Northwest Tree Improvement Cooperative

Annual Report

January–December 2002

October 2003

Oregon State University
College of Forestry

Members of the Northwest Tree Improvement Cooperative for the year 2002

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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.
John Hancock Life Insurance Co.
Lone Rock Timber Company
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USDA Forest Service, Region 6
Washington Department of Natural Resources
Western Forest Products Ltd
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Cover photo – High-gain 1.5-generation grafted Douglas-fir orchard block at the Oregon Department of Forestry's orchard complex, June 2002.

NORTHWEST TREE IMPROVEMENT COOPERATIVE

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Contents

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

The year 2002 was marked by continued activity in cooperative breeding and testing of Douglas-fir.

South Central Coast

The South Central Coast (SCC) metacooperative completed the largest single testing effort accomplished so far by a second-generation Douglas-fir metacooperative. Six mainline tests, three Swiss Needle Cast tests and 134 full-sib blocks were established in February to March 2002, with over 52,000 trees planted including fillers and buffers.

SCC combined selections from six first-generation breeding units: Umpqua Coast, Umpqua Swisshome, Reedsport, Mapleton High, Mapleton Low, and Coquille Coast. The parents used in crossing were chosen based on 2,000 tested first-generation families. SCC had eight members controlling 435,000 acres of Douglas-fir timberland at the time of test establishment, and crosses had been made at three seed orchards (Roseburg Forest Products' orchard at Lebanon, and the Bureau of Land Management's Tyrell and Horning orchards).

Large, woody styro-20 seedlings grown in British Columbia were used in these tests. They faced a dry spring and an unseasonable frost in late May. It later transpired that too much slow-release fertilizer had been added to the cavities. The combination of frost, excessive fertilizer and drought killed about 30% of the trees on three sites. Restrictions on using herbicides proved to be a hindrance for one member in terms of controlling weeds. However survival and growth were good on several sites, with some trees growing to over three feet tall during the first season. It appeared that on moist fog-belt sites, good weed control and the high fertilizer dose promoted rapid growth.

While this planting had its share of challenges, experience gained in the HEMTIC, NOCTIC and Vernonia/Ryderwood test establishment in 2001 were used to advantage. Despite the problems with slow-release fertilizer, the large planting stock has definitely been a plus. Fencing, layout and mapping were executed to a high standard. It was once again underscored that finding good test sites needs time and effort, and that site selection should begin the summer before seed are sown in the nursery.

Puget Sound and Other Installations

The Puget Sound metacooperative Phase I test crop was grown through the year as stryo-15 containerized seedlings at the IFA nursery in Nisqually, WA. Five test sites were identified, prepared and fenced. Test sites ranged from near Arlington in the northeast to near Battleground on the southeast, and west to the north-east tip of the Olympic Peninsula. This metacooperative had four members controlling 745,000 acres of commercial Douglas-fir timberland. One difference in this metacooperative was that the Washington DNR (the largest member in terms of acreage) opted to contribute most of its membership dues via in-kind assistance in site layout, site installation, mapping and overall project coordination. Another difference was that a significant number of non-local crosses were included in the sowing.

Tests established by the Vernonia/Ryderwood and NOCTIC metacooperatives in 2001 were all visited in 2002 and some maintenance steps taken. The summer drought experienced during the first growing season had caused only moderate mortality in the V/R tests; survival was high in the NOCTIC sites. In the NOCTIC sites as well, restrictions on the use of herbicides hindered the efforts

Table 1. Summary of South Central Coast Phase I sowing

Type of Test	Number of families	Number of locations	Total Number of Test Trees	Purpose
Mainline	283 (+ 4 controls)	6	28,197	Rank families and parents Verify breeding zone(s) Make forward selections
Family Blocks	134	3	7,483	Make forward selections
Swiss Needle Cast	50 (+ 4 controls)	3	3,228	Rank families and parents for ability to grow in the presence of Swiss Needle Cast disease Make forward selections

of one member to control weeds on its two sites. A somewhat high level of error was identified in layout and mapping in the NOCTIC and Vernonia/Ryderwood tests.

Crossing continued for the NOCTIC, TRASK, Vernonia/Ryderwood WA Cascades, and WA Coast programs. This was the final crossing season for Vernonia / Ryderwood. Seed from TRASK Coast Phase I, and Vernonia/Ryderwood Phase II were sent off for stratification (at Sylvan Vale Nursery in British Columbia and IFA-Nisqually in Washington respectively) in December. South Central Coast debated the option of a Phase II sowing and some crossing took place; however this metacooperative had not formally agreed on a second sowing by the end of the year. Due to the limited number of members and budget constraints, the WA Cascades metacooperative (WACTIC) decided to scale down the size of the testing population, from the original 470+ crosses to around 260-300. Uncertainty about the ownership of the landbase remained an issue for WACTIC.

Crossing within the Forks, Cowlitz BU-4 and Cowlitz BU-5 began this year. The overall progress and status is summarized in Table 2.

Table 2. Status of / plans for cooperative second-generation Douglas-fir breeding populations as of December 2002.

	Status	Number of Local & Semi-Elite Crosses		Test Sites		
		Target	Already Tested or Sufficient Seed	Target no.	Start planting planting in spring of	Complete in planting in spring of
Washington Cascades	Crossing	361	[a]150	10	[a] 2004	[a]2007
Puget Sound	Planting 5 sites in 2003 (Phase I, 143 crosses)	94	81	10	2003	[a]2005
Washington Coast	Crossing	176	50	6	[a] 2006	[a]2006
Vernonia / Ryderwood	Planted 5 sites in 2001 (Phase I, 254 crosses)	404	272	10	2001	2004
North Oregon Cascades	Planted 6 sites in 2001 (Phase I, 234 crosses)	414	317	12	2001	2004
Trask (*Coast + Inland + Swiss Needle Cast elite*)	Crossing	764	222	24	2004	2006
South Central Coast	Planted 6 sites in 2002 (283 Crosses) + 3 Swiss Needle Cast sites	310	283	6	2002	2002[1]
TOTAL		*2,423*	*1,375*	*78*		

[1] No Phase II sowing was planned at this point.

