Northwest Tree Improvement Cooperative

Annual Report

January 1, 2003 to March 31, 2004

August 2004

Oregon State University

Members of the Northwest Tree Improvement Cooperative for the year 2003

Boise Cascade Corp.
British Columbia Ministry of Forests
USDI Bureau of Land Management
Canadian Forest Products, Ltd.
Cascade Timber Consulting, Inc.
Crown Pacific, Ltd.
Hampton Tree Farms, Inc.
Hancock Forest Management
Lone Rock Timber Company
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Moore Mill Timber Company
Oregon State Department of Forestry
Plum Creek Timberlands L.P.
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Port Blakely Tree Farms L.P.
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Roseburg Resources Co.
Seneca Jones Timber Co.
Simpson Resource Co.
South Coast Lumber Co.
Starker Forests, Inc.
Stimson Lumber Co.
The Campbell Group
The Timber Company
Timber West Forest, Ltd.
Washington Department of Natural Resources
Western Forest Products Ltd
Weyerhaeuser Company

Cover photo – Uniform well-managed test sites are a pleasure to visit – South Central Coast metacooperative's 6Gs family block site (Roseburg Resources), two years after planting.

Northwest Tree Improvement Cooperative

A n n u a l R e p o r t

January 1, 2003 to
March 31, 2004

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August 2004

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Cooperative Second-Generation Breeding and Testing of Coastal Douglas-fir

The overall progress and status of the various advanced-generation programs is summarized in Table 1.

Puget Sound

The Puget Sound metacooperative Phase I tests were established successfully on five sites in spring 2003. These sites were all visited in November 2003 (immediately after an early cold front had dropped snow on a large part of western Washington). Survival after the first growing season was very high, but the trees had grown little in height. This was at least partly due to the fact that in order to minimize variation caused by variable numbers of fertilizer prills per cavity, no slow-release fertilizer had been added to the containers. Test installation was coordinated by the Washington Department of Natural Resources, that chose to contribute staff time as their main method of funding their share of the program. This model is to be repeated in other metacoops in which DNR participates.

Washington Cascades (WACTIC) and Washington Coast

Crossing continued for these two metacooperatives. For WACTIC, late snow hindered access in one United States Forest Service orchard, and there was little flowering in another orchard. This slowed crossing for Cowlitz breeding units 3, 4 and 5. Despite this delay, a first sowing for WACTIC in December 2004 seemed feasible, given the progress in the Skagit, Snoqualmie and DNR breeding units and other Cowlitz breeding units. After purchasing Cowlitz land from The Campbell Group, Port Blakely Tree Farms became a member of the Washington Cascades program.

Vernonia/Ryderwood

Seedlings for the second and final phase of this metacooperative were grown at IFA – Nisqually, and outplanted on five sites in March 2004. Nonlocal crosses from Washington Coast, Puget Sound, TRASK, and South Central Coast were included. Based on the experience with the Puget Sound tests, the nursery added a constant amount of slow-release fertilizer to each container after germination. It will be interesting to see the results of this approach.

The Phase I tests were all visited; some test trees exceeded six feet in height after three growing seasons. Mapping errors were corrected on three of the sites and mortality replanted in April 2004 on four sites. The first measurement is likely to occur in 2005 or 2006.

TRASK

Seedlings for TRASK Coast Phase I were grown at Sylvan Vale, and outplanted on six sites in February 2004. This planting included 215 crosses and a woodsrun control from the Astoria district. When visited in April 2004, these seedlings were already flushing vigorously – in the absence of late spring frosts good growth could be expected.

Seed for TRASK Inland Phase I were sent to Sylvan Vale in December 2003. As of March 31, 2004, there appeared to be seedlings from 149 crosses and two woodsrun controls (the same Astoria district control used in TRASK Coast Phase I, and a control used in the Bureau of Land Management's BU-12 test). Non-local crosses from Vernonia/Ryderwood were included.

Five good sites and one back-up site had been located for the Inland Phase I tests, and site preparation was well underway. Stimson Lumber applied herbicides to one of their TRASK Inland sites (Stock Tank) before harvest, the same approach taken the year before by Starker Forests for their TRASK Coast site. The logic for this approach is that some hard-to-kill perennial brush species (eg. salal, vinemaple) with a tendency to resprout are best treated when they have a full complement of foliage to absorb herbicides (i.e. before harvest). The plan is to then give them enough time to translocate the herbicide to the roots, eliminating the problem once and for all.

NOCTIC

Seed for NOCTIC Phase II were sent to Sylvan Vale in December 2003. As of March 31, 2004, there appeared to be seedlings from 178 crosses and three woodsrun controls (one control each used in the Bureau of Land Management's BU-30 and BU-33 tests, and the control used in the Molalla Genetic Gain trial). Non-local crosses from WA Cascades, Puget Sound, Vernonia/Ryderwood, TRASK Inland, and South Central Coast were included. Five good sites had been located for the tests, and site preparation was well underway. NOCTIC opted to use the larger container size (615A) for this sowing. With these large plugs and good weed control, NOCTIC can hope to close the four-year gap between the Phase I and Phase II tests by one or two years.

