Pacific Northwest Tree Improvement Research Cooperative

Annual Report
2007-2008

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Longview Timber Company

Olympic Resource Management

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About the PNWTIRC

The Pacific Northwest Tree Improvement Research Cooperative (PNWTIRC) was formed in 1983 to conduct research in support of operational tree improvement in the Pacific Northwest. Emphasis is on region-wide topics dealing with major coniferous species. Membership has included representatives from public agencies and private forestry companies in western Oregon, western Washington, and coastal British Columbia.

Our Mission is to:

- Create a knowledge base concerning genetic improvement and breeding of Pacific Northwest tree species
- Develop reliable, simple, and cost-effective genetic improvement methods and apply these methods to solve tree-breeding problems
- Promote effective collaboration and communication among public agencies and private industries engaged in tree improvement in the region

All participants provide guidance and receive early access to research results. Regular and Associate members provide financial and in-kind support and are represented on the Policy/Technical Committee. This committee is responsible for making decisions on program strategy and support, identifying research problems, establishing priorities, and assisting in the planning, implementation and evaluation of studies. Because Contractual Participants provide less financial support, they have no voting rights on the Policy/Technical Committee. Liaison Members provide no financial support and have no voting rights. The PNWTIRC is housed in the Department of Forest Science at Oregon State University.

DIRECTOR: GLENN HOWE

ASSISTANT DIRECTOR: MARILYN CHERRY

POLICY/TECHNICAL COMMITTEE CHAIR: RANDALL GREGGS

GRADUATE STUDENT: VIKAS VIKRAM

HIGHLIGHTS OF 2007-2008

- We published the second PNWTIRC Report on the Wood Quality Study entitled "Genetic variation in direct and indirect measures of wood stiffness in coastal Douglas-fir." A manuscript was submitted to the Canadian Journal of Forest Research.

- We estimated genetic gains in bending stiffness (MOE_{bl}) of 8.6% to 12.3%. Relative efficiencies (REs), the relative gains in MOE_{bl} expected from indirect selection for correlated traits, were 78% to 93% for traits measured with the log acoustic tool (HM200), 57% to 58% for traits measured with the standing-tree acoustic tool (ST300), 38% for the basic wood density of basal discs (Den_{bd}), and 98% for the oven-dry density of logs estimated from the lumber (Den_{ol}). The HM200 is an efficient tool for improving MOE_{bl}, but gains will be lower using the ST300 on standing trees. Indirect selection on Den_{bd} should be used with caution because the RE was low and Den_{bd} was negatively correlated with growth (-0.49 to -0.73).

- In the Miniaturized Seed Orchard Study, we continued the pruning treatments and collected flowering data in the spring of 2008 at Roseburg Forest Product's Vaughn seed orchard in Lebanon. The timing of pruning seems to influence the numbers of female and male flowers in relation to the volume of the crown. Seed orchard maintenance continued at the other orchards.

- PNWTIRC personnel completed two journal articles and reports (i.e., published or in press) and gave four presentations (see Appendices 1-2).

- We co-organized three technology transfer events: Annual Meeting of the Center for Advanced Forestry Systems, Wood Quality Research Workshop, and the Conifer Translational Genomics Network Workshop.

MESSAGE FROM THE DIRECTOR

The PNWTIRC has become increasingly involved in grant-funded collaborative research, including the Center for Advanced Forestry Systems (CAFS), Conifer Translational Genomics Network (CTGN), and the Taskforce on Adapting Forests to Climate Change (TAFCC). These projects are supported by external funds, but also rely on cash and in-kind support from PNWTIRC members. The Center for Advanced Forestry Systems (CAFS) is a multi-university project within the NSF Industry/University Cooperative Research Center Program. The mission of CAFS is to optimize genetic and cultural systems for producing forest products by integrating research at the molecular, cellular, individual-tree, stand, and ecosystem levels. CAFS funds will be augmented by PNWTIRC funds to support a graduate student working on a project entitled "Effects of site and genetics on Douglas-fir growth, stem quality, and adaptability." The goal of the Taskforce on Adapting Forests to Climate Change (TAFCC) is to develop strategies that forest managers can use to maintain healthy and productive forests in the face of climate change. We hired a Director to oversee this project who will be supported by external funds and additional project-specific funds contributed by PNWTIRC members. The Conifer Translational Genomics Network (CTGN) is a USDA-funded project that seeks to bring marker-based breeding to application in U.S. tree breeding programs within the next five years. External funds will be used to obtain molecular marker genotypes in Douglas-fir breeding programs and to augment existing measurements with new measurements of wood stiffness, vegetative bud phenology, and flowering phenology. Members of the PNWTIRC and Northwest Tree Improvement Cooperative will provide Douglas-fir trees for genotyping, existing data, and additional in-kind support. In the past, almost all PNWTIRC research was undertaken using contributions from members. The trend toward supporting tree breeding research with external funds will become increasingly important, however, because PNWTIRC dues haven't kept pace with the increasing costs of research and member needs. Although we can use external funds to expand our research program, PNWTIRC members lose some control when research priorities must be aligned with collaborators and external granting agencies. Nonetheless, I see this as an encouraging and probably necessary trend. By melding external grant funds with member dues, we can expand our research program, keep member costs low, better integrate applied and basic research, and better train the next generation of tree breeders and forest geneticists. Furthermore, without cooperatives like the PNWTIRC, we couldn't have participated in the CAFS and CTGN projects, and these opportunities would have been lost to researchers in the Pacific Northwest. I hope we can be as successful in the future as we were this past year.

Glenn Howe

TECHNOLOGY TRANSFER

Our technology transfer efforts include distribution of cooperative research reports, meetings with cooperators, annual meetings, annual reports, and workshops. Last year, we published a PNWTIRC Report entitled "Genetic variation in direct and indirect measures of wood stiffness in coastal Douglas-fir," which is the second report from our Wood Quality Study. We also co-organized three workshops and meetings (in addition to the PNWTIRC Annual Meeting). The first Annual Meeting of the Center for Advanced Forestry Systems was held on February 20-21, 2008 in Portland OR, and included a field trip to forest research sites and a log sort yard. We also co-organized a workshop entitled "Wood Quality Research," which was held on May 28, 2008. The agenda for this workshop, which included results from our wood stiffness research, is presented in Table 1. Finally, we presented a workshop on the Conifer Translational Genomics Network on June 25, 2008, which was held in conjunction with this year's PNWTIRC annual meeting. The agenda for this workshop is presented in Table 2.