Cooperative Second-Generation Breeding and Testing of Western Hemlock

Progress on the Oregon/Washington Test Sites

All sites established in 2001 were visited in the summer of 2002. Several sites have shown good survival and growth, with some test trees exceeding five feet in height and one inch root caliper at the end of the second season after planting. All 11 sites in Oregon and Washington were pinned and tagged, and mortality was replanted. Contrary to views on operational reforestation, western hemlock has proven quite susceptible to browse; tubes were installed on two sites to protect the seedlings from damage. Weeds and brush were controlled on several sites, and hemlock volunteers were manually controlled on one site. HEMTIC voted to measure height on two sites in fall/winter 2002: the Local Diallel site at East Humptulips (planted 1998) and the Elite Population site at Vollmer Creek (planted in 1999).

While established outside the HEMTIC umbrella, trees in the satellite trial planted by Crown Pacific on two sites in the Skagit area have grown well. Future results from this trial will indicate the adaptability of HEMTIC material in the Oregon and Washington Cascades.

Progress in the BC Western Hemlock Forest Genetics Program for 2002/03 (by Charlie Cartwright)

Last year we measured the four HEMTIC "Elite" trials that were outplanted in 1999 (Branch 265, Stove Creek, Tlupana River, and Michelsen Point). Only survival and height age 5 were recorded; no time has as yet been spent in cleaning the data, or analysis. Two realized-gain trials established in 1994 were measured as well; height, DBH, and survival to age 10 years from seed were recorded. Gains were about 20% in age-5 height for the best seedlot comprised of about a dozen of the top HEMTIC parents (Forks and BC). A preliminary look at the data suggests a similar level of gain in height at age 10.

A 17% drop in internal funding of the program led to diminished efforts for long term maintenance. Only the youngest trials, a HEMTIC elite family block test at Nimpkish River, and a HEMTIC F-1 (local Diallel) trial off the Varney Main (both established in 2001) were manually weeded and a survival check done.

Results from provenance trials established in 1993 were analyzed this spring and will be presented at the Western Forest Geneticist's Association meeting July 28 to 31st in Whistler BC. In brief, site and provenance effects were significant for survival and height to age-10 for 8 sources across 6 sites. A more in depth report will be available in the Fall covering more sources and sites. A four year old potted provenance trial to screen susceptibility to hemlock dwarf mistletoe was also assessed and analysis of variance performed, with results also to be presented at Whistler. There was statistically significant differences in provenances for height age 4 but not susceptibility to mistletoe. Family effects were not significant, but probably because there were only 6 trees per open-pollinated parent. Although provenances were not significant for susceptibility, Duncan's multiple range test identified one that stood out as having half as many successful infestations as other sources. As well, there was considerable family variability for each provenance, although insufficient plants per family to make the differences statistically significant. The provenance study was intended as a preliminary one, with screening of the top 50 HEMTIC parent trees already in orchards to follow if results were encouraging. The intent was that resistant seedlots could be developed in a few years for deployment to sites where harvested blocks harbor contagion due to residual stems.

Genetic Gain Verification Trial and Demonstration Plantings

The second phase of the Genetic Gain trial planted in spring 2001, planted on five sites in the Noti breeding zone, experienced heavy mortality during its second summer and had to be abandoned. We are unable to pinpoint what exactly went wrong; small planting stock (styro-10s), inadequate supervision during planting, and a dry first spring and summer were all proposed as reasons for the failure of this trial. NWTIC membership voted to proceed with the Grays Harbor genetic gain trial (coordinating that trial with the first Type IV installation of the Stand Management Cooperative if possible), sowing the seed at the end of 2003.

NWTIC is promoting the installation of small but effective genetic gain demonstration plantings by all its members. More than information, the objective of these plantings is to provide simple visual demonstration of the growth of genetically improved vs. woodsrun planting stock. Menasha FPC installed such a planting in 2002, adding to Boise's installation in 2001. All four members of the Puget Sound metacooperative planned to install demonstration plantings in spring 2003.

Data Management, Analysis and Reports

Work has continued on the parent tree Geographic Information Database. We expect to get data from 31,286 parent trees. During 2002 we progressed the number with complete data to 25,028 (80% of the total). This percentage is lower than reported in the 2001 Annual Report, since we have raised the standard required for a record to be considered complete. Of interest is the fact that 1,113 first-generation parents 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. Microsoft Access views were created for the benefit of those without with SQL server software; such views will be created for other tables in the database. Cooperators were sent reports on first-generation test sites and first-generation sowing schedules and asked to correct inaccurate information and fill gaps in the records. As of December 31, data were complete for:

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

Information on second-generation crosses made by the Douglas-fir metacooperatives and first-generation measurement data were updated as information was received. Based on cooperator requests, summaries on first-generation test sites, genetic variances, heritabilities and estimated gains for height, diameter and stem form were collated for the NOCTIC, Vernonia / Ryderwood, and TRASK programs. It should be noted that the estimated gains were based on the existing standard analyses.

