregon, USA. Populations, or families in populations, exhibited genetic variation in all traits except number of stem units in predetermined growth. Heritabilities for stem-unit measurements were higher than those for height increment in the first growing season, but not in the second. Correlations among measurements of stem units and height increments were only moderate (generally <0.70). It is concluded that stem units are not likely to be better measurements of height in early selection of Douglas-fir than are measurements of either predetermined or free growth.

[OSU Link](#)

[Non-OSU Link](#)

48. Kaya, Z., R.K. Campbell and W.T. Adams. 1989. Correlated responses of height increment and components of increment in 2-year-old Douglas fir. *Canadian-Journal-of-Forest-Research* 19(9): 1124-1130.

Keywords: genetic tree improvement
tree phenology
growth
genetic relationships

Abstract: The consequences for growth and phenology of early selection for height or its growth components were evaluated in 160 open-pollinated families of Douglas fir (*Pseudotsuga menziesii*) from SW Oregon. Seedlings from 2 inland and 2 coastal populations (40 families each) were grown for 2 growing seasons in a 'moist' and 'dry' nursery environment. Predicted response to selection suggests

that risk of low juvenile-mature correlation and maladaptation with early selection would be less in the inland than in the coastal region. Early bud set in the 1st yr was genetically correlated with larger overwintering buds in seedlings from both inland and coastal regions. These larger buds yielded a large increment of predetermined growth in the 2nd yr, followed by little or no free growth and early bud set. Seedlings with late bud set in the 1st yr had the converse pattern. Inland seedlings set buds much earlier on av. than coastal seedlings, hence seedlings from the 2 regions had different growth patterns. Risks that can attend early selection for ht. generally would be decreased in both regions by selecting for predetermined growth, but several qualifications are discussed.

[OSU Link](#)

[Non-OSU Link](#)

49. Kimball, B.A., G.R. Johnson, D.L. Nolte and D.L. Griffin. 1999. An examination of the genetic control of Douglas-fir vascular tissue phytochemicals: implications for black bear foraging. *Forest-Ecology-and-Management* 123(2/3): 245-251.

Keywords: genetic tree improvement
tree/stand protection
growth
tree physiology
genetic relationships

Abstract: Silvicultural practices can influence black bear (*Ursus americanus*) foraging preferences for Douglas fir (*Pseudotsuga menziesii*) cambial-zone vascular tissues, but little is known about the role of genetics. To study the impact of genetic selection, vascular tissue samples were collected from Douglas fir trees in 6 half-sib families from 5 different sites in north central Oregon. Four replications of 3-tree non-contiguous plots were sampled at each site to examine inter- and intra-site variation. Tree growth was measured as tree diameter at breast height, and the absolute concentrations of 26 different terpenoids were determined by gas chromatography/flame ionization detection from ethyl acetate extracts. The simple carbohydrates fructose, glucose, and sucrose, and the phenolic glycoside coniferin were quantified using anion-exchange chromatography with pulsed amperometric detection. Cluster analysis was used to reduce the number of variables used in analyses of variance. Results for the families studied here indicate that tree growth and some terpenoids were under some level of genetic control. Furthermore, allocation of constitutive terpenoids in vascular tissues was not at the expense of tree growth. The sugars present in vascular tissue were affected by environment (site) and genetics (family) and their interaction.

[OSU Link](#)

[Non-OSU Link](#)

50. King, J.N., F.C. Yeh and J.C.H. Heaman. 1988. Selection of growth and yield traits in controlled crosses of coastal Douglas-fir. *Silvae-Genetica* 37(3-4): 158-164.

Keywords: genetic tree improvement
growth
genetic relationships

Abstract: Analysis of variance of several yield traits including height, height increment, diameter and volume in a full-sib progeny test of Douglas fir (*Pseudotsuga menziesii*) on 2 sites in British Columbia revealed significant amounts of additive genetic variance but small and non-significant amounts of dominance genetic variance. Individual tree heritabilities were between 0.08 and 0.16 for growth traits and family heritabilities were between 0.55 and 0.73. Acceptable gains were predicted with progeny test re-selection (10% volume gain per unit selection intensity). Age 6 height was an effective selection trait, and correlated well with age 12 volume, giving 70% relative efficiency for family selection. Age 12 height measurement and height increment between 10 and 12 did not express significant genetic differences on the individual site analyses due in part to uncontrolled within-plot variation. Diameter showed higher heritabilities and was less sensitive to inadequacies in experimental design than the later height measurements. Index selection for stem volume also demonstrated that diameter was the most effective growth trait to predict the breeding value of parents for individual tree stem volumes.

[OSU Link](#)

[Non-OSU Link](#)

51. Koshy, M.P. and D.T. Lester. 1994. Genetic variation of wood shrinkage in a progeny test of coastal Douglas-fir. *Canadian-Journal-of-Forest-Research* 24(8): 1734-1740.

Keywords: genetic tree improvement
wood quality
genetic relationships

Abstract: Directional (longitudinal, tangential and radial) and volumetric wood shrinkage were analysed in 413 trees belonging to 48 full-sib families (4 paternal and 12 maternal parents) from an 18-year-old coastal Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) progeny test in British Columbia. Six samples per ring position (ring positions 1-5 from pith along stem radii), with two rings in each ring position, were examined in a bolt taken at breast height from the tree. Genetic effects were minimal for shrinkage, except for longitudinal shrinkage at ring positions 1 and 2. High variability was expressed among trees within plots and among samples with trees. The lack of statistically significant family variance eliminates the possibility of improving the shrinkage traits by genetic means, except for longitudinal shrinkage in the first few rings. However, the high amount of variability expressed between trees within plots and between samples within trees warrants special attention for achieving uniformity of wood. Much of this variability can be reduced by silvicultural methods.

[OSU Link](#)

[Non-OSU Link](#)

52. Koshy, M.P. and D.T. Lester. 1997. Wood shrinkage and tree growth in coastal Douglas-fir: implications of selection. *Canadian-Journal-of-Forest-Research* 27(1): 135-138.

Keywords: genetic tree improvement
wood quality
growth
genetic relationships

Abstract: Phenotypic and genetic correlations of height and diameter at breast height with wood shrinkage were studied in an 18-year-old Douglas fir (*Pseudotsuga menziesii*) progeny trial in British Columbia. Correlations between growth traits and shrinkage were minimal except for longitudinal shrinkage at rings close to the pith. In early ring positions, there was a negative correlation between height and longitudinal shrinkage, such that selection for increased height is expected to reduce longitudinal shrinkage at ring positions closer to the pith. The results support current efforts to increase wood production through genetic improvement in growth rate by showing that current programmes of selection for rapid early height growth will not result in significant increase in wood shrinkage.

[OSU Link](#)

[Non-OSU Link](#)

53. Li, P. and W.T. Adams. 1993. Genetic control of bud phenology in pole-size trees and seedlings of coastal Douglas-fir. *Canadian-Journal-of-Forest-Research* 23(6): 1043-1051.

Keywords: genetic tree improvement
genetic relationships
tree phenology
growth

Abstract: The extent to which bud phenology is genetically controlled and related to growth traits was examined in seedlings and pole-size trees of coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*). Data on bud burst, bud set, and stem growth were collected from pole-size trees of 60 open-pollinated families growing in four plantations in Oregon, and from seedlings of 45 of these same families growing in a bare-root trial in Washington, and greenhouse and transplant trials in Washington and Oregon. In both age-classes, bud burst was under moderate to strong genetic control ($h^2 > 0.44$) and family breeding values were stable across test environments, indicating that this trait could be readily altered in breeding programmes. Bud set was inherited strongly in pole-size trees ($h^2 = 0.81$) but weakly in seedlings ($h^2 < 0.30$). Both bud burst and bud set were positively correlated with growth in seedlings and pole-size trees. Thus, selection for greater growth at either age-class is expected to delay bud burst and bud set. An evaluation was made of the accuracy of two alternatives for assessing bud burst phenology in pole-size trees compared with the traditional method. It was shown that bud-burst date on lateral branches can be used to rank accurately both individuals and families for bud-burst date on less accessible leader shoots. In addition, it was found that families can be ranked for mean bud-burst date by the proportion of trees per family that have flushed on a given scoring day. This method is only effective, however, when between 25 and 75% of all trees in the test have flushed at the time of scoring.

[OSU Link](#)

[Non-OSU Link](#)

54. Li, P. and W.T. Adams. 1994. Genetic variation in cambial phenology of coastal Douglas-fir. *Canadian-Journal-of-Forest-Research* 24(9): 1864-1870.