Table 1. Agenda for the Wood Quality Research workshop held on May 28, 2008.∗

Speaker	Topic
Tony Zhang	Enhancing wood quality attributes and stand value through intensive forest management
Barb Lachenbruch	Factors associated with stiffness and strength in Douglas-fir
David Briggs	Estimating wood stiffness along the tree-to-product chain: Tools, relationships, and silviculture influences
Glenn Howe	Genetics of Douglas-fir wood stiffness: Acoustic tools, bending stiffness, and candidate gene markers
Keith Jayawickrama	Selecting for wood stiffness in cooperative Douglas-fir genetic improvement programs: Context, lessons from other conifers, pros and cons, and non-genetic alternatives
Glen Murphy	Prospects for segregating logs during harvesting based on wood density and stiffness
All speakers	Panel discussion and wrap-up

∗ Workshop was co-organized by the PNWTIRC, Northwest Tree Improvement Cooperative, Stand Management Cooperative, and the Western Forestry Conservation Association.

Table 2. Agenda for the Conifer Translational Genomics Network workshop held on June 25, 2008.∗

Speaker	Topic
Glenn Howe	Welcome and introductions
Dave Harry	Genetic markers: Background and applications
Nick Wheeler	Marker applications in tree improvement
Nick Wheeler	Conifer Translational Genomics Network (CTGN)
Keith Jayawickrama	CTGN and the Northwest Tree Improvement Cooperative
Glenn Howe	Douglas-fir CTGN research
Michael Coe	Workshop evaluation
Glenn Howe	Discussion and action items

∗ Workshop was co-organized by Conifer Translational Genomics Network and the PNWTIRC

Wood Quality Study

Introduction

Wood stiffness is one of the most important properties of structural lumber, and has been identified as a high priority research topic by PNWTIRC members. Because corewood (wood from the inner core of a tree) is less stiff than the outerwood, the quality of Douglas-fir wood products may decline as rotation lengths decrease and proportionally more of the wood is derived from the inner core (Megraw 1985; Kretshmann et al. 1993). Therefore, breeders are becoming interested in either maintaining or improving wood stiffness in breeding programs that typically focus on improving volume growth. Because wood properties are genetically variable and often highly heritable, it may be valuable to incorporate wood stiffness into Douglas-fir breeding programs (Howe et al. 2006).

Objectives of the Wood Quality Study

Our objectives are to:

- Estimate potential genetic gains for direct measures of Douglas-fir wood stiffness (modulus of elasticity, MOE)
- Determine which indirect measurements of MOE are useful for improving wood stiffness in operational tree improvement programs, and to estimate the relative gain efficiencies of the various indirect measures tested
- Determine whether the wood properties of seed orchard parents can be used to predict the wood properties of their progeny
- Identify molecular genetic markers that are associated with desirable wood properties

Until recently, it has been difficult to measure wood stiffness on the numbers of trees needed to understand the quantitative genetics of wood stiffness and to precisely estimate breeding values. Direct estimates of wood stiffness (modulus of elasticity, MOE) can be obtained by applying a load to a wood sample and measuring the wood's resistance to deflection (Carter et al. 2005), but these bending tests are time consuming, costly, and difficult to perform on standing trees (but see Launay et al. 2002). In contrast, acoustic tools are now available that can be used to quickly estimate the stiffness of wood in standing trees or logs in the field. Indirect estimates of bending stiffness can be obtained by measuring green wood density and the velocity of acoustic waves traveling through the wood, and then calculating acoustic MOE using one dimensional wave theory (acoustic MOE = green wood density*velocity^2) (Pellerin and Ross 2002).

Field tools for estimating acoustic velocity have been developed, providing new opportunities to enhance wood stiffness via tree breeding and stand management (Kumar et al. 2002, 2006; Briggs et al. 2005). The Fibre-gen Director HM200™ (HM200) can be used to measure acoustic velocity and estimate the stiffness of logs, whereas the Fibre-gen Director ST300™ (ST300) can be used on standing trees (http://www.fibre-gen.com/products.html). If these traits are highly correlated with bending stiffness, breeders may want to select for acoustic velocity and acoustic MOE to improve bending stiffness.

The ST300 measures the time-of-flight (TOF) for a single acoustic wave passing through the outerwood of a standing tree between a transmitter probe and a receiver probe (Carter et al. 2005). The HM200 estimates the acoustic velocity from the resonant frequencies created by repeated acoustic echoing

ACOUSTIC TOOLS CAN BE USED TO ESTIMATE WOOD STIFFNESS (MOE)

$MOE_d = Den * Vel^2 * 10^{-9}$ where:

MOE_d = dynamic modulus of elasticity (GPa)
Den = wood density (kg m^{-3})
Vel = acoustic wave velocity (m s^{-1})

Fibre-gen Director HM200

The HM200 is used to estimate the stiffness of logs. A hammer is used to strike the end of the log, creating a soundwave that travels back and forth between the two log ends. The HM200 uses the resonant frequency of the soundwave and the log length to estimate the acoustic velocity. Stiffness (MOE) can then be estimated from the acoustic velocity and wood density. For details visit http://www.fibre-gen.com/hm200.html.

Fibre-gen Director ST300

The ST300 is designed to be used on standing trees. The ST300 uses ultrasound technology to automatically measure the distance between two pins that are inserted into the bole about 1 meter apart. The transmitter probe is hit with a hammer, and the receiver probe measures the time for the soundwave to arrive. Because the pins are inserted only a small distance into the wood, the ST300 measures wood stiffness in the outer rings of the bole. For details visit http://www.fibre-gen.com/st300.html.

between the two ends of a log. Because the ST300 only measures acoustic velocity of the outer, generally stiffer wood of the tree, it tends to overestimate the stiffness of the entire log, and may be sensitive to large knots and branches, especially in small-diameter trees (Briggs et al. 2007). In contrast, the HM200 measures acoustic velocity of the entire log, thereby capturing information on both the stiffer outerwood and less stiff corewood.