Table 3. Summary of data analyses and reports completed in 2002

Breeding Unit	Second-Generation Breeding Plan Generated
Cowlitz: Breeding Unit 1	Yes
Cowlitz: Breeding Unit 3	Yes
Port Gamble	Yes
Skagit: North-High	Yes
Skagit: North-Low	Yes
Skagit: South-High	Yes
Skagit: South-Low	Yes
Grants Pass: Breeding Unit 2	No
Cave Junction: Breeding Unit 1	No
South Umpqua Breeding Unit 2	No

All remaining data and analysis files were transferred from diskettes and compact disks to the hard drive's NWTIC directory. Work also continued on the NWTIC web page, posting some technical reports and workshop proceedings. An overview of the NWTIC database is given in Figure 1.

NWTIC maintained a strong emphasis on data analysis, completing analyses and reports for 14 first-generation breeding units. NWTIC continued to work on a backlog of analyses for breeding units from southwest Oregon.

Training and Technical Information

In collaboration with the Pacific Northwest Tree Improvement Cooperative, NWTIC held a workshop on "Genetic Improvement of Wood Quality in Coastal Douglas-fir and western hemlock" in June 2002. Along with presentations on the inheritance of wood properties and stem quality, there were presentations on general aspects of wood quality, industry goals for wood quality, wood quality and silviculture, wood quality work at INRA (France) and for Douglas-fir in New Zealand, and some possibilities for future research and implementation. The workshop was attended by 49 people from three states in the USA, from British Columbia in Canada, France and New Zealand. The proceedings from this meeting were provided to attendees, and are available to NWTIC members through its website.

A summary paper on "Genetic Improvement and Deployment of western hemlock in Oregon and Washington" was circulated among members and also submitted to Silvae Genetica. NWTIC's "Guidelines for cooperative second-generation testing of Douglas-fir and western hemlock" was updated. One goal was to set targets for the current round of tests, such as for survival, weed control, growth rate and heritability.

As part of the effort to keep NWTIC members aware of advances in tree breeding outside the region, notes and presentations were provided on Sitka spruce improvement in the United Kingdom, Douglas-fir genetic improvement in France, genetics and silviculture achievements in the southeastern United States, and MeadWestvaco's test establishment protocol and standards in south Carolina.

Getting Genetic Gain In Operational Plantations

A high-gain "1.5" generation seed orchard (the Interim Dallas orchard) was grafted in February at the J.E. Schroeder Seed Orchard complex. Over 1,000 field grafts were made of the best selections from nine first-generation programs (containing a total of nearly 2,000 tested families), with a strong emphasis on parental ("backwards") selections. The orchard is to be moved to its permanent location in fall/winter 2003.