Keywords: genetic tree improvement
genetic relationships
tree phenology

growth

Abstract: The objectives of this study were to (i) determine the extent of genetic variation and genetic control of cambial phenology in coastal Douglas fir (*Pseudotsuga menziesii* var. *menziesii*), (ii) assess the degree to which cambial phenology is genetically related to bud-burst timing, (iii) examine genetic relationships between cambial phenology and growth traits, and (iv) evaluate the potential for indirectly altering cambial phenology in breeding programmes when selection is for stem volume. Dates of diameter-growth initiation and cessation, and duration of diameter growth (i.e., cambial phenology traits), as well as diameter increment for the 1987 growing season (15-yr-old), were estimated from cumulative diameter growth curves of individual trees of 60 open-pollinated families growing in one plantation in Oregon. Data on stem height and diameter at breast height (d.b.h.), and date of bud burst in 1987 were also collected. Dates of diameter-growth initiation and cessation differed significantly among families, but had lower estimated individual heritabilities (≤ 0.23) than date of bud burst (0.87). Weak genetic correlations between date of bud burst and dates of diameter-growth initiation and cessation (range -0.09 to 0.26) indicate that timing of diameter growth cannot be reliably predicted from observations of the more easily measured bud burst. Cambial phenology traits were weakly correlated with 1987 diameter increment and moderately correlated with 15-year d.b.h. and volume. Selection of parents in this study for stem volume at age 15 and subsequent crosses among them, would be expected to lead to earlier initiation of diameter growth in the offspring, and possibly later cessation as well. The practical implications of these indirect responses in terms of increased risk of frost damage are unclear, since projected changes are small (i.e., a few days).

[OSU Link](#)

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55. Magnussen, S. and F.C. Sorensen. 1991. Outliers in forest genetics trials: an example of analysis with truncated data. *Scandinavian-Journal-of-Forest-Research* 6(3): 335-352.

Keywords: genetic tree improvement
genetic relationships

Abstract: Previously published data for distribution of height in a Douglas fir (*Pseudotsuga menziesii*) progeny trial in the Oregon Cascades with open (wind) pollinated (OP) and control pollinated (CP) progenies showed an excess of short trees, especially in OP (inbred) progeny, compared with a normally distributed population. Short trees had a disproportionate influence on variance components and heritability estimates. Data truncation of potential outliers was carried out with varying intensity in order to investigate its influence on genetic parameter estimates. Truncation was done by either fixed threshold values or by a proportional elimination of trees from below. Truncated data was analysed either directly or subsequent to a maximum likelihood (ML) recovery of the estimated means and variances of the expected completed samples. ML estimates became increasingly stable as truncation proceeded into the main body of data. Prior to data truncation, the estimated additive variance and heritability estimates of the CP population were significantly greater than corresponding estimates for the OP population. However, ML estimates obtained after a proportional elimination of about 12% of the trees in each plot supported the contention that there was no important difference in additive genetic variance or heritability between OP and CP populations.

[OSU Link](#)

[Non-OSU Link](#)

56. Magnussen, S. and A.D. Yanchuk. 1993. Selection age and risk: finding the compromise. *Silvae-Genetica* 42(1): 25-40.

Keywords: genetic tree improvement
growth

Abstract: Selection ages for height in coastal Douglas-fir (*Pseudotsuga menziesii*) at four sites on Vancouver Island, Canada, were determined by stochastic simulation of age-to-age correlations. Stochastic perturbations of expected age-to-age correlations at both family and within-family levels were derived from bootstrapping more than 4000 records of 23 years of observed height growth. Stochastic dominance principles were used to isolate stochastic efficient (risk averse) selection ages in both family and forward selection schemes. The optimum age for family selection depended strongly on the number of progenies tested in each family and on the test site. Early family selection (age <15) required at least 20 trees per family; very early family selection (age <10) is feasible at a low risk at family sizes above 40. Selection ages in forward selection schemes depend on gain expectations from the within-family selection and on the number of trees selected per family. Reliance on gain from within-family selection pushed the stochastic efficient selection age upwards. Selecting fewer trees per family, but more families, increased the recommended selection ages. Age 17 appears to be the minimum 'safe' age for conventional forward selection schemes.

[OSU Link](#)

[Non-OSU Link](#)

57. Magnussen, S. and A.D. Yanchuk. 1994. Time trends of predicted breeding values in selected crosses of coastal Douglas-fir in British Columbia: a methodological study. *Forest-Science* 40(4): 663-685.

Keywords: genetic tree improvement
genetic relationships
growth

Abstract: Analytical techniques for estimating time trends and projections of breeding values from sparse data, unbalanced mating designs and irregular assessments periods are presented and discussed. Time trends (ages 4 to 23 yr) in genetic parameters of tree heights in 14 full-sib and 4 half-sib Douglas fir (*Pseudotsuga menziesii*) crosses among six male trees from Coastal British Columbia and six female trees from Washington and Oregon planted on four test sites on Vancouver Island were examined, and tentative projections of genetic gains were made. Annual height estimates were derived by fitting splines to height measures at ages 4, 7, 12, 18 and 23 yr. Genetic variances were derived from direct computations of covariances among all possible half-sib combinations; a method deemed superior to the conventional factorial analysis. Irregular fluctuations in genetic parameter estimates vanished after minor adjustments (<1.5%) of variance-covariance matrices with negative eigenvalues. Sites effects were highly significant, but site-to-site correlations for pair-cross means were all nonsignificant. Additive genetic control of height growth was weak to moderate ($h^2=0.1$), but generally increasing with age. The best genetic discrimination was observed on the more productive sites. A stable ranking of full-sib family means was reached at age 7 yr on one site versus age 18 for the other sites. Trends in breeding values were described with a mixed linear autoregressive time series model from which 10-yr projections were made. Projections took into consideration both the error structure surrounding the breeding values and the errors of the parameter estimates in the time series

model. Selection of the best parent out of six for breeding and deployment on a single site type would generate an expected gain of about 2-5% in height growth between ages 4 and 23 yr.

[OSU Link](#)

[Non-OSU Link](#)

58. Maze, J., S. Banerjee and Y.A. El-Kassaby. 1989. Variation in growth rate within and among full-sib families of Douglas-fir (*Pseudotsuga menziesii*). *Canadian-Journal-of-Botany* 67(1): 140-145.

Keywords: genetic tree improvement
growth

Abstract: Variation in growth rate in the 4 uppermost lateral branches of 2-yr-old seedlings in a common garden was greatest among individuals within full-sib families. Results are consistent with those from other studies on conifers which indicated that there is more within than between intraspecific group variation. Growth rate was greatest in seedlings produced by crossing trees with the highest av. increment (ht. and diam.) and least in seedlings produced by crossing trees with the lowest av. increment. Seedlings with the lowest growth rate, however, were similar to those produced by crosses between other trees with high av. increment. This implies that phenotypically superior parents, as assessed in a natural stand, do not necessarily produce superior offspring in the second year of growth. Results are discussed in relation to evolutionary theory.

[OSU Link](#)

[Non-OSU Link](#)

59. McCreary, D.D., D.P. Lavender and R.K. Hermann. 1990. Predicted global warming and Douglas-fir chilling requirements. *Annales-des-Sciences-Forestieres* 47(4): 325-330.

Keywords: genetic tree improvement
nursery operations
tree phenology
growth

Abstract: Containerized Douglas fir (*Pseudotsuga menziesii*) seedlings from warm coastal and cool mountainous Oregon seed sources, grown under natural conditions, were chilled at constant temperatures of 5, 7 or 9 degrees C for 9, 11, 13 or 15 weeks beginning in mid-October. After a growth period of 9 weeks following chilling, degree of budbreak and dry weight of new shoot growth were measured. The longest and coldest chilling treatment produced the greatest growth response for all seed sources. Results are discussed with reference to predicted global warming, in particular the potential difficulty of reducing Douglas fir chilling requirements through tree breeding programmes.

[OSU Link](#)

[Non-OSU Link](#)

60. McDonald, P.M. and G.O. Fiddler. 1993. Feasibility of alternatives to herbicides in young conifer plantations in California. *Canadian-Journal-of-Forest-Research* 23(10): 2015-2022.