All the Phase I tests were visited in October 2003. After three growing seasons, some test trees exceeded six feet in height. Cascade Timber Consulting had planted coastal redwood just outside the test, and the redwood trees are currently growing faster than Douglas-fir at 2,400 feet. Whether this trend continues to hold remains to be seen. Mapping errors were corrected on three of the sites, tubes were installed on one site to prevent browse, and mortality was replanted on three sites in April 2004. Due to the slow growth on several of these sites (partly due to elevation) the first measurement may need to be delayed to 2006.

South Central Coast

For the most part, the South Central Coast (SCC) tests grew well during their second growing season. All the sites were visited in October-November 2003. On sites where weeds could be controlled with herbicides, many trees exceeded five feet in total height while the tallest observed was over seven feet tall two years after planting (see Photos). The rapid growth on these productive sites suggested that a first measurement could take place five or even four years after planting.

SCC expanded southward to include the Gold Beach breeding zones during 2003, in conjunction with agreeing to a Phase II sowing. Plum Creek Timber and South Coast Lumber joined, adding 150,000 acres. Further, Plum Creek merged two of its Coos Bay advanced-generation programs (Coastal Low and Interior Low, both established in 1998) to SCC. Along with this change, SCC members agreed to joint access to the data and genetic material from the first-generation programs (including Gold Beach and GP/Plum Creek) contributing to SCC.

The final crossing season was completed in April 2004, with over 40 crosses attempted. These mainly combined the top parents across the first-generation programs ("Elite Semi-Local crosses"), with some crossing also within the Gold Beach I and II programs.

South Central Coast Phase I and II, plus the two Plum Creek programs, add up to over 700 crosses on a total of 20 sites. These will be a rich source of information and genetic material for Douglas-fir, for some very productive lands on the southern Oregon coast.

Table 1. Summary of advanced-Generation Douglas-fir trials established in 2003 and 2004

		Number of			
Program	Entries	Locations	Test Trees	Test Trees + Fillers + Buffers	Purpose
Puget Sound	143 families + 2 woodsrun controls)	5	14,700	19,100	Rank families and parents
TRASK Coast Phase I	215 families + 1 woodsrun controls	6	26,400	36,250	Verify breeding zone(s)
Vernonia/ Ryderwood Phase II	168 families + 2 woodsrun controls	5	15,937	23,684	Make forward selections

Table 2. Status of / plans for cooperative second-generation Douglas-fir breeding populations as of April 2004.

		Number of Local & Semi-Elite Crosses			Test Sites	
	Status	Target	Already Tested or Sufficient Seed	Target no.	Start planting in spring of	Complete planting in spring of
Washington Cascades	Crossing	260	≈150	16	≈2006	≈2010
Puget Sound	Planting 5 sites in 2003 (Phase I, 143crosses)	94	90	10	2003	≈2007
Washington Coast	Crossing	176	≈75	6	≈2008	≈2008
Vernonia/ Ryderwood	Planted 5 sites in 2001 (Phase I, 254 crosses) and 5 sites in	404	400	10	2001	2004
North Oregon Cascades	Planted 6 sites in 2001 (Phase I, 234 crosses), planting 5 sites in 2005 (180 crosses)	414	410	11	2001	2004
Trask (*Coast* + *Inland* + *Swiss Needle Cast elite*)	Planted 6 sites in 2004 (Coast Phase I, 215 crosses). Planting 5 sites (Inland Phase I, 150 crosses) in 2005.	550	427	20	2004	2007
South Central Coast	Planted 6 sites in 2002 (283 Crosses) + 3 Swiss Needle Cast sites + 1 family block planting	760[1]	716[1]	24[1]	1998[1]	2006
TOTAL		***2,658***	***≈2,268***	***97***		

[1] Including Plum Creek's advanced-generation Coos Bay program which was amalgamated to South Central Coast in 2003

Cooperative Second-Generation Breeding and Testing of Western Hemlock

All sites established in 2001 were visited in the fall of 2003. Most sites have shown good survival and growth, with some test trees exceeding 10 feet in height. By summer 2003, height data were collected on five Local Diallel sites (East Humptulips, Bob 1, Jordon 2 & 3, Kiyu, and Russell) and four Elite sites (Vollmer Creek, Michelsen, Stove, Tlupana) and were used for preliminary analysis. The predicted genetic gains in age-5 height (over unimproved seed) for the best forward selections was about 1.5 times the gain for the top parents. We expect heritabilities and gains in the remaining Oregon and Washington tests to be considerably higher than the gains in the first group of tests, and gains at age-10 or age-12 (whenever the final measurement takes place) to be higher still. Further, gains in volume are typically about three times as high as gains in height.

HEMTIC members voted to measure height on the remaining WA/OR sites in fall 2003. Given the rate of growth, some trees could approach 15 feet in height by then.

Grays Harbor Genetic Gain Verification Trial /Stand Management Type IV Installation

NWTIC membership voted at the October 1, 2003 annual meeting to proceed with the Grays Harbor genetic gain trial (coordinating that trial with the first Type IV installation of the Stand Management Cooperative). Similarly, the Stand Management Cooperative approved their Type IV trial at their September 2003 meeting. The two cooperatives are coordinating a joint trial, which is described in more detail in the Appendix.

Seed were sent to the Sylvan Vale nursery in December for the first three sites, to be planted in spring 2005. Fewer seedlings germinated for the unimproved control seedlot than expected, but there will be enough seedlings for the measurement trees and one buffer row. The other seedlots germinated well. By March 2004, several promising sites had been located and reviewed.