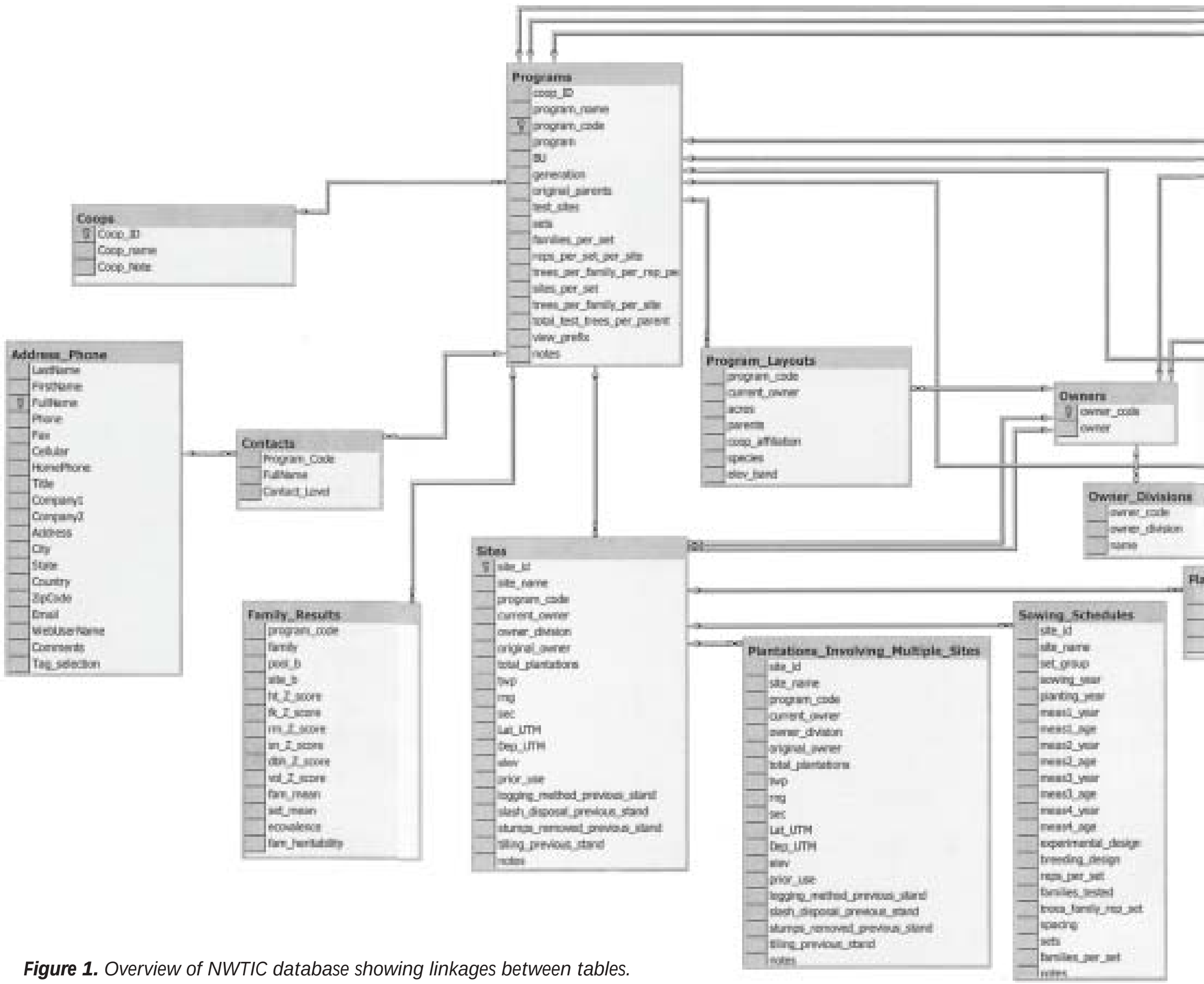
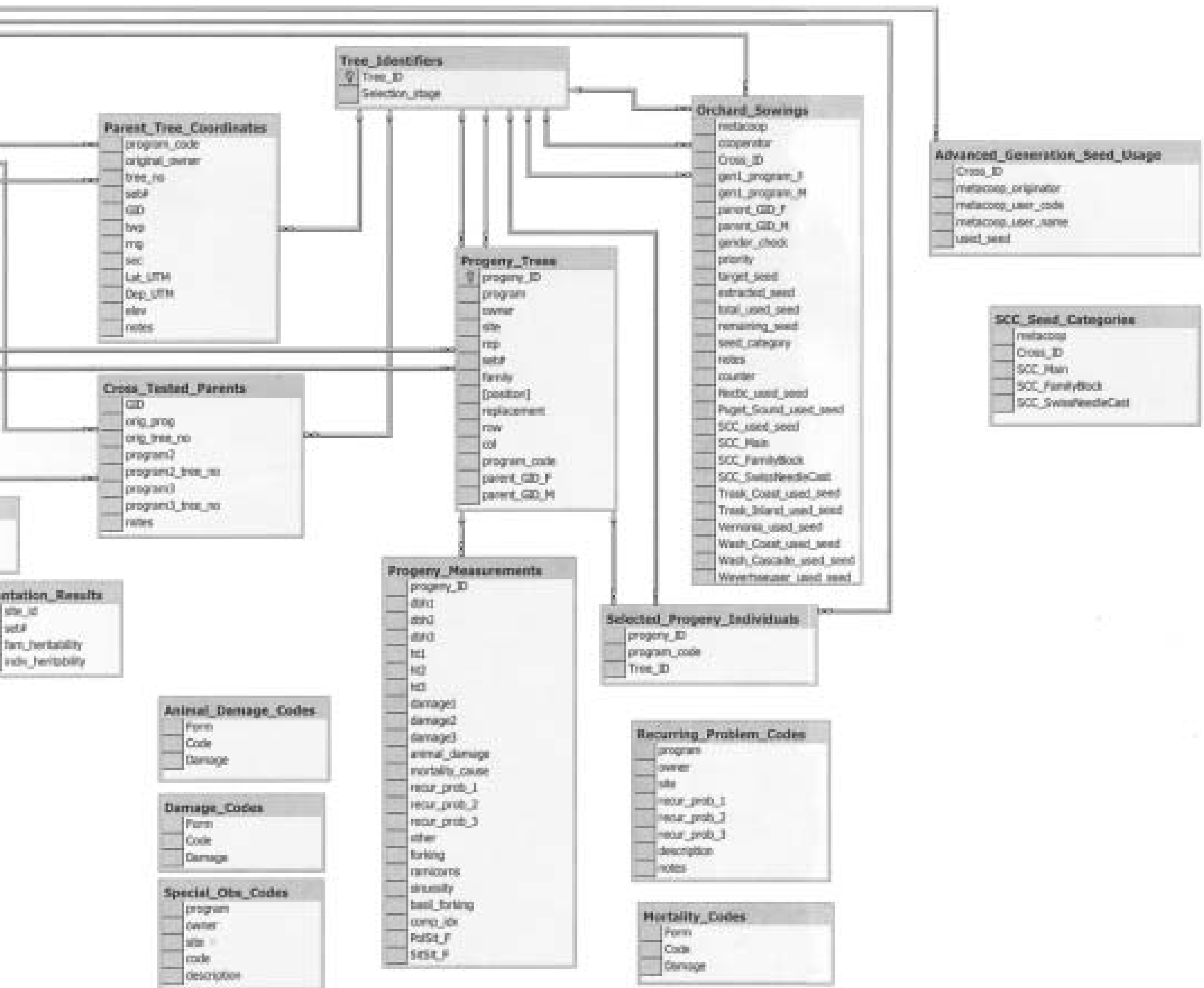