Keywords: genetic tree improvement
site preparation
prescribed fire
release treatments
manual release
chemical release
growth
economics

Abstract: A research programme (involving 40 studies) was started in 1980 to compare the effectiveness and cost of various vegetation management techniques used for enhancing growth of 1- to 3-yr-old conifer (*Pseudotsuga menziesii*, *Pinus ponderosa*, *P. jeffreyi*, *Abiesmagnifica* and *A. concolor* var. *lowiana*) plantations in California. The studies were ended after 10 yr when competition became intraspecific. The techniques used included direct methods such as manual manipulation, mulching, herbicides (Garlon 3A [triclopyr], 2,4-D or Velpar [hexazinone]), and grazing for releasing conifer seedlings from undesirable vegetation, and several silvicultural practices (broadcast burning, group selection, genetically improved seedlings) that serve as indirect methods for reducing or avoiding vegetation problems. Manual release and mulching were effective but expensive. Herbicides were effective, applicable to almost all plant communities, and relatively inexpensive. Grazing was good for cattle and sheep, but did not significantly enhance conifer seedling growth. Silvicultural control of weeds was promising, but there was not enough information to evaluate feasibility. It was concluded that in most instances, forests cannot be managed economically without herbicides, if the objective is to grow seedlings at the potential of the site and the plant community includes sprouting broadleaves and shrubs or rhizomatous forbs and ferns. If the objective is to create a forest with several age-classes and variable structure, but with slower seedling growth, longer rotations, and less species diversity in early seral stages, then it is possible to accomplish this using other vegetation management techniques.

[OSU Link](#)

[Non-OSU Link](#)

61. O'Neill, G.A., W.T. Adams and S.N. Aitken. 2001. Quantitative genetics of spring and fall cold hardiness in seedlings from two Oregon populations of coastal Douglas-fir. *Forest-Ecology-and-Management* 149(1/3): 305-318.

Keywords: genetic tree improvement
tree/stand protection
tree/stand health
genetic relationships

Abstract: Genetics of autumn and spring cold hardiness were investigated in two western Oregon (USA) breeding populations (Coast and Cascade mountains) of Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*). Seedlings from 40 open-pollinated families from each population were grown in raised nursery beds and subjected to two soil moisture regimes (well-watered and mild drought) to evaluate the influence of summer drought on ranking of families for cold hardiness. Artificial freeze testing (AFT) of detached shoots, followed by visual scoring of injury, was used to evaluate needle, stem and bud cold hardiness on three dates in the autumn (September, October and November) after the second growing season, and once in the following spring (March). The Cascade population suffered significantly less cold injury than the Coast population in autumn AFT. However, in spring AFT

the Cascade population was less cold hardy, although population differences were seldom significant. Families within both breeding zones varied significantly in cold hardiness, with mean estimates of individual heritabilities greater in spring ($h^2=0.57$) than autumn ($h^2=0.37$), greater in the Coast ($h^2=0.52$) than in the Cascade ($h^2=0.42$) population, and greater in the wet ($h^2=0.54$) than in the dry moisture regime ($h^2=0.40$) (autumn means based on October tests). A single test date seems adequate to assess autumn cold hardiness, because estimated genetic correlations for cold injury between autumn test dates were strong ($r_A=0.80$). Genetic correlations between spring and autumn cold injury, however, were moderately negative ($r_B=-0.66$ and -0.21 , Coast and Cascade, respectively), indicating that cold hardiness needs to be managed as two traits (i.e. autumn and spring cold hardiness). Selection for cold hardiness based on a single shoot tissue is expected to increase cold hardiness in the other tissues as well, because genetic correlations between tissues in cold injury were moderately-to-strongly positive in both autumn ($r_B=0.67$) and spring ($r_B=0.84$). Seedlings grown under summer drought incurred significantly less cold injury in the autumn than those that were well-watered; nevertheless, strong genetic correlations in autumn cold injury between moisture regimes ($r_B=0.91$) indicate that summer moisture conditions had little influence on family rankings for autumn cold hardiness. Correlations of injury resulting from a natural frost event in November of the first year with injury from AFT in the autumn of the second year ($r_A=0.72$ and 0.78 for needle and bud injury, respectively) confirmed that AFT reliably predicts cold hardiness to natural frost events.

[OSU Link](#)

[Non-OSU Link](#)

62. O'Neill, G.A., S.N. Aitken and W.T. Adams. 2000. Genetic selection for cold hardiness in coastal Douglas-fir seedlings and saplings. *Canadian Journal of Forest Research* 30(11): 1799-1807.

Keywords: genetic tree improvement
tree/stand protection
genetic relationships
tree phenology

Abstract: Genetic control of cold hardiness in two-year-old seedlings in a nursery in Oregon, USA, was compared with that in 7-year-old field saplings, for 40 open-pollinated families in each of two low-altitude breeding populations (Coast and Cascade) of coastal Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) from western Oregon. The field trials were also in the Coast and Cascade breeding zones of Oregon (7 and 6 sites, respectively). In addition, the efficacy of bud phenology traits as predictors of cold hardiness at the two stages was explored. Autumn and spring cold hardiness were assessed using artificial freeze testing. Similar genetic control of cold hardiness in seedlings and saplings is suggested by strong type-B genetic correlations (r_B) between the two ages for autumn and spring cold injury traits ($r_B \leq -0.78$) and by similar trends in individual tree heritability estimates (h^2), e.g., h^2 was greater in spring (mean 0.73) than in autumn (mean 0.36) and greater in the Coast population (0.69) than in the Cascade population (0.40) at both ages. Strong responses to direct selection are expected for spring cold hardiness at both ages and for autumn cold hardiness in seedlings, even under mild selection intensities. Similar heritabilities in seedlings and saplings, and strong genetic correlations between ages for cold-hardiness traits, ensure that selection at one age will produce similar gains at the other age. Type-A genetic correlations (r_A) between autumn and spring cold hardiness were near zero in the Cascade population (0.08 and -0.14 at ages 2 and 7, respectively) but were moderate and negative in the Coast population (-0.54 and -0.36 , respectively). Bud-burst timing appears to be a suitable surrogate to artificial freeze testing for assessing spring cold

hardiness in both seedlings and saplings, as is bud set timing for assessing fall cold hardiness in seedlings, but bud set timing is a poor predictor of fall cold hardiness in saplings.

[OSU Link](#)

[Non-OSU Link](#)

63. Regan, R.P. and W.M. Probesting. 1989. Development of Douglas-fir clones for Christmas trees. *In* Combined Proceedings: International Plant Propagators' Society (Vol 38): 187-191.

Keywords: genetic tree improvement
growth
wood quality

Abstract: Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) clones have been selected for vigour and ornamental quality in Christmas tree production in Oregon. Preliminary evaluations in commercial plots suggest that these clones have significantly higher value than seedlings.

[OSU Link](#)

[Non-OSU Link](#)

64. Riitters, K.H. and D.A. Perry. 1987. Early genetic evaluation of open-pollinated Douglas-fir families. *Forest-Science* 33(2): 577-582.

Keywords: genetic tree improvement
genetic relationships
growth
tree phenology

Abstract: A summary is given of experiments to determine the correlation of seed wt. and growth and phenology of seedlings of 14 families in a cold frame with ht. of saplings from earlier seed crops of the same families in 5 plantations at 9, 12 and 15 yr old. With some exceptions, correlations of seedling variables with field ht. were poor. Highest correlations with 15-yr ht. were for budset at 117 days, ht. and branching index of seedlings. Seedling growth and phenology values were generally poorly correlated with seed wt. Seedling/sapling correlations, however, were related to seedling/seed wt. correlations. Seedling/sapling correlations improved between 9 and 15 yr old.

[OSU Link](#)

[Non-OSU Link](#)

65. Risbrudt, C.D. and S.E. McDonald. 1986. How effective are tree improvement programs in the 50 States? North-Central-Forest-Experiment-Station,-USDA-Forest-Service Research-Paper NC-RP-276. 6 p.

Keywords: genetic tree improvement
economics

Abstract: Data were collected from all 50 State Foresters on the extent and cost of activities in producing genetically improved trees for timber production, the use of State and Private Forestry funds

for such activities and the species being improved. Future timber volume attributable to genetic improvement and benefit/cost ratios were estimated. Only the benefits of planting on nonindustrial private forest lands are considered. Loblolly pine improvement accounted for 40% of the total annual expenditure of \$4 million. Improvement of loblolly pine, Douglas fir, slash pine and ponderosa pine represented 80% of all expenditure. Analysis showed the high sensitivity of the benefit/cost ratios to the discount rate because of the long time before tree improvement benefits are realized. It is concluded, however, that the tree improvement programme is a logical public effort because of the significant long-term benefits of increased timber harvests.

[OSU Link](#)

[Non-OSU Link](#)

66. Schermann, N., W.T. Adams, S.N. Aitken and J.C. Bastien. 1997. Genetic parameters of stem form traits in a 9-year-old coastal Douglas-fir progeny test in Washington. *Silvae-Genetica* 46(2/3): 166-170.