All the sites of the Molalla gain trial were visited by Jeff Riddle (USFS PNW Research Station) in 2003, and site owners have been contacted regarding maintenance needs. Jeff has removed some of the hardwood sprouts. The paper on age-5 results has been accepted for publication by the Western Journal of Applied Forestry, and is to be published in summer 2005.

Genetic Gain Demonstration Plantings

All four members of the Puget Sound metacooperative installed genetic gain demonstrations in spring 2003. In spring 2004, the Campbell Group established a planting using Vernonia-Ryderwood Phase II stock, and both Oregon Department of Forestry-Tillamook and Hampton Tree Farms established plantings using TRASK Coast Phase I stock. This brought the total of NWTIC-led demonstration plantings to nine. Of these the oldest (Boise's, established in 2001), was visited in February 2004.

Data Management, Analysis and Reports

Work has continued on the parent-tree records. Of the 31,076 parent trees expected, the database contained complete data for 30,783 records (93% of the total) by March 2004. The database includes information on 1,268 first-generation parents from 68 programs which were cross-tested outside the breeding zone of origin.

Data on program layouts, first-generation test sites and sowing schedules, and parent tree pedigree records were moved to the SQL server database. Views filtering relevant records and fields of interest were created for the benefit of cooperators and staff working with the data; such views will be created for other tables in the database. Cooperators were sent reports on first-generation test sites and sowing schedules and asked to correct incorrect information and fill gaps in the records. As of March 31, 2004, data were complete for:

- 95 first-generation programs (of 124)
- 104 first-generation test sites (of 911)
- 866 first-generation sowing schedules (of 1089)

Starting in mid-2003, the main focus in data management was in loading progeny measurement files into SQL server and making them available through views that could be called up in Microsoft Access or on the web. By March 31, 2004 1,288,501 records had been loaded, and 290 views had been created.

Information on full-sib crosses (mainly those made by the advanced-generation metacooperatives) were updated as information was received. By March 31 the database contained records on 2,979 full-sib crosses.

NWTIC maintained a strong emphasis on data analysis, completing analyses and reports for 25 first-generation breeding units and 2 advanced-generation programs. A more detailed description of the genetic gain predictions using Best Linear Unbiased Prediction is given later in this report.

Table 3. Summary of data analyses and reports completed January 1 2003 to March 31 2004

First Generation Analyses including Genetic Gain Predictions using BLUP

Cowlitz BU-1
Cowlitz BU-2
Cowlitz BU-3
Dallas Low
Gold Beach BU-1
Gold Beach BU-2
Gold Beach BU-2 Extension
Grays Harbor
Jacksonville BU-3
Mapleton High
Mapleton Low
Molalla
North Umpqua BU 1&2
Port Gamble
Prospect BU-1
Reedsport
Umpqua Coast
Umpqua Swisshome
Vernonia Original

Second Generation Analyses including Genetic Gain Predictions using BLUP

HEMTIC Age-5 (mainly BC sites)
Plum Creek Toledo Age-7

Other First Generation Analyses

BLM BU-30
BLM BU-33
North Umpqua BU-2
Powers Low
Snow Peak High
Snow Peak Low

Training and Technical Information

Genetics and Growth Modeling Workshop

In November 2003, NWTIC helped organize and fund a 3-day "Genetics and Growth Modeling" workshop in Vancouver, Washington. The PNWTIRC, USDA-PNWRS, OSU Department of Forest Science, SMC and Port Blakely Tree Farms were the other organzations organizing and funding this workshop. The first day had introductory presentations on growth modeling and forest genetics, followed by theoretical and real-life examples on incorporating gains from tree improvement into growth models. A smaller group convened on days two and three to discuss the implementation of some insights from the workshop. The workshop was attended by 55 people from six states in the USA, from British Columbia in Canada, Australia and New Zealand.

Presentations from this workshop are to be made available via the PNWTIRC website (www.fsl.orst.edu/pnwtirc). A summary paper capturing the main insights of this workshop is to be submitted for publication. Researchers from the PNWRS have submitted several proposals on the topics of genetic gain and growth modeling to the PNWRS Agenda 2020 pool of funding.

Tour of Forestry and Tree Improvement in New Zealand

At the October 2001 annual meeting of the NWTIC, there was interest in coordinating a tour of forestry and tree improvement in New Zealand. Following this mandate, Keith Jayawickrama made inquiries from contacts in New Zealand. Preparations were further energized following Leith Knowles (Manager of the NZ Douglas-fir cooperative) visit to the USA in June 2002. An invitation was extended to other cooperatives in the Pacific Northwest and to colleagues in British Columbia.

The tour took place in February 2003, coinciding with the annual meeting of the New Zealand Douglas-fir cooperative. NWTIC, the British Columbia tree improvement program, the Swiss Needle Cast Cooperative and PNW growth modeling were all represented. Visitors from the USA and Canada were outnumbered by a contingent of NZ Douglas-fir enthusiasts, who took the opportunity for a comprehensive review of Douglas-fir research and operational forestry. The South Island tour began at Dunedin and wound through the hills and plains of the central South Island to Christchurch. Several PNW visitors continued to a shorter visit to Rotorua, Forest Research and radiata pine forestry in the central north island.

Tour participants were very appreciative of the big organization effort of Forest Research staff (especially Leith Knowles, Nick Ledgard, Mike Menzies and Charlie Low) and the hospitality and cordiality of other New Zealand participants. It proved to be a pleasant, invigorating, educational and very well-organized 11 days.