Figure 1. *Overview of NWTIC database showing linkages between tables.*



Tree_Identifiers
Tree_ID
Selection_stage
Parent_Tree_Coordinates
program_code
original_owner
tree_no
seb#
GID
twp
rng
sec
Lat_UTM
Dep_UTM
elev
notes
Orchard_Sowings
metacoop
cooperator
Cross_ID
gen1_program_F
gen1_program_M
parent_GID_F
parent_GID_M
gender_check
priority
target_seed
extracted_seed
total_used_seed
remaining_seed
seed_category
notes
counter
Nordic_used_seed
Puget_Sound_used_seed
SCC_used_seed
SCC_Main
SCC_FamilyBlock
SCC_SwissNeedleCast
Trask_Coast_used_seed
Trask_Inland_used_seed
Vernonia_used_seed
Wash_Coast_used_seed
Wash_Cascade_used_seed
Weyerhaeuser_used_seed
Advanced_Generation_Seed_Usage
Cross_ID
metacoop_originator
metacoop_user_code
metacoop_user_name
used_seed
SCC_Seed_Categories
metacoop
Cross_ID
SCC_Main
SCC_FamilyBlock
SCC_SwissNeedleCast
Progeny_Trees
progeny_ID
program
owner
site
rep
seb#
family
[position]
replacement
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col
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parent_GID_M
Cross_Tested_Parents
GID
orig_prog
orig_tree_no
program2
program2_tree_no
program3
program3_tree_no
notes
ntation_Results
site_id
set#
fam_heritability
indiv_heritability
Progeny_Measurements
progeny_ID
dbh1
dbh2
dbh3
ht1
ht2
ht3
damage1
damage2
damage3
animal_damage
mortality_cause
recur_prob_1
recur_prob_2
recur_prob_3
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forking
ramicorns
sinuosity
basil_forking
comp_idx
PolSit_F
SitSit_F
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progeny_ID
program_code
Tree_ID
Animal_Damage_Codes
Form
Code
Damage
Damage_Codes
Form
Code
Damage
Special_Obs_Codes
program
owner
site
code
description
Recurring_Problem_Codes
program
owner
site
recur_prob_1
recur_prob_2
recur_prob_3
description
notes
Mortality_Codes
Form
Code
Damage

First tree planted in the south Central Coast tests. February 2002.

Puget Soun
nursery, Septe

Howard Dew at NC
site/

d test crop in
ember 2002.

Charley Moyer at HEMTIC test site, July 2002.

Good growth in a South Central Coast test site 14 months after planting.

OCTIC test

The Interim Burnt Woods Orchard, also located at Schroeder was rogued heavily in fall 2002, in order to increase average gain levels and to infuse high-gain clones from adjacent breeding units such as BLM BU-13. Members of this orchard cooperative also began plans for a pilot controlled mass pollination (CMP) project, with the first step being large-scale pollen collection in spring 2003 and stimulation of ramets for pollination in spring 2004. This is an exciting move given that operational CMP is far from routine for coastal Douglas-fir in the Pacific Northwest.

NWTIC staff visited the site on which Crown Pacific planned to establish a western hemlock seedling orchard, recommended planting distances and preparation of planting spots, and estimated seed production over time. In addition to these orchard blocks in which NWTIC had a significant involvement, other cooperators are actively roguing and otherwise upgrading seed orchards to boost gain. NWTIC also outlined some options for Hampton Tree Farms to capitalize on previous investments and boost gain for landholdings in northern Washington.

Other Projects

The Sitka Spruce cooperative program made very little progress in 2002. Depressed lumber prices, the takeover of Willamette Industries (a strong advocate for the program) and the need to concentrate energies on the Douglas-fir program contributed to this lack of action.

Given the number of different tasks in hand, NWTIC opted to delay the measurement of a high-elevation site of the 1959 Douglas-fir provenance trial till 2003. However the NWTIC initiative motivated Patti Brown (CanFor) to apply for and obtain funding to measure three sites of the same trial in British Columbia; these sites were measured in fall 2002.

Membership Changes

With the purchase of Willamette Industries, Weyerhaeuser Company became a member of NWTIC for the first time. Weyerhaeuser later advised NWTIC that it would retain membership at least through 2003. NWTIC was pleased to welcome such a major player in forestry and tree improvement in the Pacific Northwest. Seneca Jones Timber Company stated its intent of joining from the beginning of 2003.

Regrettably, the US Forest Service Region 6 ended its membership in NWTIC at the end of 2002; reduced harvest, replanting, emphasis on timberland productivity, and support for tree improvement, made this withdrawal almost inevitable. Given the sheer size of the USFS Region 6 tree improvement program in its heyday in the 1980s (in terms of personnel, trees selected, progeny tests and seed orchards established), this was indeed a sign that times had changed. Avery Interests also advised of its withdrawal from NWTIC and NOCTIC at the end of 2002.

Cooperators

Randall Greggs (Simpson Timber Co.) began his third year as NWTIC Chair at the 2002 annual meeting. NWTIC members voted to reinstate the Steering Committee (renaming it the Operations Committee) at that same meeting.

NWTIC representatives for 2002 were:

Pete Mastenbroek (Avery Interests)

Don Wales (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 (Crown Pacific-Olympic Division)

Beth Fitch (Hampton Tree Farms)

John Davis (John Hancock Life Insurance Co.)

Bryan Nelson (Lone Rock Timber)

Erik Lease (Longview Fibre Co.)

Ron Durham (Menasha Corp.)

Joe Steere (Miami Corp.)

Brett Weidemiller (Moore Mill Co.)

Rosemary Mannix & Sara Lipow (Oregon Department of Forestry)

Loren Hiner (Plum Creek Timber-lands L.P.)

Bryan Schulz (Pope Resources)

Brandon Austin & Tim Truax (Port Blakely Tree Farms)

Jessica Josephs (Rayonier Timberlands)

Dave Walters (Roseburg Resources)

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)

Tim Crowder (Timber West Forest)

Sheila Martinson (USDA Forest Service, Region 6)

Jeff DeBell (Washington Department of Natural Resources)

Annette van Niejenhuis (Western Forest Products)

Greg Johnson & Christine Dean (Willamette Industries, Inc./ Weyerhaeuser Co.).

Co-op Staff

Members of the NOCTIC, TRASK and Vernonia/Ryderwood metacooperatives voted to have the installation of second-generation tests coordinated by NWTIC, and to make funds available to create a Test Coordinator position at NWTIC starting in 2003. With fewer company personnel to oversee test installation and maintenance, members felt that their interests would be well served by funding an NWTIC staff person to keep close track of the new second-generation tests. No other staff changes took place.