Keywords: genetic tree improvement
growth
wood quality
genetic relationships
tree phenology

Abstract: The genetic control of stem form traits was investigated in a 9-year-old progeny test comparing 80 open-pollinated families of *Pseudotsuga menziesii*, located in a fertile Pacific coast site in Washington, USA. In addition to stem form traits (internode sinuosity, and number of forks and ramicornes per tree), stem volume (height and DBH), bud phenology (earliness of budburst and budset), and occurrence of second flushing on the leader shoot (9th growing season) were measured. Trees with at least one fork or ramicorn were frequent (26% and 46%, respectively), as were trees with second flushing (26%). Most of the trees exhibited sinuosity of limited magnitude. Due to strong differences among family means and at least modest family heritabilities (0.35 to 0.66), all traits were found to be amenable to genetic improvement. The estimated genetic correlation (r_A) between numbers of forks and ramicornes was relatively strong (0.54), and both forking defects traits exhibited similar genetic associations with other traits. Forking defects were strongly and positively associated with frequency of second flushing, a trait which in turn is positively and moderately correlated with both DBH (0.32) and earliness of budburst (0.39). These results are consistent with previous findings. Breeding consequences for simultaneous improvement of both stem volume and form are discussed.

[OSU Link](#)

[Non-OSU Link](#)

67. Schowalter, T.D. and M.I. Harverty. 1989. Influence of host genotype on Douglas-fir seed losses to *Contarinia oregonensis* (Diptera: Cecidomyiidae) and *Megastigmus spermotrophus* (Hymenoptera: Torymidae) in Western Oregon. *Environmental-Entomology* 18(1): 94-97.

Keywords: genetic tree improvement
seed orchard management
tree/stand protection

genetic relationships
tree/stand health

Abstract: Seed losses due to the cecidomyiid *Contarinia oregonensis* and the chalcid *Megastigmus spermotrophus* were measured in a Douglas-fir (*Pseudotsuga menziesii*) clonal seed orchard and in a Douglas-fir progeny plantation in western Oregon. Seed losses due to both insects differed significantly among clones and among the progeny of selected parental crosses. Seed loss differed more than 3 times between least-infested and most-infested clones or progeny. Seed losses in the progeny plantation indicated that resistance to these 2 insects is a heritable trait, with greater resistance showing a tendency to dominate over lesser resistance. Insect responses to host genotype may be modified by factors associated with the position of the tree within the stand. Implications of these results for tree improvement programmes and seed orchard management are discussed.

[OSU Link](#)

[Non-OSU Link](#)

68. Schowalter, T.D., M.I. Haverty, S.A. Dombrosky and J. Sexton. 1986. Response of Douglas-fir cone gall midge and Douglas-fir seed chalcid to host plant genotype. In Proceedings of the 2nd Conference of the Cone and Seed Insects Working Party, Station de Zoologie Forestiere, Olivet, France, September 3-5, 1986. Ed. A. Roques. pp. 217-223.

Keywords: genetic tree improvement
seed orchard management
tree/stand protection
genetic relationships
tree/stand health

Abstract: Seed losses due to 2 species of insects were measured from cones of 51 parental crosses (or families, distinct combinations of 6X11 parents) in a 12-year-old progeny plantation of Douglas fir (*Pseudotsuga menziesii*) in western Oregon. In 1983 and 1984, seed losses due to *Contarinia oregonensis* were significantly different among host families. During 1984, 4 of 5 families with the highest midge damage ($x=79\%$) shared a common parent and 4 of 5 families with the lowest midge damage (43%) shared a common parent. This indicates that resistance or susceptibility to the cecidomyiid is probably heritable. Losses due to *Megastigmus spermotrophus* were measured only in 1984 and were also significantly different among host families. Insect responses to host genotype appeared to be influenced by the position of the tree within the plantation, by the size of the cone crop and, in the case of *M. spermotrophus*, by prior activity of *C. oregonensis*.

69. 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.

[OSU Link](#)

[Non-OSU Link](#)

70. Sorensen, F.C. 1999. Relationship between self-fertility, allocation of growth, and inbreeding depression in three coniferous species. *Evolution* 53(2): 417-425.

Keywords: genetic tree improvement
seed orchard management
growth
tree/stand health
carbon allocation

Abstract: Mortality and growth of self and outcross families of three wind-pollinated, mixed-mating, long-lived conifers - Douglas fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), and noble fir (*Abies procera*), were followed from outplanting to age 26 (25 for noble fir) in spaced plantings at a common test site in the Oregon Coast Range, near Monmouth. Response to inbreeding differed greatly among species over time and in all regards. Only Douglas fir and noble fir are discussed, because ponderosa pine usually was intermediate to the other two in its response to inbreeding. In earlier reports, compared with noble fir, Douglas fir had a higher rate of primary selfing and larger inbreeding depression in seed set. Douglas fir continued to have higher inbreeding depression in nursery and early field survival. The species differed in time courses of inbreeding depression in height and in allocation of growth due to crowding. Between ages 6 and 12, the relative elongation rate (dm/dm per year) of Douglas fir was significantly greater in the selfs than in the outcrosses. The response was not observed in noble fir. At final measurement, inbreeding depression in diameter relative to inbreeding depression in height was greater in Douglas fir than in noble fir. At final measurement inbreeding depression in height was inversely related to inbreeding depression in survival. Cumulative inbreeding depressions

from time of fertilization to final measurement were 0.98, 0.94, and 0.83 for Douglas fir, ponderosa pine, and noble fir, respectively, which indicates that selfs will not contribute to the mature, reproductive populations.

[OSU Link](#)

[Non-OSU Link](#)

71. Sorensen, F.C. and R.K. Campbell. 1997. Near neighbor pollination and plant vigor in coastal Douglas-fir. *Forest-Genetics* 4(3): 149-157.

Keywords: genetic tree improvement
seed orchard management
growth

Abstract: Nineteen seed parents in a young, patchy second-growth stand of *Pseudotsuga menziesii* were manually pollinated by near (NN; 12 m) and far neighbours (FN; 100-500 m), and by wind (W) in a heavy-flowering year (1971). Progenies were compared in the nursery and for 10 additional years at close spacing (0.75 m) in the field. In a separate test, the effects of conelet bagging were evaluated using plants of 10 of the same seed parents. Progeny from W and NN pollinations were slightly, but non-significantly smaller than progeny from FN pollination. seed parent x pollen type interactions were highly significant. Bagging effects were significant at the seedling stage, but disappeared in field tests, and did not interact with seed parent at any age. Estimated rates of biparental inbreeding, based on these results and previous reports, are 0 to ~20%. Such variation seems compatible with the variation in natural regeneration habits of the species. If biparental inbreeding is considered as resulting from half-sib mating, the associated inbreeding depression in height is estimated as 0 to 2.3%. At the close spacing used in this study, depression in biomass appeared to be 4-5 times as great as depression in height at age 12.

[OSU Link](#)

72. Sorenson, F.C. and R.K. Campbell. 1993. Seed weight-seedling size correlation in coastal Douglas-fir: genetic and environmental components. *Canadian-Journal-of-Forest-Research* 23(2): 275-285.

Keywords: genetic tree improvement
growth
genetic relationships

Abstract: The effect of seed weight of coastal Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) on nursery seedling height was analysed in two experiments. In the first experiment, 16 seeds per family from 111 families were individually weighed and sown in the autumn. In the second experiment, another group of 16 seeds were individually weighed and stratified and sown in the spring. Four-tree non-contiguous family plots were randomly assigned to two densities in two replications in each experiment. Date of emergence and duration and rate of shoot elongation were determined over 2 years of growth. Seedlings in the first experiment were unintentionally exposed to damaging frost after emergence. Some seedlings in the second experiment suffered Lygus bud damage to the terminal shoot. Developmental associations between seed weight, a maternally inherited trait, and seedling height and its components were examined using sets of path analyses with and without adjustments for planned

and accidental treatment effects. Results suggested both 'environmental' and 'genetic' contributions of seed weight to seedling height. The weight (environmental) component, alone, decreased with time. The genetic component, which was indicated by lack of direct effect of seed weight on seedling height in the path analyses and by changing female:male variance ratios over time, was quite stable across treatment effects. Because of the genetic relation, seed weight adjustment is not recommended as a procedure for increasing precision in early selection of coastal Douglas fir families.

[OSU Link](#)

[Non-OSU Link](#)

73. St-Clair, J.B. 1994a. Genetic variation in tree structure and its relation to size in Douglas-fir. I. Biomass partitioning, foliage efficiency, stem form, and wood density. *Canadian-Journal-of-Forest-Research* 24(6): 1226-1235.