There is limited information on the genetics of wood stiffness in coastal Douglas-fir. Previous studies of Douglas-fir wood properties focused mainly on wood density, which is under moderate to high genetic control (McKimmy 1966; King et al. 1988; Vargas-Hernandez and Adams 1991, 1992; Koshy 1993; Johnson and Gartner 2006). Because wood density has a moderate negative genetic correlation with tree growth, breeders have been concerned that selection for increased growth will lead to a decline in wood quality (King et al. 1988; Vargas-Hernandez and Adams 1991; Koshy 1993; Johnson and Gartner 2006). More recently, genetic studies of other Douglas-fir wood properties have been reported, including acoustic MOE. Using the HM200, moderate heritabilities were found for acoustic MOE in a test of 39 wind-pollinated families at four test locations (Johnson and Gartner 2006).

The *Wood Quality Study* was approved by PNWTIRC members at the 2005 Annual Meeting. Collaborating organizations include the University of Washington Stand Management Cooperative (SMC), the University of California at Davis (UC Davis), Olympic Resource Management (ORM), and the USDA Forest Service Pacific Northwest Research Station (PNWRS). We studied wood stiffness and other traits in three wind-pollinated first-generation progeny test plantations. We used the HM200 and ST300 to measure acoustic MOE, and bending tests to measure bending MOE on lumber milled from a subset of the trees harvested at one of the progeny test locations.

PLANT MATERIALS

We measured wood traits in three progeny tests and one seed orchard owned by Olympic Resource Management. In last year's annual report, we presented results from our analyses of acoustic MOE measured in the Hood Canal Seed Orchard (Howe and Cherry 2007). The progeny tests (Shine, Watershed, and Opsata) are part of the Port Gamble first-generation progeny test series owned and managed by Olympic Resource Management. These tests, which are located on the Kitsap and Olympic Peninsulas of northern Washington, were systematically thinned when the trees were 25 years old, giving us the opportunity to (1) destructively measure bending stiffness and (2) estimate acoustic velocity on both standing trees and logs. At each test site, 8 blocks were nested within each of 4 sets consisting of 30 to 40 families apiece (130 families in total). Within each block, 4 trees per family were randomly planted at a spacing of 10x10 feet.

MEASUREMENTS

Diameter at breast height (cm) was measured on all trees at ages 13 (DBH_{13}) and 25 (DBH_{25}) prior to thinning. Tree height (m) was measured at age 13 (Ht_{13}). Tree stem taper at age 13 ($Taper_{13}$, cm m^{-1}) was estimated as $DBH_{13}/(Ht_{13}$-1.4 m), and volume at the same age (Vol_{13}, m^3) was estimated as $(\pi / 40{,}000) * DBH_{13}^2 * Ht_{13}$.

Wood disks were cut from the base (~0.3 m from the ground) of every butt log at Shine, and then used to measure green wood density (Den_{gd}, kg m^{-3}), basic wood density (Den_{bd}, kg m^{-3}), and moisture content (MC, %). Prior to harvesting, the ST300 was used to measure acoustic velocity (Vel_{ST}) on a subset of trees that were to be thinned at Shine and Opsata. Eight trees in each of 12 to 13 families were measured per set at each location. Vel_{ST} was measured near breast height using probes spaced about 1 m apart on two opposite sides of the stem, with 3 measures taken per side. These values were later averaged to obtain one Vel_{ST} value per tree. After harvesting, we used Den_{gd} to calculate acoustic MOE (MOE_{ST}) for the trees at Shine. We used the HM200 to measure acoustic velocity (Vel_{HM}) on the basal log of each thinned tree at Shine and Watershed, and acoustic MOE (MOE_{HM}) at Shine. One acoustic measurement was recorded on each delimbed log according to the manufacturer's instructions, and the length of each log, which varied from 2.0 to 12.2 m, was measured. We used Den_{gd} plus either Vel_{HM} or Vel_{ST} to estimate MOE_{HM} or MOE_{ST} from the one-dimensional wave equation: MOE (GPa) = $Den_{gd} * Vel^2 * 10^{-9}$, where Den_{gd} is green wood density (kg m^{-3}) and Vel is acoustic velocity (m s^{-1}) (Carter et al. 2005).

The trees measured with the ST300 at Shine were also used for milling the basal logs into 2x4s (~1.5″x3.5″x7′). The basal logs were shipped to Oregon State University (OSU), and then milled into 2x4s using a WoodMizer portable sawmill. One to ten 2x4s were obtained from each log. Lumber oven dry density (kg m^{-3}) was estimated for each 2x4, and the average lumber density of each tree (Den_{ol}, kg m^{-3}) was then obtained by averaging the densities of all 2x4s per tree. Bending MOE (MOE_{bl}, GPa) of each 2x4 was measured using a 4-point bending test (third-point loading) at the OSU Wood Engineering Laboratory with a 40 kip MTS Model 332.21 Universal Testing Machine (MTS Systems Corp.). The MOE_{bl} for each log was then obtained by averaging the values for all corresponding 2x4s.

RESULTS AND DISCUSSION

HERITABILITIES

To estimate heritabilities and genetic gains, the additive genetic variation was estimated as $3\sigma^2_{f(s)}$ to account for possible relatedness between the open-pollinated progeny ($\sigma^2_{f(s)}$ is the family-within-set variance component). Therefore, our heritabilities and genetic gains are only 75% of the values that would be obtained if one assumes that the additive genetic variation equals $4\sigma^2_{f(s)}$, which is a common alternative approach. Because different traits were measured on different numbers of trees (Table 3), we estimated family heritabilities ($h^2_{f(s)}$) and genetic gains (ΔG) assuming that family means were based on 12.3 trees per family and site. That way, we can compare family heritabilities among traits.

Wood bending stiffness, acoustic velocity, acoustic MOE, and wood density were all heritable (Table 3). Wood properties had moderate heritabilities at the Shine progeny test. Individual-tree heritabilities (h^2_i) ranged from 0.23 to 0.43, whereas family heritabilities ranged from 0.45 to 0.63. The among-site heritability for Vel_{HM} was similar to the single-site heritability, but not for Vel_{ST}.

Genetic Correlations

We estimated genetic, environmental, and phenotypic correlations for selected pairs of traits, focusing on correlations between (1) direct versus indirect measures of stiffness, (2) acoustic measures of stiffness measured with the HM200 versus the ST300, (3) acoustic measures of stiffness estimated with versus without Den_{gd}, (4) stiffness versus wood density, and (5) wood properties versus growth (Tables 4 and 5).