Forwards vs. Backwards Selection for Seed Orchards and Cooperative Second-Generation Breeding in the US Pacific Northwest

Randy Johnson and Keith Jayawickrama

Executive Summary

Gain from various orchard strategies were modeled. The scenario tested 2,000 first-generation open-pollinated families, from which orchards of 20 selections were formed, using either parents, progeny or both. This was followed by a second-generation breeding population in which 200 full-sib families were tested followed by a second-generation orchard of 20 selections.

The results showed that a 1.5 generation seed orchard (recruit from many first-generation open-pollinated testing programs with lots of parents from which to choose) using parents would give more gain than all-progeny orchards and is essentially equal to the gain from selecting both progeny and parents. However, the situation was changed in the second cycle; in many cases progeny will have the highest expected gain. Gains from a second cycle of breeding and testing 200 full-sib families (and choosing the best 20 parents or progeny) approached gains from testing 2,000 open-pollinated families and selecting the top individuals from the top 200 families. This is reassuring given that the second cycle will cost only around 10% of the first cycle, if costs per planted tree remain constant.

There appeared to be good justification for selecting based on age-6 data, establishing an orchard, and roguing based on age-12 data rather than waiting for age-12 data to begin building the orchard.

Introduction

The question has arisen whether to use “backwards” selections (i.e. tested parents), “forwards” selections (in this case, mainly untested progeny from open-pollinated tests), or a combination of parents and progeny, both in seed orchards and in breeding. Those are the three main options currently available for cooperative breeding programs and seed orchards in the US Pacific Northwest. Which option will give the most gain, and which is the most reliable? The questions are important, since several 1.5 generation orchards are being established and we are in a period of intense activity for second-generation breeding and testing. They have been explored in some publications (e.g. Burdon and Kumar in press, Hodge 1985 and 1997, Hodge and White 1993, Ruotslainen and Lindgren 1998) ; however, a study focusing on the situation in the US PNW is also worthwhile. We therefore tried to shed some light on this issue for the benefit of NWTIC members.

When using parents, we have a good idea of what to expect because we have already tested their progeny. We also have good precision when selecting parents since across-site family mean heritabilities (h^2_f) tend to be between 0.6 and 0.8 for many cooperative first-generation test series. The expected gain from selecting families is a direct function of family mean heritability (expected genetic value = h^2_f x family mean). Assuming a family-mean heritability of 0.75, the correlation between the family mean and its genetic value is $r = ÷ h^2_f = h_f = ÷0.75 = 0.87$. If we deploy seed by family (i.e., seed orchard parent) and want to match families and sites, then it is always good to be sure we have the appropriate family.

We can also select progeny for seed orchards. In theory we increase gain every generation of breeding so the next generation of selections should be better than the last. A concern with forward selections is that the breeding value of each selection has considerable variation associated with it (unlike parental selections). This is because selecting the best trees within families is relatively imprecise (within-family heritability = h_w^2 = 0.15-0.25). One solution is to select several trees from the best families (after testing) because at least one selection usually ranks highly. This is strictly a function of increasing the sample size (population size) to reduce the extra variation associated with forward selections. It is also possible that individual trees have been wrongly labeled and mapped - such errors usually have more serious consequences on forward selections than on selecting families. Mislabeling 1% of the trees thought to belong to a half-sib family will have little effect on the ranking of the parent, however, if we mistakenly use a mislabeled forward selection it could affect gain considerably. So, while identifying good families is fairly fool-proof, we aren't sure we have the best progeny selections. Another drawback to an orchard of forward selections is that you don't have data to match families to sites.

There is also a difference in selection efficiency between selecting individuals from open-pollinated families and full-sib families. In open-pollinated families we can pick the right female parent with good precision, but have no data on the male parent. Full-sib families allow us to choose the right female parent and male parent. In theory, the variation we select upon can be partitioned into three parts; additive genetic variation associated with the female parent (1/4), that associated with the male parent (1/4) and within-family variation (1/2). In open-pollinated trials we select with the efficiency of the family mean heritability (h^2_f) on only the female parent, and the within-family heritability (h_w^2) on the rest. With full-sib families we can select both the female parent and male parent with the efficiency of h^2_{fm}; therefore one would expect more gain from selecting in full-sib trials than open-pollinated trials.

Methods

Computer simulation allows you to generate populations by first making genotypes and then adding environmental variation. You then select on the phenotypes (family means or individual values), and see what happens to the genotype (the actual genetic gains). Our simulations also considered using an early assessment (we chose age-6) and a later assessment (age-12). Age-age correlations were estimated with age-5 and age-11 height data from the Nehalem series, where the age-age genetic correlation (r_a) was estimated to be 0.716 and the age-age environmental correlation (r_e) was estimated to be 0.37. Comparing that with Johnson et al. (1997), age-age genetic correlations reported were: 5-10 = 0.69, 7-15 = 0.85, 10-20 = 0.90. For the simulations we assumed an age 6 and 12 assessment with the following correlations: r_a = 0.72, r_e = 0.37. The baseline breeding programs modeled the case starting with 2,000 open-pollinated families; though we also briefly examined first-generation simulations with differing numbers of starting OP families. This number of 2,000 families is representative of the number of families from which a typical second-generation metacooperative was formed.

Building on the first-generation of 2,000 OP families, we then selected the top 200 families based on family means (a 10% selection intensity as in the BZERC strategy). From each of these 200 families we chose the best tree based on its phenotype to go to the second generation. These 200 selections were then crossed in a disconnected 2 x 2 factorial mating design (this results in the same number of crosses per parent as the pair-matings in the BZERC strategy, and is easier to simulate).