Only a few NWTIC members could get approval to attend this tour. Keith therefore compiled some notes ("Tour of forestry and tree improvement in New Zealand", including photos and field tour notes) which are available on the NWTIC website.

Getting Genetic Gain In Operational Plantations

The full-sib Dallas Low and Dallas High orchards were felled and cleared immediately after the 2003 harvest. Nearly 900 trees belonging to the Interim Dallas 1.5 generation seed orchard were moved from the holding orchard to space released in fall-winter 2003-4. Dry weather in February helped the process. A second round of 400 pot grafts were completed in March 2004, infusing some elite clones from the BLM-13 and Plum Creek Toledo programs. These are to be planted in the orchard in fall/winter 2004-5.

High-gain parents from adjacent breeding units were infused into the Interim Burnt Woods Orchard, as field grafts. This orchard also was involved in the Schroeder orchard complex's first operational Controlled Mass Pollination project. Pollen from seven elite BLM clones were applied to 500 isolation bags on the top six Burnt Woods clones. If all goes well, over 100,000 high-gain seed could be produced from this project.

The Nehalem orchard block was rogued and thinned to make room for Swiss Needle Cast tolerant clones. The ramets are to be planted in fall 2004. Some high-gain Vernonia parents were identified based on the new BLUP analysis and grafted as part of the upgrade to the Vernonia orchard.

Similarly, Cascade Timber Consulting grafted a high-gain 1.5 generation orchard for its land-base in the Oregon Cascades, mainly for producing control-pollinated seed. Presently, elite parents

Excellent weed control two years after planting in SCC site (Menasha)

7 feet tall in two years—at South Central Coast's Lyon Ridge site (Menasha)

DNR's Southwest site (Puget Sound) site under snow

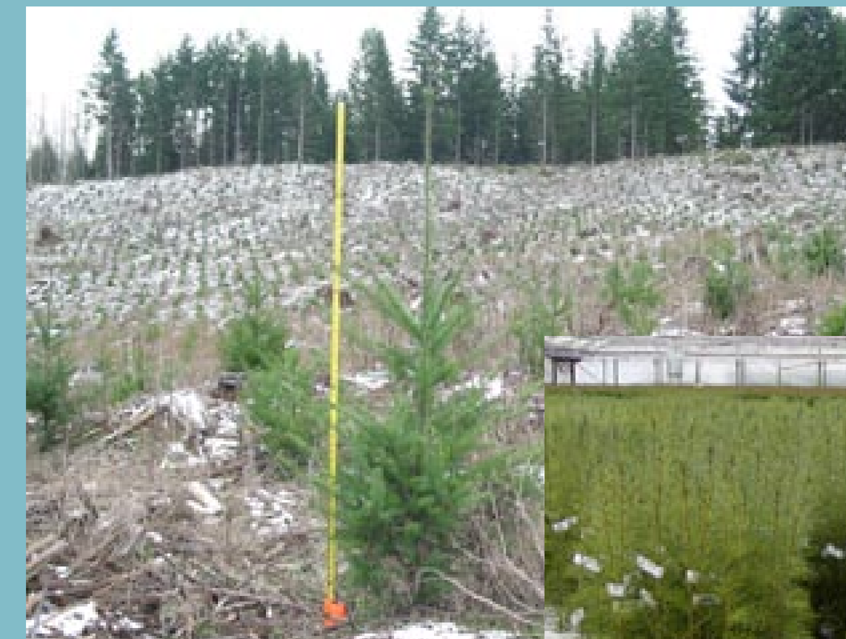
Large seedling on Pope Resources Puget Sound site

TRASK Coast Phase I Neskowin site (Simpson)

TRASK Inland Phase I Stock Tank site (Stimson) showing effects of preharvest herbicide application

TRASK Coast Phase I Branch Flats site (Starker)

TRASK Inland Phase I Burton Creek site (Hampton)



Vernonia/Ryderwood Phase I Ryderwood site (Hampton/Campbell Group

Vernonia/Ryderwood Phase II seedlings

NOCTIC Phase II McDowell Creek site (CTC)

NOCTIC Phase I McDowell Creek site (CTC)

HEMTIC Sekiu site (Crown Pacific)

HEMTIC Lake Quinault site (Quinault)

Molalla Genetic Gain site at Colton (Port Blakely) from two programs have been grafted in this orchard. The second and final round of grafting is scheduled for 2005.

Other Projects

The high-elevation Oakridge site (USFS) of the 1959 Douglas-fir provenance trial was tagged, monumented and prepared for measurement. Our original plan was to measure Crown Zellerbach's (now Weyerhaeuser's) high-elevation Molalla site, but the Oakridge site had less ingrowth problems and USFS considered (at one point) providing some staff time to help tag and measure the site. The inkind USFS help eventually fell through, but measuring this site will still be less expensive than the Molalla site. This site is to be measured in fall 2004.

Membership Changes

Seneca Jones Timber Company joined NWTIC in 2003, bringing a landbase of 141,000 acres. Roseburg Resources added 137,000 acres from its Roseburg ownership in 2003, while Plum Creek added 85,000 Coos Bay acres and Stimson Lumber expanded its NWTIC acreage signficantly in 2004. Regrettably, Canadian Forest Products and Western Forest Products left NWTIC and HEMTIC at the end of 2003. One of the tasks for 2004 will be to recruit new members.