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

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 in size, biomass partitioning and wood density, and genetic gains may be expected from selection and breeding of desirable genotypes. Estimates of heritability for partitioning traits, including harvest index (the proportion of fixed carbon converted to stemwood), were particularly high. Foliage efficiency (stem increment per unit leaf area) was correlated with harvest index and may represent an alternative measure of partitioning to the stem. Estimates of foliage efficiency where leaf area was estimated based on stem diameter or sapwood area were unrelated to foliage efficiency where leaf area was measured directly. Strong negative genetic correlations were found between harvest index and stem size, and between wood density and stem size. Large trees were more tapered than small trees. It is concluded that simultaneous genetic gain in stem size and either harvest index or wood density would be difficult to achieve.

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74. 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](#)

75. St-Clair, J.B. and W.T. Adams. 1991a. Effects of seed weight and rate of emergence on early growth of open-pollinated Douglas-fir families. *Forest-Science* 37(4): 987-997.

Keywords: genetic tree improvement
nursery operations
reproduction
genetic relationships
growth

Abstract: Open-pollinated seeds were collected from 39 Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) families in second-growth stands in the Coast Range of west-central Oregon (150-500 m altitude) in autumn 1985. Seed weight, time of emergence, and three measures of seedling size were recorded for each family in order to assess family variation in seed weight and emergence, and the influence of these seed traits on early growth. Seeds were dewinged, cleaned and stored at 0 degrees C. In April 1986, seeds and germinants were sown at a depth of 8 mm to test whether using germinants minimized seed effects on early growth. To evaluate the effect of competition on the relationships of seed weight and rate of emergence to seedling size, individuals of families were planted in mixed-family blocks at close spacing (4x4 cm), in single (pure) family blocks at close spacing (4x4 cm) and in mixed family blocks at a wide, noncompetitive spacing (16x16 cm). Families differed significantly in seed weight, total emergence percentage and rate of emergence. However, correlations of seed weight to rate of emergence, and seed weight and rate of emergence to seedling size, were not strong. Using germinants was ineffective in diminishing seed effects. Interfamily competition had a minor influence on enhancing the effect of seed traits on seedling growth.

[OSU Link](#)

[Non-OSU Link](#)

76. St-Clair, J.B. and W.T. Adams. 1991b. Relative family performance and variance structure of open-pollinated Douglas-fir seedlings grown in three competitive environments. *Theoretical-and-Applied-Genetics* 81(4): 541-550.

Keywords: genetic tree improvement
nursery operations
genetic relationships
growth

Abstract: Open-pollinated Douglas fir (*Pseudotsuga menziesii*) var. *menziesii* families were tested in 3 contrasting competitive environments to test the hypothesis that relative performance as measured by total seedling dry weight is dependent upon distance or genotype of neighbours. The 3 environments included (1) a mixture of individuals from all families sown at close spacing, (2) single (pure) family blocks sown at close spacing, and (3) individuals from all families sown at a wide, non-competitive spacing. Despite occasional large changes in rank between competitive environments and only moderate correlations of family means between competitive environments, the family x competitive environment interaction was non-significant. Furthermore, families did not differ significantly in competitive ability or density tolerance. The competitive environment in which seedlings were grown, however, had a large effect on estimates of variance components, which in turn led to large differences in estimates of heritability and genetic gain. Evaluation of families in mixture resulted in the largest estimates of heritability, while evaluation in pure family blocks resulted in the lowest. Analysis of correlated response to selection indicated that testing and selection in mixture resulted in the largest estimated gain, even if progeny of selected individuals are subsequently grown in a pure or non-competitive environment.

[OSU Link](#)

[Non-OSU Link](#)

77. St-Clair, J.B. and W.T. Adams. 1993. Family composition of Douglas-fir nursery stock as influenced by seed characters, mortality, and culling practices. *New-Forests* 7(4): 319-329.

Keywords: genetic tree improvement
reproduction
growth
genetic relationships

Abstract: Changes in family composition during nursery production were evaluated by following individual seeds and seedlings of 36 wind-pollinated Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) families sown in mixture in two operational nurseries in western Washington and Oregon. Families differed significantly in emergence (measured after 5 wk) and in percentage of seedlings culled for being too small (at end of second growing season: <4 mm stem diameter or <20 cm stem height). Filled seed germination rates (tested in the laboratory) were not related to emergence rates. Differences overall were small enough that family composition was largely unaffected. Observed changes in family composition did not markedly reduce genetic diversity and did not affect the genetic gain that may be expected from an improved population. The plantable nursery stock was, for the most part, representative of the composition of families originally sown.

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78. St-Clair, J.B., N.L. Mandel and K.J.S. Jayawickrama. 2004. Early realized genetic gains for coastal Douglas-fir in the Northern Oregon Cascades. *Western-Journal-of-Applied-Forestry* 19(3): 195-201.

Keywords: genetic tree improvement
growth

Abstract: Block-plot realized genetic gain trials were established for coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) at five sites in the northern Oregon Cascades. The long-term objectives of these trials are to explore the growth trajectories and productivity of genetically improved stands and their relationship to predicted genetic gains based on performance in progeny tests. Measurements 5 years after planting provide an opportunity for an early assessment of realized genetic gains as compared to predicted gains and provide data for determining the number of replicates needed to detect statistically significant differences between improved and unimproved populations using large block plots. Results indicate that progress from selection and breeding of Douglas-fir is readily achievable, and realized genetic gains 5 years after planting are similar to those predicted based on results from progeny tests. Realized genetic gains were about 6% for height, 8% for diameter, and 28% for stem volume, compared to predicted genetic gains of about 8% for height, 7% for diameter, and 25% for stem volume. Large numbers of replicates (30-50) are required to detect statistically significant differences in height and diameter between improved and unimproved populations given genetic gains expected in a typical tree improvement program.

[OSU Link](#)

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79. St-Clair, J.B. and R.A. Snieszko. 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](#)

80. Stevenson, J.F., B.J. Hawkins and J.H. Woods. 1999. Spring and fall cold hardiness in wild and selected seed sources of coastal Douglas-fir. *Silvae-Genetica* 48(1): 29-34.

Keywords: genetic tree improvement
tree/stand protection
tree/stand health
tree phenology
growth

Abstract: Breeding for increased growth in coastal Douglas fir (*Pseudotsuga menziesii*) could affect the level of cold hardiness of seedlings used for reforestation. If increased growth is achieved by initiating growth earlier in the spring or prolonging growth later into autumn, cold hardiness could be reduced during these seasons. Cold hardiness was measured in top-cross and first generation seed orchard trees selected for increased growth rates, and wild stand trees on Vancouver Island and near Mission, BC, throughout one growing season by visual assessment of artificial freeze tests. Significant differences in freezing damage between genetically selected and wild stand trees were found during both spring and autumn. In April, LT50 of top-cross trees was 0.7-2.4 degrees C below that of wild stand trees, while in October, LT50 of wild stand trees was 1.9-3.4 degrees C below that of top-cross trees. Mitotic index was investigated as an indicator of dormancy, and a negative correlation between mitotic index and cold hardiness was found. A significant difference in mitotic index between the genetic groups was found once in March when mitotic index in wild stand and seed orchard trees was 1.4% and mitotic index in top-cross trees was 0.9%. There were no significant differences in mitotic index at any other times during the year. Date of bud burst and rates of shoot extension were related to levels of cold hardiness in the three groups of seedlings. The stage of bud burst in May was significantly correlated with levels of hardiness found earlier in March and April. Trees that completed shoot extension earlier in the season were significantly more hardy in autumn. Top-cross trees may extend their growing season later into the fall, thereby gaining a height advantage over wild stand seedlings. These top-cross families do not have an increased mid to late autumn frost damage risk, and in fact may have reduced risk of critical spring frost damage due to delayed deacclimation.

[OSU Link](#)

[Non-OSU Link](#)

81. Stoehr, M.U., B.L. Orvar, T.M. Vo, J.R. Gawley, J.E. Webber and C.H. Newton. 1998. Application of a chloroplast DNA marker in seed orchard management evaluations of Douglas-fir. *Canadian-Journal-of-Forest-Research* 28(2): 187-195.

Keywords: genetic tree improvement
genetic relationships
reproduction

Abstract: Pollen contamination, supplemental mass pollination efficacies, and natural selfing were evaluated in a Douglas fir (*Pseudotsuga menziesii*) clonal-row seed orchard near Victoria, British Columbia, using a genetic marker on the paternally inherited chloroplast (cp) genome. A primer pair for

the polymerase chain reaction amplification of a variable region on the cpDNA in Douglas fir was developed. The amplified DNA product was highly variable in size, yielding 13 different haplotype bands from 20 orchard genotypes growing in the clonal-row seed orchard. Observed band sizes ranged from 859 to 1110 base pairs (bp). To estimate variation levels in the orchard background pollen pool, 96 assayed genotypes from surrounding stands gave rise to 36 different haplotypes, ranging from 367 to 1119 bp in size, resulting in a gene diversity estimate of 0.91. Most orchard clones' haplotypes were also present in the background. After adjusting for the presence of orchard-type haplotypes in the background, contamination was found to be 40%. Natural selfing in six individual clones ranged from 0 to 19% with an average of 6%. Supplemental mass pollination efficacy was estimated to be 55%, ranging from 39 to 73%, depending on the maternal clone and flowering phenology. This DNA marker proved to be very useful in assessing seed orchard mating dynamics and orchard management efficacies for Douglas fir.