Genetic correlations between the acoustic traits and bending stiffness (MOE_{bl}, our target trait) can be used to judge the value of using the HM200 and ST300 to indirectly select for bending stiffness. The genetic correlation between MOE_{bl} and MOE_{HM} was extremely high (r_A = 0.92, Table 4), and higher than the genetic correlation between MOE_{bl} and Vel_{HM} (0.75). These values indicate that the HM200 should be a valuable tool for estimating breeding values for wood stiffness, even if wood density is not measured. Although the genetic correlations between MOE_{bl} and the ST300 traits (MOE_{ST}, Vel_{ST}) were moderate (0.53 to 0.57), this tool should also be useful when the trees cannot be cut down.

*Table 3. Sample sizes, descriptive statistics, and heritabilities of traits measured at the Port Gamble progeny test locations.**

	MOE_{bl} (GPa)	MOE_{HM} (GPa)	MOE_{ST} (GPa)	Vel_{HM} (m s^{-1})	Vel_{ST} (m s^{-1})	Den_{gd} (kg m^{-3})	Den_{bd} (kg m^{-3})	Den_{ol} (kg m^{-3})	MC (%)	DBH_{25} (cm)
Sample sizes										
Number of locations	1	1	1	2	2	1	1	1	1	3
Number of families	50	127	50	129	50	127	127	50	127	130
Number of trees	371	1422	339	2906	800	1571	1409	372	1408	9421
Trees / family	7.4	11.2	6.8	22.5	16.0	12.4	11.1	7.4	11.1	72.5
Trees / family / location	7.4	11.2	6.8	11.2	8.0	12.4	11.1	7.4	11.1	24.2
Family means and variation (single-site)										
Mean	10.8	9.7	12.4	3433	3865	817.7	473.3	477.0	73.6	21.4
Minimum	9.8	8.4	10.9	3260	3586	771.2	431.0	445.1	63.6	18.2
Maximum	12.9	11.1	14.6	3751	4081	871.6	525.7	529.8	84.3	24.5
CPV (%)†	5.4	5.6	7.0	2.4	3.1	2.4	3.3	3.6	6.0	6.0
CGV (%)†	3.6	3.9	4.1	1.8	2.1	1.7	2.4	2.5	4.0	4.6
Heritabilities (single-site)										
h^2_i	0.31	0.31	0.30	0.33	0.43	0.26	0.34	0.41	0.23	0.18
$h^2_{F(S)}$	0.53	0.54	0.54	0.56	0.63	0.49	0.57	0.61	0.45	0.40
Heritabilities (multiple-site)										
h^2_i	-	-	-	0.30	0.29	-	-	-	-	0.11
$h^2_{F(S)}$	-	-	-	0.65	0.66	-	-	-	-	0.39

* MOE_{bl} = lumber static bending modulus of elasticity; MOE_{HM} = modulus of elasticity estimated using Vel_{HM} and Den_{gd}; MOE_{ST} = modulus of elasticity estimated using Vel_{ST} and Den_{gd}; Vel_{HM} = acoustic velocity measured by HM200; Vel_{ST} = acoustic velocity measured by ST300; Den_{gd} = green wood density of basal disks; Den_{bd} = basic wood density of basal disks; Den_{ol} = ovendry density of 2x4s; MC = green wood moisture content of basal disks; DBH_{25} = diameter at breast height at age 25.

† CPV = coefficient of phenotypic variation; CGV = coefficient of genetic variation.

*Table 4. Narrow-sense genetic (r_A), environmental (r_E), and phenotypic (r_P) correlations between wood property traits at the Shine progeny test location.**

Trait 1	Trait 2	Families	Trees	r_A	r_E	r_P
Direct (MOE_{bl}) vs indirect estimates of wood stiffness						
MOE_{bl}	MOE_{HM}	50	282	0.92	0.62	0.65
MOE_{bl}	MOE_{ST}	50	304	0.57	0.44	0.45
MOE_{bl}	Vel_{HM}	50	338	0.75	0.54	0.56
MOE_{bl}	Vel_{ST}	50	364	0.53	0.33	0.35
MOE_{bl}	Den_{bd}	50	307	0.37	0.51	0.50
MOE_{bl}	Den_{ol}	50	370	0.91	0.64	0.67
HM200 vs ST300						
MOE_{HM}	MOE_{ST}	50	308	0.93	0.57	0.61
Vel_{HM}	Vel_{ST}	50	367	0.94	0.36	0.44
Acoustic measures of stiffness estimated with vs without Den_{gd}						
MOE_{HM}	Vel_{HM}	127	1422	0.92	0.87	0.87
MOE_{ST}	Vel_{ST}	50	339	0.92	0.91	0.90
Acoustic measures of stiffness vs density						
MOE_{HM}	Den_{bd}	127	1274	0.66	0.52	0.53
MOE_{HM}	Den_{ol}	50	281	0.68	0.44	0.46
Vel_{HM}	Den_{bd}	127	1275	0.41	0.25	0.27
Vel_{HM}	Den_{ol}	50	338	0.66	0.34	0.38

*MOE_{bl} = lumber static bending modulus of elasticity; MOE_{HM} = modulus of elasticity estimated using Vel_{HM} and Den_{gd} (green wood density of basal disks); MOE_{ST} = modulus of elasticity estimated using Vel_{ST} and Den_{gd}; Vel_{HM} = acoustic velocity measured by HM200; Vel_{ST} = acoustic velocity measured by ST300; Den_{bd} = basic wood density of basal disks; Den_{ol} = ovendry density of 2x4s.

Another way to compare the two different tools is to look at the correlations between them. The genetic correlations between the acoustic MOEs (MOE_{HM} versus MOE_{ST}) and between the acoustic velocities (Vel_{HM} versus Vel_{ST}) were extremely high (0.93 to 0.94, Table 4), indicating that the tools are fairly comparable. Furthermore, the acoustic velocities (Vel_{HM} and Vel_{ST}) were highly correlated with the acoustic MOEs (MOE_{HM} and MOE_{ST}), also indicating that it may be desirable, but not necessary, to measure wood density. The r_A between acoustic velocity and acoustic MOE was 0.92 for both the HM200 and ST300.