Cooperators

Randall Greggs (Simpson Resource Co.) began his fourth year as NWTIC Chair at the 2003 annual meeting.

NWTIC representatives for 2003 were:

Don Wales & Jerry Anderson (Boise Cascade Corp.)

Charlie Cartwright (BC Ministry of Forests, Research Branch)

Liang Hsin (Bureau of Land Management)

Patti Brown (Canadian Forest Products)

Howard Dew (Cascade Timber Consulting)

Jim Unsell (Crown Pacific-Hamilton Division)

Steve Loy & John Goodrum (Crown Pacific-Olympic Division)

Beth Fitch (Hampton Tree Farms)

David Kenney (Hancock Forest Management)

Bryan Nelson (Lone Rock Timber)

Erik Lease (Longview Fibre Co.)

Ron Durham and Jim Carr (Menasha Corp.)

Joe Steere (Miami Corp.)

Brett Weidemiller (Moore Mill Co.)

Sara Lipow (Oregon Department of Forestry)

Loren Hiner (Plum Creek Timberlands L.P.)

Bryan Schulz and Dan Cress (Pope Resources)

Tim Truax (Port Blakely Tree Farms)

Jessica Josephs (Rayonier Timberlands)

Dave Walters (Roseburg Resources)

Bill Moore (Seneca Jones)

Randall Greggs (Simpson Resource Company – WA and OR operations)

Mark Diegan (Simpson Resource Company – CA Operations)

Marc Halley (South Coast Lumber)

Dick Powell (Starker Forests)

Margaret Banks (Stimson Lumber Co.)

Jim Hargrove (Quinault Indian Nation)

Jeff Madsen (The Campbell Group)

Jim Smith (The Timber Company/plum Creek)

Tim Crowder (Timber West Forest)

Jeff DeBell (Washington Department of Natural Resources)

Annette van Niejenhuis (Western Forest Products)

Greg Johnson & Christine Dean (Weyerhaeuser Co.).

Staff

Ron Rhatigan started work at the end of April 2003 as Test Coordinator, to oversee installation and maintenance of NOCTIC, TRASK and Vernonia/Ryderwood tests. Ron brought to this position graduate training at Oregon State University and several years experience in operational testing with the USFS programs in northern California.

Dan Cress, Analyst/Coordinator left the service of NWTIC in August 2003. During his long period of service at NWTIC, Dan made important contributions to cooperative tree improvement in the PNW, including greatly improving the success of advanced-generation crossing in Douglas-fir and western hemlock, and stringent protocols on test establishment. Dan stays involved in NWTIC as representative for Pope Resources.

Terrance Ye joined NWTIC staff as Quantitative Geneticist in October 2003. He brought to this position a PhD from the University of Alberta and many years experience with the Chinese fir breeding program in southern China and lodgepole pine in Alberta.

Keith Jayawickrama continued as Director and **Denise Steigerwald** as Information Management Specialist.

Predicting Genetic Gain In Cooperative Testing Programs

Terrance Ye and Keith Jayawickrama

Introduction

In May 2003, NWTIC approved implementing predicting genetic gains as a routine procedure for cooperative datasets. We wished to have genetic gain predictions (expressed as percentage gain over unimproved or population mean) calculated using a standard method, across the first-generation programs. Benefits of this information could include:

- Saying that seed produced from an orchard has 30% predicted genetic gain in volume at age-15 is more meaningful to operational foresters and managers than saying the average index value was 3.9 and the average z-score was 0.8.
- Predicted gains could also help a company allocate silviculture money to genetic improvement compared to treatments (herbicides, fertilizer, thinning etc).
- Predicted genetic gains differ between programs. For example, the best parent from program A might have a predicted gain of 32%, but 10 parents from adjacent program B might have a predicted gain greater than 32%). This would be very useful information when combining first-generation programs to create 1.5 generation orchards.
- Help decide which existing second-generation crosses should be sown for the tests.
- Predicted gains could underscore the need to rogue orchards or establish new orchards.

The Best Linear Unbiased Prediction (BLUP) approach, a very general form of mixed models, is now a common method for evaluating and predicting genetic merit in forestry, and has been adopted by NWTIC. Gains are predicted for height, dbh and volume (volume is estimated approximately as $VOL = DBH^2 \times HT$). More details are provided in NWTIC's technical document DA-8 (Methodology for predicting genetic gains).

ANOVA and variance components

The linear model includes all relevant terms (e.g., site, sowing year, set, family, replicate). For within-site analyses, we estimate variance components with untransformed data. For across-site analyses we assume that each site has a unique residual variance (heterogenous variance model) and estimate those residual variances using SAS PROC MIXED or ASReml. Then each growth trait is standardized by dividing the phenotypic measurements by the square root of the corresponding residual variance on each site. The result is a variable with a residual variance of approximately 1.0 across sites, and a homogeneous residual variance model is assumed to estimate across-site genetic parameters. The REML method is used to calculate variance components. Within site-set heritabilites and across-site heritabilities are calculated. Standard errors of heritabilities are estimated according to the delta method based on the matrices of variances and covariances associated with estimates of variance components or generated by SAS PROC MIXED or ASReml.