[OSU Link](#)

[Non-OSU Link](#)

82. Stoehr, M.U., J.E. Webber, C.C.A. Hollefreund and R.A. Painter. 2004. Potential pollen contamination effects on progeny from an off-site Douglas-fir seed orchard: 9-year field results. *Canadian-Journal-of-Forest-Research* 34(4): 981-984.

Keywords: genetic tree improvement
seed orchard management
reproduction
tree/stand health
growth

Abstract: To evaluate the potential effects of seed orchard pollen contamination from surrounding background sources, we made control pollinations with outside orchard pollen and inside orchard pollen on trees of a Douglas-fir (*Pseudotsuga menziesii*) coastal-interior transition zone seed orchard. This zone encompasses the coast mountains from the Washington border to Alaska, USA. The resulting progeny were tested on a transition zone and a coastal site. After nine growing seasons, survival was above 90% on both sites for both pollen sources, and the tree height differences due to pollen source were statistically non-significant. Wildstand operational seedlots, used as controls, were 17% shorter than the contaminated seedlings. Orchard management implications of these results are discussed.

[OSU Link](#)

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83. Stoehr, M.U., J.E. Webber and R.A. Painter. 1994. Pollen contamination effects on progeny from an off-site Douglas-fir seed orchard. *Canadian-Journal-of-Forest-Research* 24(10): 2113-2117.

Keywords: genetic tree improvement
seed orchard management
growth
genetic relationships
reproduction

Abstract: The effects of background pollen contamination were evaluated for first-year height growth pattern of seedlings originating from a Douglas fir (*Pseudotsuga menziesii*) coastal-interior transition zone seed orchard located on southern Vancouver Island, British Columbia. Pollen collected from five stands surrounding the orchard (background pollen) and pollen from five half-sib families of the seed orchard were applied to six individual trees in the orchard. The resulting 60 seed lots were raised outdoors in a coastal-climate nursery with five seed lots collected from wild stands of the transition zone. Heights were measured at 10-day intervals during the growing season. Final heights, maximum height growth rate and growth cessation were subjected to analysis of variance. Growth rate and cessation were derived from data fitted to the logistic growth curve using nonlinear regression analysis. Seedlings sired by the background pollen had significantly greater final heights and growth rates. There were no differences in orchard seedlings in growth cessation probably because all seedlings were exposed to a blackout treatment to force bud set in mid-August. The average final height of wild-stand seedlings from the transition zone was 15% and 21% lower than that of pure orchard seedlings and seedlings sired by the background pollen lots, respectively. Standard deviations for measured traits were similar between orchard seedlings sired by background pollen and orchard pollen. If pollen contamination is not prevented, the faster growing seedlings sired by the background pollen may be preferentially selected during culling in the nursery and outplanted on sites to which they are maladapted.

[OSU Link](#)

[Non-OSU Link](#)

84. Stonecypher, R.W., R.F. Piesch, G.G. Helland, J.G. Chapman and H.J. Reno. 1996. Results from genetic tests of selected parents of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) in an applied tree improvement program. *Forest-Science-Monograph* (32): 35.

Keywords: genetic tree improvement
planting operations
growth
tree phenology
genetic relationships

Abstract: Results from genetic tests, and genotype x environment interaction studies in six low-elevation breeding zones of Weyerhaeuser Company's Western Washington and Oregon Douglas fir (*Pseudotsuga menziesii*) tree improvement programme are summarized. Phenotypic selection in natural stands resulted in a 5% improvement in juvenile height over nonselect seed lots. Comparisons with nonselect sources, of offspring from parents in the top 50% performers in tests, indicated a 10% increase for the same trait. Seed produced in a 50% rogued seed orchard is thus expected to provide improved planting stock with a gain of 10% in juvenile height growth. Several select parents are producing offspring that are consistently performing in excess of 10% over nonselects. Estimates of breeding zone, breeding zone by location, and family by location interaction effects are small relative to family and planting location effects. Tests of families established on environmentally diverse sites indicate a striking lack of large family by planting location interaction. In tests showing statistically significant interactions, such interactions are caused by a relatively small number of families. Earlier budbreak and a higher spring frost susceptibility of Oregon sources established on Washington sites were observed. It is concluded that allocation and utilization of select families within Weyerhaeuser's Oregon and Washington ownership should not be constrained by the currently defined breeding zone boundaries, but based on parental performance and stability for growth and

adaptive traits in general. It is suggested that the necessity for maintaining separate breeding zones, within Washington and Oregon, in subsequent cycles of recurrent selection is questionable. Average individual tree heritability, from 65 6-parent disconnected diallels, is 0.13 for age 6 and age 8 height. Dominance genetic variance is estimated to be one-half that of additive genetic variance for the same traits.

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85. Temel, F. and W.T. Adams. 2000. Persistence and age-age genetic correlations of stem defects in coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco). *Forest-Genetics* 7(2): 145-153.

Keywords: genetic tree improvement
genetic relationships
growth
wood quality

Abstract: Persistence of stem defects, including bole sinuosity, large branch size and the occurrence of steep-angled branches (i. e., forks and ramicorns), and the efficiency of early selection against these traits, were investigated in 90 open-pollinated families of Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) from coastal Oregon, USA. Trees originally measured for these traits at age 12 were remeasured at age 24 in three progeny test plantations. The majority of trees scored as having ramicorn branches at age 12 (62%) still had them at age 24, but most forks (53%) had become ramicorns by the second measurement. Thus, there seems little need to score forks and ramicorns separately; simply counting the number of whorls with steep-angled branches seems sufficient for selection purposes. Branch size scores were relatively consistent between the two ages, but not scores for bole sinuosity. Because of low estimated individual and family heritability estimates (≤ 0.13 and ≤ 0.41 , respectively), predicted genetic responses in diameter at breast height (DBH) and individual stem-defect traits were only modest for this population. Nevertheless, with the exception of sinuosity, genetic correlations between comparable stem-defect traits at the two ages were strong ($r \geq 0.82$), and predicted responses in traits at age 24, from selection at age 12, were nearly as great as responses expected if selection was delayed until age 24. Branch size and occurrence of steep-angled branches were unfavourably (positively) correlated with DBH (estimated $r = 0.56$ and 0.41 , respectively). Thus, it is important to include these stem defect traits as selection criteria in Douglas fir breeding programmes, if stem volume growth is to be improved without sacrificing wood quality.

[OSU Link](#)

86. Thomson, T.A. 1989. Evaluating some financial uncertainties of tree improvement using the capital asset pricing model and dominance analysis. *Canadian-Journal-of-Forest-Research* 19(11): 1380-1388.

Keywords: genetic tree improvement
economics

Abstract: Although uncertainty considerations are of prime importance in capital budgeting, forestry investments are often evaluated without comparing their uncertainty level with their rates of return. An

examination was made of some financial uncertainties of a Douglas fir (*Pseudotsuga menziesii*) tree improvement programme in the US Pacific Northwest with analysis of likely rates of return on investment. Biophysical uncertainties such as amount of genetic gain or uncertainty of site quality were determined by a priori assumption to be non-market; thus, use of expected value adjusted for these risks. The market uncertainties of tree improvement were found to be reasonable in relation to other investments, as sensitivity analysis showed that the financial risks were small or the measured beta (covariance of the assets' returns with the market's returns divided by the variance of the market) was low. It is concluded that the tree improvement investment is worthwhile, considering its risk as well as return.

[OSU Link](#)

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87. Vargas-Hernandez, J. and W.T. Adams. 1991. Genetic variation of wood density components in young coastal Douglas-fir: implications for tree breeding. *Canadian-Journal-of-Forest-Research* 21(12): 1801-1807.