To what extent can wood density be used to improve wood stiffness? The genetic correlation between lumber density (Den_{ol}) and bending stiffness (MOE_{bl}) was very high (r_A = 0.91), and much larger than the correlation between disk density (Den_{bd}) and MOE_{bl} (r_A = 0.37) (Table 4). These results seem to indicate that wood density may be a good indirect measure of wood stiffness if one can obtain a good estimate of log density. However, density estimated from a wood disk collected at the base of the tree does not seem to

...the HM200 should be a valuable tool for estimating breeding values for wood stiffness, even if wood density is not measured.

be highly genetically correlated with bending stiffness. The relationship between wood density and bending stiffness (including density estimated from increment cores) deserves further study.

The genetic correlations between bending stiffness (MOE_{bl}) and the growth traits (DBH_{25}, DBH_{13}, Ht_{13}, and Vol_{13}) were weakly to moderately positive (0.10 to 0.46, Table 5), and the genetic correlations between Vel_{HM} and the growth traits were near-zero or weakly negative. Although previous results in Douglas-fir have consistently demonstrated strong negative genetic correlations between growth and wood density, these results suggest that the correlation between bending stiffness and growth is weak at best. In contrast, the genetic correlations between MOE_{HM} and the growth traits (-0.55 to -0.87) were stronger, consistently negative, and not substantially different from the correlations between Den_{bd} and the growth traits (-0.49 to -0.73). Because wood density is used to calculate MOE_{HM}, this negative relationship may be mostly driven by the negative genetic correlation between growth and wood density. In contrast, the genetic correlations between Den_{ol} and the growth traits were near zero or weakly negative (r_A = -0.01 to -0.22), and the reason for this difference is unclear. In summary, the genetic correlations differed depending on whether disk density or lumber density were used, indicating that this topic deserves additional study.

GENETIC GAINS

Estimates of genetic gain integrate information on trait heritability, genetic correlations between the measured trait and the target trait (bending stiffness), and levels of genetic variation. Potential genetic gains were estimated assuming that the parents would be selected among all available sets, and that the selected genotypes would be placed in a grafted wind-pollinated seed orchard with random mating and no pollen contamination. Gains from parental selection were estimated based on choosing (1) the best 25 of 200 parents (selection intensity of 12.5%; i_f of 1.636 for n = 200), or (2) the best 25 of 1,000 parents (selection intensity of 2.5%; i_f of 2.338 for n = 1,000) (Falconer and Mackay 1996). The second scenario assumes that the parents from 5 first-generation programs are combined, which is realistic given the recent expansion of the second-generation breeding zones for the Northwest Tree Improvement Cooperative breeding programs (Howe et al. 2006).

Gains from parental (backward) selection were 12.3% for MOE_{bl} (2.5% selection intensity), and were only slightly lower than the estimated gains in

*Table 5. Narrow-sense genetic (r_A) correlations for wood properties vs growth traits measured at the Port Gamble progeny test locations.**

	DBH_{25}	DBH_{13}	Ht_{13}	Vol_{13}	$Taper_{13}$
MOE_{bl}	0.10	0.18	0.46	0.20	-0.23
MOE_{HM}	-0.55	-0.75	-0.65	-0.87	-0.00
Vel_{HM}	-0.20	0.02	0.08	0.06	-0.15
Den_{bd}	-0.49	-0.59	-0.52	-0.73	-0.07
Den_{ol}	-0.01	-0.19	-0.05	-0.18	-0.22

* MOE_{bl} = lumber static bending modulus of elasticity; MOE_{HM} = modulus of elasticity estimated using Vel_{HM} and Den_{gd} (green wood density of basal disks); Vel_{HM} = acoustic velocity measured by HM200; Den_{bd} = basic wood density of basal disks; Den_{ol} = ovendry density of 2x4s; DBH_{25} = diameter at breast height at age 25; DBH_{13} = diameter at breast height at age 13; Ht_{13} = height at age 13; Vol_{13} = stem volume at age 13; $Taper_{13}$ = stem taper at age 13.

MOE_{HM} (13.6%) and MOE_{ST} (13.9%) (Table 6). Gains in Den_{bd} were considerably lower (8.6%). Gains from progeny (forward) selection based on combined family and within-family performance (i.e., choosing the best individual of 100 progeny from each of the selected families) were approximately equal to those from backward selection (data not shown).

Relative Efficiency

The correlated response to indirect selection (ΔCR) is the gain that will be achieved in bending stiffness (MOE_{bl}) when selection is based on a second, correlated trait that is used as an indirect selection criterion. We also estimated relative gain efficiencies (RE) for improving bending stiffness via backward selection. RE indicates the percentage gain that can be achieved in MOE_{bl} by indirectly selecting on a correlated trait, such as acoustic velocity, relative to the gain that can be obtained by directly selecting for MOE_{bl}. If selections were based on acoustic MOE, the indirect gains in MOE_{bl} would be about 93% (MOE_{HM}) or 57% (MOE_{ST}) of the gains resulting from direct selection on MOE_{bl} itself (Table 6). If selections were based on acoustic velocity, the RE for MOE_{bl} would be about 78% for Vel_{HM} and 58% for Vel_{ST}. If selections were based on wood density, the RE for MOE_{bl} would be about 38% for Den_{bd} and 98% for Den_{ol}. If selections were based on DBH_{25}, changes in MOE_{bl} would be positive but low (RE = 9% for backward selection). Under a reverse scenario, with selection based on MOE_{bl}, changes in DBH_{25} would also be positive and low (RE = 12%; data not shown). However, if selections were based on Den_{bd}, the indirect response in DBH_{25} would be moderately negative (RE = -64%; data not shown).