Different trial designs were modeled for each generation to mimic the differences in cooperative first- and second-generation trials. First-generation trials had eight progeny test sites with 12 trees per family per site; second-generation trials had six progeny test sites with 20 trees per family per site. Genetic variation was partitioned such that narrow sense heritability at a site was 0.25 and the type B genetic correlation among sites was r=0.70. The additive variance was set to 10 and dominance variance was 4.

For both the first- and second-generation programs, we looked at seed orchard gains from nine different selection options. For each generation, we used only the progeny test information from that generation, i.e., we did not use first-generation data when selecting second-generation parents or progeny. For a given set of data, seed orchard candidates could be progeny, parents or both. For each of these options we examined three selection age scenarios:

- Select the top 20, limited to 1 selection per family, using age-6 data.
- Select the top 40 (no more than 2 per family) on age-6 data, and rogue to the best 20 using age-12 data.
- Select the top 20 selections, limited to 1 selection per family, using age-12 data.

Gains were derived from age-12 genetic values in standard deviation units, scaled to 30% gain for the scenario modeling the first generation where the best 20 parents or progeny are selected on age 12 data. 30% gain is a reasonable target for age-12 or age-15 volume gain from a 20-clone orchard based on 2,000 tested families. For the option where we selected both parents and progeny with age-12 data, we noted the number of parents selected (as opposed to progeny).

Simulations were run 225 times, and the average gain and standard deviation of the gains were generated. The percentage of times that the 20 best progeny were better than the 20 best parents was also noted for all three of the selection age comparisons.

Results And Discussion

The average gains indicate that, for the first-generation program simulated, parental orchards are generally superior to orchards based entirely on open-pollinated progeny (Table 4, Figure 2). The opposite held in the next generation with full-sib crosses (Table 4, Figure 3). In either generation, using a combination of progeny (forwards) and parental (backwards) selections yielded the highest gains (on average).

In the first generation simulation, progeny orchards were superior to parent orchards in only 6% to 16% of the runs (Table 4). Not only were there higher gains in the parental orchards, but there was less variation associated with the gain estimates (Figure 2). The combined orchards using age-12 data averaged 19 parents and only one progeny. The advantage of using parental-selections increases with increasing numbers of starting parents (OP families) (Table 5). This is because as more parents are tested, a larger number will be found that have truly superior breeding values. With small number of starting parents, a progeny orchard could well be superior.

Table 4. Percentage of times that a progeny (forwards selections) orchard was superior to a parental (backwards selections) orchard for a first –generation open-pollinated program and a second-generation control-pollinated program (see text for details).

Orchard Scenario	Breeding program type	
	1st-generation open-pollinated	2nd-generation control-pollinated
Best 20 based on age-6 data	15 %	93 %
Best 40 based on age-6 data, roguing to best 20 on age-12 data	6 %	84 %
Best 20 based on age-12 data	16 %	95 %

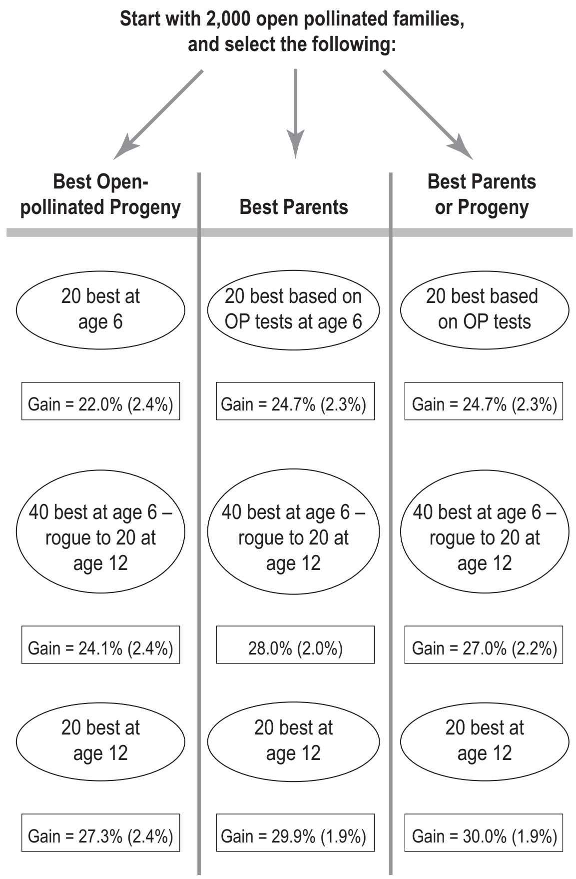

Figure 2. Gains from a first-generation testing program: for a 20-clone, 1.5 generation orchard constructed by one of nine methods. Standard deviations of gain estimates given in parentheses.

It is hard to find an OP progeny better than an outstanding parent because considerably more within-family gain is needed such a parent than an average patent. Consider the two open-pollinated (OP) families depicted in Figure 4. Both families A and B are better than the population average. The breeding value of the female parent for each of these families is twice the deviation of the family mean from the population average. This is because we assume that the pollen parents of an OP family represent the population average; and the family mean is the result of the average of female parent and the pollen average. When calculating the breeding value of a within-family selection (a progeny) we only get half the female parent's breeding value since only half its genes come from the female parent; therefore, the family gain component is represented by the family