Breeding Values and Predicted Genetic Gain

Prior to BLUP analysis, data at each site is standardized by dividing by the square root of family variance on that site. This makes the family variance approximately 1.0 at each site and, therefore, each site has a common additive genetic variance. For breeding value estimation, we assume each site has a unique residual variance but the additive genetic variance is common (i.e. constant) from site to site. Two specific models are used: The Individual Tree Model fits a breeding value for each measured individual tree. The Family Model estimates a breeding value for each parent based on its progeny. The estimated breeding value (EBV) is equal to BLUP of a tree from individual tree models or twice the BLUP of a family from family models. The software used (ASReml) can output EBVs for each tree and family simultaneously by specifying pedigree files. Therefore, only the single tree model is needed when using ASReml.

Genetic gains are predicted for each family and individual tree based on their BLUP values using the following formula:

$$Gain\ (\%) = \frac{EBV}{\overline{Y}} \times 100$$

where $\overline{Y}$ is the adjusted population mean obtained by fitting models with only fixed effects in the model, and *EBV* is the estimated breeding value of a tree or family. Three gain predictions are provided. Gain1 and Gain2 specify sets in the model (Gain1 as fixed effects, Gain2 as random effects), and are very highly correlated. Gain3 leaves sets out of the model (essentially absorbing set effects into families and individual trees), and can be noticeably different from Gain1 and Gain2. Gain predictions are provided for parent trees and for forward selections from open-pollinated tests. Standard errors of estimated breeding values and genetic gains are also provided.

Other statistics provided

Rank changes from site to site are reported as the percent of significant crossover interactions for each family. The basic test for *COI* is to compare the growth of two families at two sites and to test if the difference is significantly less than zero at one site but significantly greater than zero at the other site. For form traits (forking, ramicorn branches and sinuosity), z-scores and the percent difference from the overall mean are reported. In addition to the gain predictions and z-scores, unadjusted family means across sites are also provided.

Pearson's correlation coefficients are also reported among traits (growth, form, geographic traits, etc.), to indicate the strength of the relationships between traits. The number of trees per family, the number of sites for which data were analyzed, parent tree location information (latitude, longitude, elevation,) least-squares means at each site and family ranks based on these least-squares means are also reported.

A report is written along with the analysis, which documents the procedures and attempts to interpret the results.

Interpretation, context and validation

Typically predicted age-15 volume gains for the best parents exceeds 50%. Predicted volume gains are typically three times as high as the predicted height gains. These calculations involve several assumptions (such as no relatedness within the woods-collected, open-pollinated families, a uniform pollen cloud for the woods-collected open-pollinated families, seed are collected in the orchard after pollination by trees of similar genetic worth), that are probably violated to some degree. Volume as dbh^2 x height is an approximation to true volume. If the fast-growing families have begun to suppress slow-growing families by age-15, heritabilities and hence gain predictions may be inflated. The sites tested do not perfectly represent the future sites on which operational seed will be deployed. Further, rotation-age gains (as percent of volume) could be less than age-15 gains.

Thus while this protocol is an efficient, documented, unbiased and reproducible method comparable to methods used by many other operational tree improvement programs, it is not presented as a guarantee of gains to be obtained in operational plantations. These considerations underscore the value of the realized genetic gain trials (existing and planned) organized by NWTIC to calibrate predicted gains against realized gains.

Effects of Advances in Genetics, Silviculture and Nutrition on Productivity and Quality of Douglas-fir Plantations: NWTIC Genetic Gain Trial & SMC Type IV Joint Design

David Briggs, Rob Harrison, Keith Jayawickrama, Brad St. Clair and Eric Turnblom

Introduction

The Northwest Tree Improvement Cooperative (NWTIC) is primarily an operational tree breeding cooperative, formed in 1985 to coordinate and serve cooperative tree improvement in the Pacific Northwest. However, since 1992 it has funded two separate research trials (the Molalla Gain trial in the Oregon Cascades, planted in 1997, and the Noti Gain trial in the Oregon Coast Range, planted in 2001) to verify the genetic gain predicted from progeny trials. The first two trials included three levels of genetic gain (elite, intermediate and unimproved) planted at two spacings (6′ and 12′). A third trial was planned in the Grays Harbor area, and crossing got underway around 1995.

Since forming in 1985, The Stand Management Cooperative (SMC) has developed a portfolio consisting of 3 types of field research installations with the mission:

> "to provide a continuing source of high-quality information on the long-term effects of silvicultural treatments and treatment regimes on stand and tree growth and development and on wood and product quality"

Type I installations were established from existing plantations of Douglas-fir and western hemlock that were reaching the onset of competition. They tested the effect of spacing (by various levels of thinning), pruning, and fertilization. Most of these plantations originated in the late 1970s to early 1980s and reflected the genetic improvement, seedling culture, planting spacing, and early stand culture prevailing at that time. Type II installations were established in older stands reaching the commercial thinning stage and consist of 5 plots undergoing thinning regimes. Most Type II plantations originated in the 1960s and early 1970s and hence reflected a different era in terms of genetic improvement, seedling culture and early stand culture. Type III installations were planted after 1986 to a planned series of six spacings and reflect the genetics, seedling stock and early management prevailing in the late 1980s through the early 1990s. In these installations, the choice of genetic stock, seedling culture and seedling type was left to the landowner.

In 1998, the SMC began discussions with other cooperatives in the region to discuss a new set of installations (referred to hereafter as Type IV) that would reflect the recent advances and discoveries that each had made. Due to the overlap in membership and objectives of the proposed Type IV trial and the Genetic Gain trial, the two cooperatives eventually converged on a joint design to be implemented in the Grays Harbor area. This design was approved in September – October 2003.