*Table 6. Genetic gains, correlated responses to selection, and relative efficiencies for backward selection of parents based on progeny performance in the Port Gamble progeny test.**

Parental selection intensity (%)	MOE_{bl} (GPa)	MOE_{HM} (GPa)	MOE_{ST} (GPa)	Vel_{HM} ($m\ s^{-1}$)	Vel_{ST} ($m\ s^{-1}$)	Den_{gd} ($kg\ m^{-3}$)	Den_{bd} ($kg\ m^{-3}$)	Den_{ol} ($kg\ m^{-3}$)	MC (%)	DBH_{25} (cm)
Gain from direct backward selection (ΔG, %)										
12.5	8.6	9.5	9.7	4.4	5.5	3.9	6.0	6.4	8.9	9.5
2.5	12.3	13.6	13.9	6.3	7.8	5.6	8.6	9.1	12.7	13.6
Correlated response in MOE_{bl} from indirect backward selection (ΔCR, %) †										
12.5	8.6	8.0	4.9	6.7	4.9	0.7	3.3	8.4	1.6	0.7
2.5	12.3	11.4	7.0	9.6	7.1	1.0	4.7	12.0	2.2	1.1
Relative efficiency of indirect backward selection (RE = ΔCR / $\Delta G_{MOE_{bl}}$, %) ‡										
12.5	100.0	93.3	57.4	77.9	57.6	8.5	38.1	97.8	18.3	8.7
2.5	100.0	93.3	57.4	77.9	57.6	8.5	38.1	97.8	18.3	8.7

* MOE_{bl} = lumber static bending modulus of elasticity; MOE_{HM} = modulus of elasticity estimated using Vel_{HM} and Den_{gd}; MOE_{ST} = modulus of elasticity estimated using Vel_{ST} and Den_{gd}; Vel_{HM} = acoustic velocity measured by HM200; Vel_{ST} = acoustic velocity measured by ST300; Den_{gd} = green wood density of basal disks; Den_{bd} = basic wood density of basal disks; Den_{ol} = ovendry density of 2x4s; MC = green wood moisture content; DBH_{25} = diameter at breast height at age 25.

† ΔCR is the correlated response (indirect gain) in MOE_{bl} when selection is based on the listed trait.

‡ Relative efficiency (RE) is the gain in MOE_{bl} obtained by basing selection on a second correlated trait relative to the gain that could be obtained by selecting for MOE_{bl} directly.

SUMMARY AND CONCLUSIONS

- Wood bending stiffness, acoustic measures of wood stiffness, and density are all heritable.
- Substantial genetic gains can be made in bending stiffness (8.6 to 12.3%) and in acoustic MOE (9.5 to 13.9%), and these gains are expected to be larger than gains in wood density (6.0 to 9.1%).
- Acoustic tools can be used to improve wood stiffness. The HM200 is an efficient tool for improving bending stiffness, but requires destructive sampling, whereas the ST300 is less reliable than the HM200, but is nondestructive.
- Gains in wood stiffness may be low when selections are based on measuring the density of basal wood disks (Den_{bd}). Indirect selection on Den_{bd} seems to be disadvantageous because the RE is low, and Den_{bd} is negatively correlated with growth (-0.49 to -0.73).
- There is no strong evidence that selection for growth will have a large adverse impact on bending stiffness.

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PLANS FOR 2008-09

The above results will be reported in a peer-reviewed journal. Statistical analyses of additional lumber traits will continue, including (1) acoustic velocity via the stress wave timer, (2) longitudinal vibration, (3) microfibril angle, and (4) lumber grade. These latter results will be published in Vikas Vikram's M.S. thesis.

Miniaturized Seed Orchard Study

Introduction

The Miniaturized Seed Orchard Study was undertaken to test alternatives to conventional Douglas-fir seed orchards. Miniaturized seed orchards (MSOs) mimic the management of fruit tree crops—seed crops are produced on many small trees instead of fewer, larger trees at wider spacings, which is typical of conventional Douglas-fir orchards. Intensively-managed MSOs have the potential to (1) increase genetic gains by facilitating controlled mass pollination and reducing pollen contamination, and (2) reduce management costs because of the smaller trees. However, they may require more intensive crown management, perhaps involving specialized equipment.

We previously described flower stimulation techniques that are appropriate for young MSOs (Cherry et al 2006). At our strategic planning meeting in December 2007, MSO research was ranked by member representatives as one of the two highest priorities for the PNWTIRC. Within the MSO topic area, pruning treatments and flower stimulation were of most interest for future research.

Objectives of the MSO Study

Our objectives are to:

- Compare three orchard types for seed production and management efficiency
- Define the best age to begin floral stimulation in MSOs
- Evaluate crown control techniques
- Compare pollination methods (e.g., CP, SMP)
- Evaluate clonal response to MSO management regimes

Figure 1. 1x3 meter seed orchard spacing.

Plum Creek Miniaturized Seed Orchard

Design

Our study compares three tree spacings using 24 clones that were grafted between 2002 and 2004 in a Plum Creek Timber Co. seed orchard (Table 7). More details on the objectives, potential advantages, and design of the MSO project, are included in previous PNWTIRC Annual Reports (Howe et al. 2002, 2003; Cherry et al. 2004). Our goal is to compare management regimes on three alternative planting densities (Figures 1-3) at an operational scale that will provide realistic estimates of management costs and seed yields for Douglas-fir (Anekonda and Adams 1999).

Accomplishments for 2007-08

The trees at the Plum Creek seed orchard are being managed and maintained until they are large enough to begin experimental treatments. Ongoing site maintenance by Plum Creek included weed control, irrigation, fertilization, and rootstock removal. In the 1x3 and 2x4 spacings, trees above the target heights were top-pruned to maintain the desired height (Table 7).

Figure 2. 2x4 meter seed orchard spacing.

Figure 3. 4x6 meter seed orchard spacing.

A cone crop was collected in the fall of 2007. Although the orchard was not stimulated, most clones produced cones. Altogether, 6,500 cones were produced. The 2x4 m spacing produced the most cones (4,100 cones per hectare), compared to 2,800 in the 1x3 and 2,400 in the 4x6 m spacings (Fig. 4).

MSO research was ranked by member representatives as one of the two highest priorities for the PNWTIRC

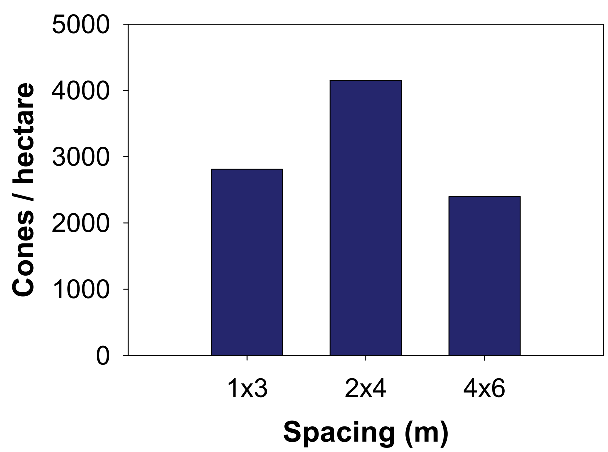


Figure 4. Cones per hectare in 2007 in the 1x3, 2x4, and 4x6 orchard spacings.