Keywords: genetic tree improvement
genetic relationships
wood quality
growth

Abstract: A study was made of the genetic control of wood density components (earlywood density, latewood density, and latewood percentage) and their relationships with overall density in coastal Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) to assess the usefulness of this information in breeding for wood density. The genetic relationships of wood density with intra-ring density variation and bole volume growth were also investigated. Increment cores were taken at breast height from 15-yr-old trees of 60 open-pollinated families growing in the Coyote Creek progeny test plantation near Eugene, Oregon, during summer 1988. Averages across each core for overall wood density, its components and intra-ring density variation were determined by using X-ray densitometry. Bole volume at age 15 yr for the same trees was derived from tree height and diameter at breast height measurements taken at the end of the 1987 growing season. Although wood density components varied significantly among families and were under moderate genetic control (individual-tree heritability (hisuperscript 2) >0.24), none had a higher heritability than overall density (hisuperscript 2 = 0.59). Density components had strong genetic correlations with overall density ($r \leq 0.74$), but were also strongly related among themselves ($0.57 \leq r \leq 0.92$). Thus, density components have limited value in improving the efficiency of selection for overall density. Overall density was positively correlated with intra-ring density variation ($r = 0.72$) and negatively correlated with bole volume ($r = -0.52$). However, comparison of several selection indices incorporating wood density and one or more growth traits showed that it is possible to obtain substantial gains in bole volume without loss in (or even with a modest increase in) wood density. By restricting the response in wood density, the change in intra-ring density variation can also be limited.

[OSU Link](#)

[Non-OSU Link](#)

88. Vargas-Hernandez, J. and W.T. Adams. 1992. Age-age correlations and early selection for wood density in young coastal Douglas-fir. *Forest-Science* 38(2): 467-478.

Keywords: genetic tree improvement
genetic relationships
wood quality

Abstract: Age-age correlations and age-associated changes in the genetic control of wood density and its components (earlywood density, latewood density, and latewood proportion) were investigated in 15-yr-old trees of 60 open-pollinated families of coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) in Oregon. The possibility of using wood density components as secondary traits to increase the efficiency of early selection for overall wood density was also explored. Heritability estimates for overall density and its components increased with age, mainly because of a decrease in the error variance as the number of rings in the core sample increased. Overall density and its components at age 15 yr had strong genetic correlations with their respective traits at all younger ages analysed. Moreover, with few exceptions, age-age genetic correlations were greater than phenotypic correlations. Early selection to improve overall density at age 15 yr was quite efficient (relative efficiency >79%), even when selection was based on core density at the youngest age (7 yr). Using wood density components as secondary traits produced a slight increase in the efficiency of early selection only at the youngest ages, presumably because age-age correlations for overall core density were already strong, limiting the potential for additional improvement.

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89. Vargas-Hernandez, J. and W.T. Adams. 1994. Genetic relationships between wood density components and cambial growth rhythm in young coastal Douglas-fir. *Canadian-Journal-of-Forest-Research* 24(9): 1871-1876.

Keywords: genetic tree improvement
genetic relationships
wood quality
tree phenology
growth

Abstract: Genetic relationships of wood density, and its components, with cambial growth rhythm traits were examined in a 15-year-old progeny test of coastal Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) in Oregon, in an attempt to better understand the genetic control of wood formation, and to assess the potential effect of selecting for increased wood density on adaptation of trees. Timing of diameter growth during the 1987 growing season was determined in an earlier study, and wood formation traits were estimated by X-ray densitometry of increment core samples. Wood formation traits were under weak genetic control ($h^2 < 0.20$). Duration of earlywood and latewood formation were mostly determined by the timing of latewood transition. Overall core density was negatively correlated with the dates of cambial growth initiation ($r_A = -0.41$) and latewood transition ($r_A = -0.62$), and positively correlated with the date of cambial growth cessation ($r_A = 0.40$). As a result of these relationships, higher wood density was associated with a longer duration of cambial growth ($r_A = 0.67$) and a slower rate of wood formation ($r_A = -0.37$). All density components showed similar relationships with cambial phenology and wood formation traits. Selection for increased wood density is expected to cause only a slight extension of the cambial growth period, but it would also cause an earlier transition to latewood formation, negatively affecting growth rate.

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90. Vargas-Hernandez, J., W.T. Adams and R.L. Krahmer. 1994. Family variation in age trends of wood density traits in young coastal Douglas-fir. *Wood-and-Fiber-Science* 26(2): 229-236.

Keywords: genetic tree improvement
genetic relationships
wood quality

Abstract: Changes in ring density and its components with increasing distance from the pith (i.e. age trends) were examined in 15-yr-old trees from 60 open-pollinated families of coastal Douglas fir [*Pseudotsuga menziesii*] grown in the Coyote Creek progeny test plantation near Eugene, Oregon. Earlywood, latewood, and overall densities of each annual ring, obtained by X-ray densitometry of increment cores, were weighted by the area of the ring occupied by each trait, relative to the total stem cross-sectional area at breast height for the trait. Age trends in weighted values differed among traits but, with the exception of earlywood density, family variation was not detected. Weighted earlywood density (WED) steadily increased from pith to bark in some trees, while in other trees a plateau occurred at age 11 or later. Significant family differences were found in the proportion of trees reaching a plateau in WED by age 12. This proportion was under moderate genetic control (family $h^2 = 0.30$) and was not genetically correlated with overall core density or stem growth at age 15. Although there are reasons to hypothesize that the plateau in WED is an indication of transition from juvenile to mature wood formation, this hypothesis needs to be verified in older trees.

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91. Vargas-Hernandez, J.J., W.T. Adams and D.G. Joyce. 2003. Quantitative genetic structure of stem form and branching traits in Douglas-fir seedlings and implications for early selection. *Silvae-Genetica* 52(1): 36-44.

Keywords: genetic tree improvement
nursery operations
growth
genetic relationships
wood quality

Abstract: Open-pollinated (OP) and full-sib (FS) families of coastal Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) were grown in two replicated nursery regimes to evaluate the magnitude and repeatability of genetic parameter estimates for stem form (stem sinuosity, forking) and branching (number, length and angle of branches) traits in 2-year-old seedlings, and the relationships of these traits with stem growth. With data from older trees of the OP families growing in the field (ages 12 and 24), genetic control of similar traits was compared at the different ages, and nursery-field correlations (r_{xy}) were estimated. With the exception of forking, estimates of family heritability (h^2_f) were moderate to strong for stem form and branching traits in seedlings ($0.32 < h^2_f < 0.94$; mean=0.73), and similar to growth traits ($0.45 < h^2_f < 0.90$; mean=0.75). Family performance and estimates of genetic parameters were relatively stable across nursery regimes and

family type. Genetic relationships among traits in seedlings were similar to those observed in older field-grown trees, indicating that these traits are controlled by similar sets of genes in the two age classes. Nursery-field correlations between comparable traits were consistent across nursery regimes, but r_{xy} was strong enough to be useful for early testing purposes (i.e. $|r_{xy}| \geq 0.30$), only for number of whorls with steep-angled branches (WSAB), branch length, and branch angle in older trees. Predicted gains from early selection for these or correlated traits were at least 40-50% of those expected from selection at older ages. Because of unfavourable genetic correlations, selection for stem growth potential alone at the seedling stage is expected to produce unfavourable impacts on WSAB and stem sinuosity in older trees. To avoid such negative effects on wood quality, both stem form and branching traits should be included as selection criteria in Douglas fir breeding programmes.

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92. Wang, T., S.N. Aitken, J.H. Woods, K. Polsson and S. Magnussen. 2004. Effects of inbreeding on coastal Douglas fir growth and yield in operational plantations: a model-based approach. *Theoretical-and-Applied-Genetics* 108(6): 1162-1171.

Keywords: genetic tree improvement
seed orchard management
planting operations
yield

Abstract: In advanced generation seed orchards, tradeoffs exist between genetic gain obtained by selecting the best related individuals for seed orchard populations, and potential losses due to subsequent inbreeding between these individuals. Although inbreeding depression for growth rate is strong in most forest tree species at the individual tree level, the effect of a small proportion of inbreds in seed lots on final stand yield may be less important. The effects of inbreeding on wood production of mature stands cannot be assessed empirically in the short term, thus such effects were simulated for coastal Douglas fir [*Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco] using an individual-tree growth and yield model TASS (Tree and Stand Simulator). The simulations were based on seed set, nursery culling rates, and 10-year-old field test performance for trees resulting from crosses between unrelated individuals and for inbred trees produced through mating between half-sibs, full-sibs, parents and offspring and self-pollination. Results indicate that inclusion of a small proportion of related clones in seed orchards will have relatively low impacts on stand yields due to low probability of related individuals mating, lower probability of producing acceptable seedlings from related matings than from unrelated matings, and a greater probability of competition-induced mortality for slower growing inbred individuals than for outcrossed trees. Thus, competition reduces the losses expected due to inbreeding depression at harvest, particularly on better sites with higher planting densities and longer rotations. Slightly higher breeding values for related clones than unrelated clones would offset or exceed the effects of inbreeding resulting from related matings. Concerns regarding the maintenance of genetic diversity are more likely to limit inclusion of related clones in orchards than inbreeding depression for final stand yield.