Objectives

The main objectives of the combined Genetic Gain / Type IV Grays Harbor installation are:

A. To understand the long-term effects on productivity, quality, and diversity of Douglas-fir trees and stands when the latest advances in genetics, seedling culture, and early vegetation management are deployed together.

B. To compare estimates of growth and yield parameters among genetic populations having different expected growth potentials.

C. To develop a predictable relationship between expected genetic gain based on individual-tree growth characteristics and realized genetic gain on a per-unit area basis.

Justification

Creating and monitoring these installations would allow better prediction of the growth and yield, quality, and value when recent advances in genetics, seedling culture, and vegetation control are deployed in combination at various spacings and as such stands are subsequently managed under nutrition and thinning regimes to rotation. A sampling of questions that can be addressed include:

- Combining these latest advances, what combination(s) produces the maximum productivity within the ranges of factors tested?
- How do ***predicted*** genetic gains in progeny tests (typically established in single-tree-plot designs with families of very different genetic gain levels competing with each other) compare with ***realized*** gains in plantations where only selected subsets compete with each other, and which are carried through to a full rotation?
- Do the advances in technologies and application of treatment regimes produce additive results, positive synergies, or negative synergies?
- Do these responses remain constant over the life of the stand or do they change?
- Are the effects and responses influenced by site?
- What is the effect on tree and log quality, wood quality, and product value?

The Genetic Gain / Type IV Installations could be used by scientists from many disciplines to study the long term behavior in terms of growth and yield, tree/log quality, wood quality, diversity and vegetation structure, and value. Genetic Gain/Type IV installations will provide an interdisciplinary alternative to the usual piecemeal approach that will improve the generality and precision of models and information provided to managers.

Methods: Joint NWTIC/SMC Experimental Approach

I. Treatments & Treatment Levels

A. Planting Spacing (**S**): 1 level in genetic gain trial; 3 levels in Type IV

1. (**S1**) 15' x 15' (194 spa, nominally 200). Plot size = .75ac
2. (**S2**) 10' x 10' (435 spa, nominally 440): Plot size = .59ac. **Genetic Gain trial will use this spacing only**.
3. (**S3**) 7' x 7' (889 spa, nominally 900).Plot size = .60ac
   - ❑ All seedlings planted will be 515As with fertilizer.
   - ❑ Plot sizes shown above include 30 ft buffer surrounding the measurement plot

B. Genetic Quality (G): 3 Levels in genetic gain trial; 2 levels in Type IV

1. (**G1**) Unimproved: will use in Type IV. Represents what would be planted in the absence of tree improvement. Bulk equal quantities of seed collected from a random selection of 50 individual 'wild' trees well distributed through the planting zone
2. (**G2**) Moderate gain: a sample of 20 intermediate-gain parents, crossed once with each other to produce and blend 10 full-sib families.
3. (**G3**) High gain: will use in Type IV. A sample of 20 highly-ranked parents in the breeding program, crossed once with each other to produce 10 high-gain full-sib families.

C. Vegetation Control (V): 1 Level in genetic gain trial; 2 levels in Type IV

1. (**V1**) Current Practice
2. (**V2**) Complete until crown closure; this will be the standard. All Genetic Gain plots would have this treatment.

II. Design

There will be 6 test sites located in the region of the Grays Harbor First Generation Tree Improvement Cooperative. Each test site will have plots comprised of the following

A. Genetic Gain Trial:

- G1 (unimproved), G2 (medium gain), and G3 (high gain) at spacing S2 (10x10) with V2 (complete vegetation control)
- 5 replications → 15 plots

Genetic Gain Trial Plot Matrix for One Mock-up Site		
G1	**G2**	**G3**
Ggt 1	*Ggt 6*	*Ggt 11*
Ggt 2	*Ggt 7*	*Ggt 12*
Ggt 3	*Ggt 8*	*Ggt 13*
Ggt 4	*Ggt 9*	*Ggt 14*
Ggt 5	*Ggt 10*	*Ggt 15*

B. Type IV

- G1(unimproved) & G3 (high gain) x S1 (15x15), S2 (10x10) & S3 (7x7) with V2 (complete vegetation control) in a complete block design → 6 plots
- V1 (standard current practice vegetation control) in incomplete blocks of 3 → 3 plots

Type IV Plot Matrix for Mock-up Site

	G1 (unimproved)		G3 (High Gain)	
	V1 (standard vegetation ctrl)	V2 (complete vegetation ctrl)	V1 (standard vegetation ctrl)	V2 (complete vegetation ctrl)
S1 (15x15)		*Type IV 1*	*Type IV 8*	*Type IV 4*
S2 (10 x 10)	*Type IV 7*	*Type IV 2*		*Type IV 5*
S3 (7 x 7)		*Type IV 3*	*Type IV 9*	*Type IV 6*

C. Shared, Common Plots, and Acreage per Site

Plot Type IV-2 is identical to any of the genetic gain plots Ggt-1-5 and Plot Type IV-5 is identical to any of the genetic gain plots Ggt-11-15. Eliminating these 2 duplicates (solid circles) reduces the Type IV from 9 to 7 plots. The overall study size is reduced from 24 (15 + 9) plots to 22. The total acreage needed for the 22 plots on a given site is 13.4 acres.