Table 7. Orchard spacings and current target heights at the Plum Creek MSO.

Orchard type	Spacing (m)	Trees per hectare	Total number of trees	Final height (m)
Macro	4x6	416	640	4
Mini	2x4	1,250	640	3
Micro	1x3	3,333	768	2

PLANS FOR 2008-09

Plans for next year include top-pruning trees that are above target heights and continuing with site maintenance. We will take baseline data on cone production from non-stimulated trees and begin flower stimulation using girdling and $GA_{4/7}$ for the first time in the spring of 2009.

The original MSO study objectives from 1999 assumed that seed orchards would be intensively managed. However, the current trend in seed orchard management is to practice lower levels of management. Therefore, we will convene the MSO Advisory Committee to prioritize research studies for the next few years and revise the original study objectives as needed.

VAUGHN PRUNING STUDY

DESIGN

The pruning study at Roseburg Forest Product's Vaughn Seed Orchard was designed to test the effects of pruning timing and leader retention on crown form and cone production in order to learn about physiological responses to pruning. Early results will guide pruning techniques at the Plum Creek MSO. The Vaughn Seed Orchard contains slightly older, larger trees than the Plum Creek MSO. We assumed that the trees would be pruned every other year (i.e., same 2-year cycle as for flower stimulation), and then hypothesized that cone production would be affected by the timing of pruning in relation to the flower stimulation treatments. Eighteen clones with five to nine previously untopped ramets per clone were included in each of the six treatments (Table 8). The treatments are described in more detail in Table 8 and in Cherry and Howe (2005).

ACCOMPLISHMENTS FOR 2007-08

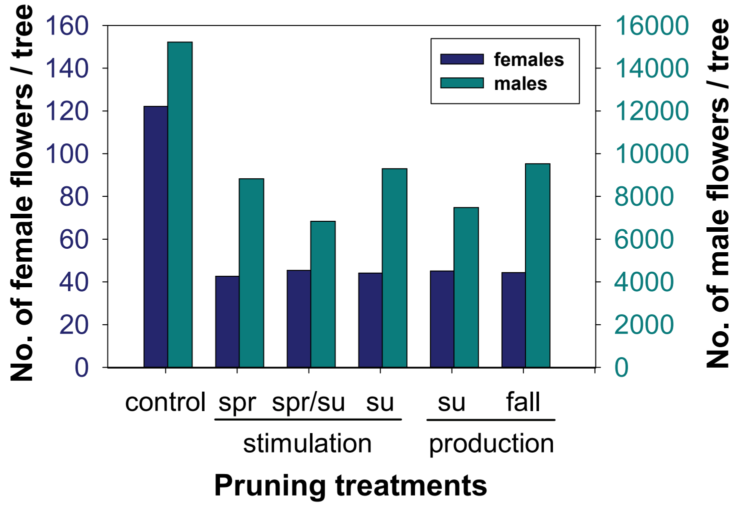
The second cycle of pruning began in 2007 on trees that were last pruned in 2005. During the summer of 2007, the trees in treatment #4 were pruned after bud set. In the spring of 2008, male and female flowers were counted (Fig. 5).

Two to three times as many flowers were produced on the non-pruned trees compared to the pruned trees (Fig. 5), but the unpruned trees also had much larger crowns (Fig. 6). Although there were no large differences in the numbers of female flowers

Table 8. Pruning treatments at the Vaughn Seed Orchard.

Treatment no.	Description of treatments applied every second year
1	Control = no pruning
Treatments in the year of flower stimulation (begun Spring-Summer '05)	
2	Top prune and prune branches before bud flush
3	Prune branches before bud flush; top prune in summer, after bud set
4	Top prune and prune branches in summer, after bud set
Treatments in the year of cone production (begun Summer-Fall '06)	
5	Top prune and prune branches in summer, after bud set
6	Top prune and prune branches in fall, after cone harvest

Figure 5. Male and female flower production by pruning treatment. 'Control' denotes the non-pruned treatment (#1). 'Stimulation' denotes treatments in the year of flower stimulation (spr=#2, spr/su=#3, su=#4). 'Production' denotes treatments in the year of seed production (su=#5, fall=#6) (see Table 8).



per tree among the pruned treatments (Fig. 5), the trees that were pruned after the trees had set bud in year of flower stimulation (treatment #4) had the smallest crowns. As a result, treatment #4 had the greatest number of female flowers per cubic meter of crown volume (2.4, compared to 2.1, 1.9, 1.5, 1.4, and 1.5 for treatments 1, 2, 3, 5, and 6). Although the differences are not large, it may be desirable to use pruning treatment #4 to keep the trees smaller, while still producing the same number of cones per tree. Female flower production was variable across the clones (Fig. 7).

Cumulative tree mortality was tallied and examined by clone and treatment (Fig. 8). In treatment #2 (pruning lateral branches and terminal shoots in the spring prior to bud flush) 17 trees died, or 14% of the total, whereas the other treatments had approximately 7% mortality.

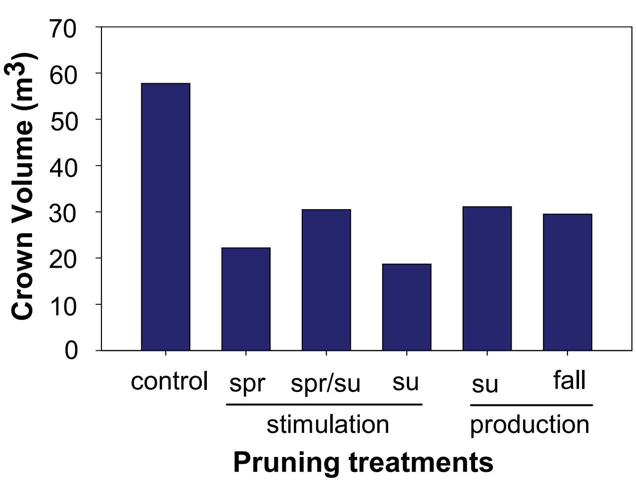


Figure 6. Crown volume by pruning treatment. The number of flowers per cubic meter of crown volume was 2.1, 1.9, 1.5, 2.4, 1.4, and 1.5 for treatments 1 through 6 (see Fig. 5).