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93. White, T.L. 1987. Drought tolerance of southwestern Oregon Douglas-fir. *Forest-Science* 33(2): 283-293.

Keywords: genetic tree improvement
tree/stand protection
tree phenology
tree/stand health

Abstract: Seedlings of 2 open-pollinated families from each of 36 seed sources were tested for their ability to survive simulated drought in a growth room, greenhouse and cold frame. Generally, seedlings of sources from higher alt. and, to a lesser extent, drier sites were more drought tolerant. Seedlings from drought-tolerant sources tended to have earlier bud set, smaller initial ht. and less winter injury (needle mortality). The main selective force leading to earlier bud set and smaller ht. growth appeared to be the colder temp. regime at higher alt. Seedlings from higher alt. entered dormancy sooner and were better able to survive drought.

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94. Woods, J.H., D. Kolotelo and A.D. Yanchuk. 1995. Early selection of coastal Douglas-fir in a farm-field test environment. *Silvae-Genetica* 44(4): 178-186.

Keywords: genetic tree improvement
planting operations
site preparation
mechanical preparation
release treatments
chemical release
manual release
genetic relationships
wood quality
growth

Abstract: Farm-field tests are progeny tests established using intensive site preparation, close spacing and nearly complete weed control. Early growth and wood density of coastal Douglas-fir (*Pseudotsuga menziesii*) in a farm-field environment for up to 7 years from seed were compared with stem volume and wood density from 11 field sites at age 13 (20-25 of commercial rotation). The farm-field test material comprised 70 full-sib families from six 6-tree half-diallels (some reciprocals and missing crosses) without selfs. Parent trees were from natural stand selections in the coastal area of British Columbia, Canada, and the farm-field test was conducted on southern Vancouver Island. Family heritabilities were high for almost all traits in both the farm-field and field sites. Breeding-value correlations of farm-field heights with field stem volume at age 13 increased from a low of 0.5 for farm-field age 1 and levelled off at about 0.7 by farm-field age 3. Farm-field diameter with field volume age 13 breeding-value correlations were initially lower than those for height, but increased to 0.82 by age 7. Wood density breeding value correlations between field pilodyn assessments at age 13 and farm-field stem sections at age 6 were 0.83. Maximum family-selection efficiency per year (including a 5-year breeding delay), relative to direct selection on field volume 13, reached 162% using index selection on farm-field height and diameter at age 3. Within-family selection efficiencies per year were highest at age

1 and declined quickly thereafter. All selection in the farm-field test had a higher efficiency per unit time than selection in field tests. It is concluded that correctly established farm-field tests will provide greater per year gains in stem yield and wood density traits than field sites.

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95. Woods, J.H., T. Wang and S.N. Aitken. 2002. Effects of inbreeding on coastal Douglas fir: nursery performance. *Silvae-Genetica* 51(4): 163-170.

Keywords: genetic tree improvement
growth
tree/stand health
reproduction
genetic relationships

Abstract: In advanced generation seed orchards, low levels of inbreeding may be inevitable as relatedness among individuals in breeding populations increases with each generation. Unlike selfing, low level inbreeding can produce relatively large number of viable seeds. Following previous study on the effects of inbreeding on coastal Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) filled seed production, the present study investigated inbreeding on nursery performance over various cross-types, including outcrosses (inbreeding coefficient $F=0$), crosses between half-sibs ($F = 0.125$), between full-sibs ($F = 0.25$), between parents and offspring ($F = 0.25$), and selfing ($F = 0.5$). Significant differences were found among cross-types for germination, seedling mortality, seedling diameter and height, and nursery cull rate. Inbreeding also increased among-family genetic variability. Cumulative losses of seedlings at the nursery stage were 18, 33, 31, 36 and 43%, respectively for the above types of crosses. This result indicates that seeds with low levels of inbreeding may produce relatively large numbers of seedlings that meet nursery culling standards and could be used for reforestation, resulting in negative impacts on the genetic gain realized in field plantations.

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96. Yanchuk, A.D. 1996. General and specific combining ability from disconnected partial diallels of coastal Douglas-fir. *Silvae-Genetica* 45(1): 37-45.

Keywords: genetic tree improvement
growth
genetic relationships

Abstract: GCA and SCA were examined in 36, 6-parent disconnected partial diallels across 4 experimental series in coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) in British Columbia, to examine the ratios of the 2 genetic variances, the distribution of GCA and SCA effects, and estimates of genetic gain from GCA and SCA for 3 growth traits. Height at age 7 and height and volume at age 12 were measured on approximately 150 trees per full-sib family in each diallel, across 11 different test sites within each series. The average percentage ratio of SCA variance to GCA variance was 36% across all series and the 3 growth traits, with a range of 19 to 65%. GCA and SCA variances did not appreciably change for height growth from age 7 to age 12. Diallel set effects were generally negligible. From

theoretical considerations assumed for the diallel model, clear separations of additive and dominance effects (vis-a-vis the assumptions of selecting on GCA and SCA variances) are likely not possible: the effects are subject to degrees of dominance, epistasis and linkage in the population. However, these genetic details did not manifest themselves in any noticeable pattern or correlation among GCA and SCA effects. While these results confirm current strategies in Douglas-fir breeding to select primarily on GCA, there are opportunities to utilize SCA variance in the production population. Controlled matings for elite production populations are now common in coastal Douglas-fir improvement programmes, and controlled crossing with specified parents could (i) elevate gains by as much as 3.0% in 12-year volume (assuming competition effects have not biased volume estimates), and (ii) access additional sets of parents that would otherwise be disregarded. Gains for height growth from utilizing SCA are lower, which reflect either (i) lower SCA variances associated with height, or (ii) competition has biased upward volume SCA variance by age 12 (relative to height).

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97. Yeh, F.C. and J.C. Heaman. 1987. Estimating genetic parameters of height growth in seven-year old coastal Douglas-fir from disconnected diallels. *Forest-Science* 33(4): 946-957.

Keywords: genetic tree improvement
genetic relationships
growth

Abstract: A disconnected diallele mating scheme was carried out on 10 sets each of 6 parents. Seedlings were raised at Cowichan Lake Research Station and planted out after 1 yr at 11 plantations in British Columbia where coastal Douglas fir would be a good choice for reforestation. Data on ht. and survival were collected after 7 yr and analysed to partition total phenotypic variation in ht. into portions of additive genetic effect (GCA), dominance genetic effect (SCA), interaction of plantations with additive and dominance genetic effects, residual effect and random error. The GCA of the parents within the sets was highly significant and its variance was the most important source of genetic variation. The GCA by plantation interaction was large and its variance was approx. 42% of the GCA variance. Effects due to SCA of parent trees and SCA by plantation interaction were also significant, but their variances were small in comparison with the GCA variance. The heritability estimate for 7-yr ht. was 0.13. Results are discussed in relation to gains to be expected from the improvement of this species.

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98. Zhang, J.W., J.D. Marshall and B.C. Jaquish. 1993. Genetic differentiation in carbon isotope discrimination and gas exchange in *Pseudotsuga menziesii*. A common garden experiment. *Oecologia* 93(1): 80-87.

Keywords: genetic tree improvement
photosynthesis
tree physiology

Abstract: Seeds were collected in 1966 from 25 naturally regenerated Douglas fir (*Pseudotsuga menziesii*) stands across its range in the USA and Canada (from 33 degrees 30' N to 53 degrees 12' N), from 170 m to 2930 m altitude, and from coastal and interior sites. Seeds were sown in spring 1972, and at 3 yr old seedlings were transplanted to the Trinity Valley tree breeding site, British Columbia. Photosynthesis (A), stomatal conductance to water vapour (g) and the ratio of intercellular to ambient CO₂ (c_i/c_a) were measured between 09.00 and 16.00 h on 30 May, 18 July and 1 September 1990. Light levels were above saturation for photosynthesis on these days. The relative abundance of ¹³C and ¹²C (carbon isotope discrimination; Δ) ranged from 19.7‰ to 22.43‰ and was closely related to geographic location of seed source. There were no significant differences in Δ between the coastal and interior varieties. Most variation occurred within the interior variety; populations from the southern Rocky Mountains had the greatest discrimination (21.53%) and the lowest water use efficiency. Δ , g , c_i/c_a and intrinsic water use efficiency (A/g) were all correlated with altitude of origin and height and diameter at 15 yr. Observed patterns in the common garden did not conform to expectations of higher water use efficiency (measured by both A/g and Δ) in trees from the drier habitats of the interior, nor did they agree with published in situ observations of decreasing g and Δ with altitude. The genetic effect counteracts the altitudinal effect, leading to some degree of homeostasis in physiological characteristics in situ.

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