III. Site Selection and Schedule (3 sites per year)

A. Site Selection

Landowners in the Grays Harbor area will be asked to provide suitable sites for the study.

B. Schedule (3 sites per year)

Seed will be sown in late 2003 for planting the first 3 sites in 2006, in late 2004 for planting the last 3 sites in 2007.

IV. Number of trees

The number of trees per plot, per site and overall are shown in Table 4.

Table 4: Grays Harbor Genetic Gain/Type IV trial: Numbers of trees and area required for each installation and all six installations.

Elite plots

		Measurement Plot			Treatment Plot including Genetic Buffer				Treatment Plot including Genetic & Density Buffer										
Spacing	Spa	Rows	Trees	Plot area	Buffer rows	Total rows	Trees	Plot area	Density buffer rows	Total rows	Trees	Plot area	Test site area	Plots per site	Trees per site	Sites	Total elite trees	Density buffer trees	**Total trees**
15	194	8	64	0.33	2	12	144	0.74	0	12	144	0.74	1.49	2	288	6	**1,728**	0	**1,728**
10	436	10	100	0.23	2	14	196	0.45	1	16	256	0.59	2.94	5	980	6	**5,880**	1800	**7,680**
7	889	15	225	0.25	2	19	361	0.41	2	23	529	0.60	1.19	2	722	6	**4,332**	2016	**6,348**
													5.62		1,990		**11,940**	3,816	**15,756**

Intermediate Plots

		Measurement Plot			Treatment Plot including Genetic Buffer				Treatment Plot including Genetic & Density Buffer										
Spacing	Spa	Rows	Trees	Plot area	Buffer rows	Total rows	Trees	Plot area	Density buffer rows	Total rows	Trees	Plot area	Test site area	Plots per site	Trees per site	Sites	Total intermediate trees	Density buffer trees	**Total trees**
15	194	8	64	0.33	2	12	144	0.74	0	12	144	0.74	0.00	0	0	6	**0**	0	**0**
10	436	10	100	0.23	2	14	196	0.45	1	16	256	0.59	2.94	5	980	6	**5,880**	1800	**7,680**
7	889	15	225	0.25	2	19	361	0.41	2	23	529	0.60	0.00	0	0	6	**0**	0	**0**
													2.94		980		**5,880**	1,800	**7,680**

Unimproved plots

		Measurement Plot			Treatment Plot including Genetic Buffer				Treatment Plot including Genetic & Density Buffer										
Spacing	Spa	Rows	Trees	Plot area	Buffer rows	Total rows	Trees	Plot area	Density buffer rows	Total rows	Trees	Plot area	Test site area	Plots per site	Trees per site	Sites	Total unimproved trees	Density buffer trees	**Total trees**
15	194	8	64	0.33	2	12	144	0.74	0	12	144	0.74	0.74	1	144	6	**864**	0	**864**
10	436	10	100	0.23	2	14	196	0.45	1	16	256	0.59	3.53	6	1,176	6	**7,056**	2160	**9,216**
7	889	15	225	0.25	2	19	361	0.41	2	23	529	0.60	0.60	1	361	6	**2,166**	1008	**3,174**
													4.87		1,681		**10,086**	3,168	**13,254**

Outer Buffer Trees Needed = **8,784**

Total Area = 13.420 **Total Trees = 36,690**

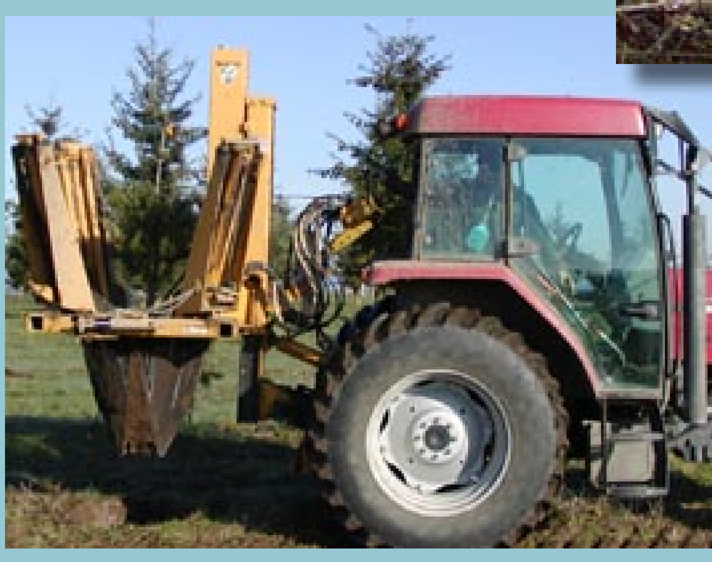
Mission of the Northwest Tree Improvement Cooperative

- Oversee cooperative breeding of Douglas-fir, western hemlock and other species of the coastal forests of the Pacific Northwest
- Guide technical aspects of implementing these tree improvement programs
- Analyze and interpret genetic test data
- Store test data and breeding records
- Provide expertise and training in tree breeding

Grays Harbor Genetic Gain / Type IV site for 2005 planting (Rayonier)

Control mass pollination in the Interim Burnt Woods orchard

The potential for intensive forestry in the PNW: high-gain seed, large planting stock, wide spacing, productive site, 13 years after planting



Moving grafted trees in the Interim Dallas orchard