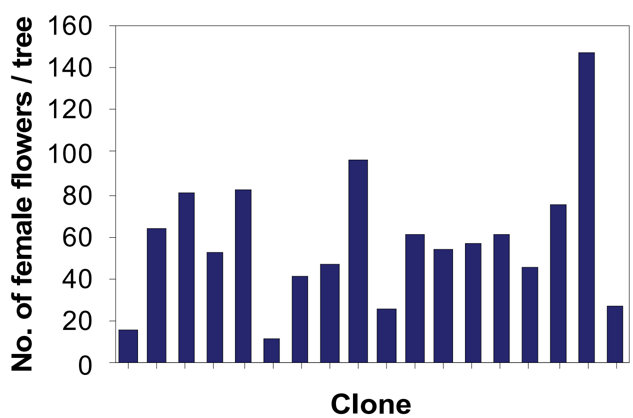


Figure 7. Clonal variation in female flower production.

PLANS FOR 2008-09

Roseburg's Vaughn Seed Orchard will be rogued and converted into a conventional orchard in the fall of 2008. Thus, our study will come to an end. Results from this study indicate that flower production per unit crown volume may be optimized when the trees are pruned in the summer of flower stimulation. In addition, trees pruned in the spring near the time of flower stimulation could experience greater mortality, but this possibility needs further study.

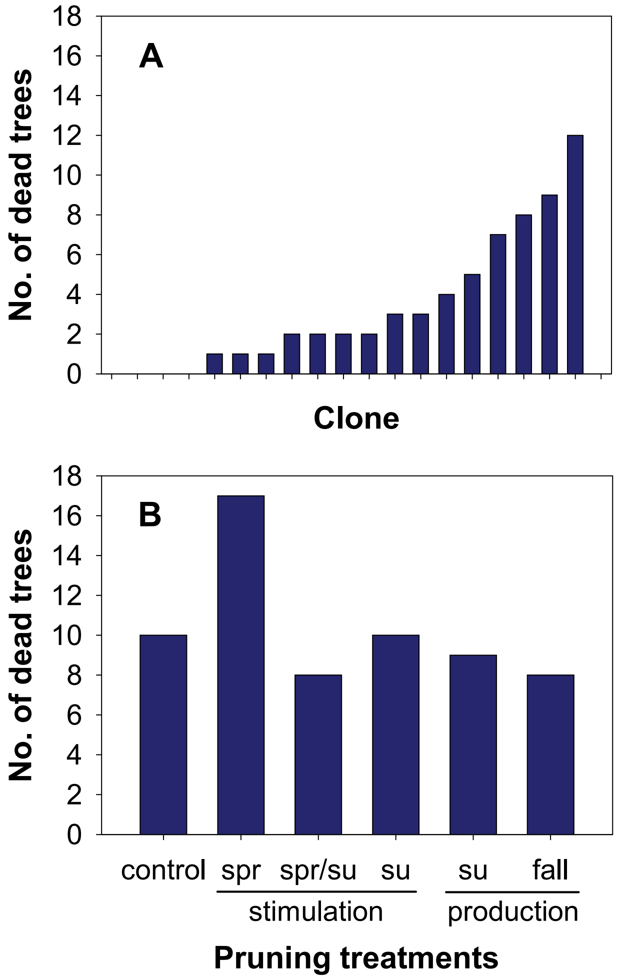


*Figure 8. Mortality by (**A**) clone and (**B**) pruning treatment as of 2008. "Control' denotes the non-pruned treatment (#1). 'Stimulation' denotes treatments in the year of flower stimulation (spr=#2, spr/su=#3, su=#4). 'Production' denotes treatments in the year of seed production*

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APPENDIX 1

PUBLICATIONS BY PNWTIRC PERSONNEL: 2007-2008

Cherry, M.L., Vikram, V., Briggs, D., Cress, D.W., and Howe, G.T. 2007. Genetic variation in direct and indirect measures of wood stiffness in coastal Douglas-fir. PNWTIRC Report #27, 30 pp.

St.Clair, J.B., and Howe, G.T. 2007. Genetic maladaptation of coastal Douglas-fir seedlings to future climates. Global Change Biology 13:1441-1454.

APPENDIX 2

WORKSHOPS, PRESENTATIONS, AND ABSTRACTS BY PNWTIRC PERSONNEL: 2007-2008

Cherry, M.L., Vikram, V., Howe, G.T., Briggs, D., Cress, D., Neale, D., and St. Clair, B. 2008. Genetics of wood quality in Douglas-fir. Invited talk, Inland Empire Tree Improvement Cooperative Annual Meeting, February 27, 2008, Coeur d'Alene, ID.

Howe, G.T., and St.Clair, J.B. 2007. Douglas-fir breeding: Past successes and future challenges. Keynote address and abstract in: Proceedings, Tree Improvement in North America: Past, Present, Future. Joint meeting of the Southern Forest Tree Improvement Conference and the Western Forest Genetics Association, June 19-22, 2007, Galveston, TX.

Howe, G.T., and St.Clair, J.B. 2008. Managing forest genetic resources in changing climates: Analysis and options. In: Building the Future with Oregon's Forests: Policies and Tools for Emerging Issues, Annual Meeting of the Oregon Society of American Foresters, May 7-9, 2008, Eugene, Oregon.

St.Clair, J.B., and Howe, G.T. 2007. Genetic resource management to mitigate the effects of climate change. Keynote address and abstract in: Proceedings, Tree Improvement in North America: Past, Present, Future. Joint meeting of the Southern Forest Tree Improvement Conference and the Western Forest Genetics Association, June 19-22, 2007, Galveston, TX.

APPENDIX 3

PNWTIRC FINANCIAL SUPPORT FOR FISCAL YEAR 2007-2008

Regular members[1]	$104,000
Associate members[1]	4,000
Contracts	2,000
Forest Research Laboratory, Oregon State University[2]	128,130
Total	**238,130**

[1] Each Regular Member contributed $8,000 and each Associate Member contributed $4,000 excluding in-kind contributions of labor, supplies, etc.

[2] The contribution from Oregon State University includes salaries, facility costs, and administrative support.