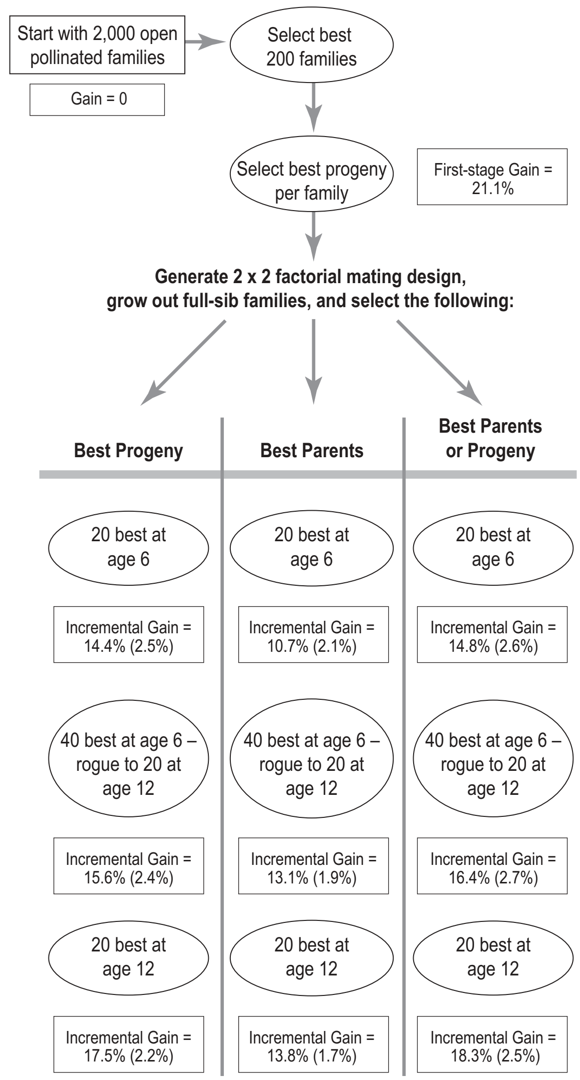

Figure 3. Gains from second-generation testing using 2 crosses per parent, where a 20 clone orchard is constructed by one of nine methods. Standard deviations of gain estimates given in parentheses.

mean. Gain from within-family selection must exceed the gain from the family selection in order for the progeny to be superior to the parent.

When we examine the full-sib crosses in the second generation of simulations, orchards using the best progeny are more often superior to orchards using the best parents (Figure 3). In the combined second-generation orchard, selecting on age-12 data, there were an average of four parents and 16 progeny in the second-generation (ranged from 0 to 8). The reason that progeny were generally better than parents is that gain from family-selection when using full-sib

Table 5. Average gains from progeny and parental orchard, the percentage of times progeny orchard is best, and percent of progeny in a combined orchard; for a first-generation open-pollinated breeding program with different numbers of starting parents, i.e. open-pollinated families. All orchard selections were based on age-12 data and selecting 20 clones.

	Starting number of open-pollinated families			
	250	500	1,000	2,000
Progeny orchard gain (%)	22.6	24.0	25.8	27.4
Parental orchard gain (%)	21.1	24.3	27.4	30.0
% of times progeny orchard gives more gain than a parental orchard	67%	45%	24%	16%
Average number of progeny selections in a combined orchard	53%	32%	14%	4%

families obtains gain from precise selection of both the female and male parents . When two superior parents are crossed, the difference between the family mean and the best parent's breeding value is much less than that with OP families. This is shown in Figure 4; less within-family gain is needed to bridge the distance from the AxB full-sib family mean to the breeding value of parent B.

As expected, gains based on age-12 data were higher than gains based on age-6 data. However, establishing an orchard based on age-6 data and roguing at age 12 approached (within 1 to 3%) the gain from waiting to age-12 to start establishing orchards.

Gains from the second cycle of breeding and testing (200 full-sib families + orchard selection) of approached gains from the first cycle (as defined by testing 200 open-pollinated families and selecting the best progeny from 200 families) at 18% compared to 21%. This is reassuring given that the second cycle will cost around 10% the cost of the first cycle, if costs per planted tree are considered constant from the first- to the second generations. The highest cumulative gain from two cycles was 39.4%, 9.4% above the highest gain from the first cycle. This gain of 9.4% does not include unknown (but potentially large) gains from expanding breeding zones and using faster-growing sources from outside the first generation breeding zone. The simulation mimics a situation where all breeding zones have the same mean; it is likely that the second cycle will pinpoint seed sources which are genetic "hotspots" and which can be deployed widely throughout the second-generation breeding zone.

It is worth pointing out that in each cycle, we can generate a certain amount of gain from breeding and testing a relatively large breeding population, and

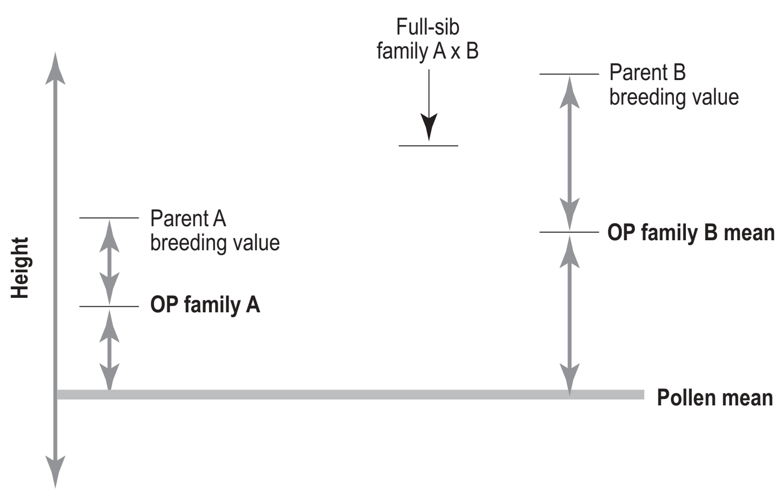

Figure 4. Relationship between a half-sib family mean and the parents' breeding value

extract further gain by "creaming off" the best for orchards (the production population). For the first cycle in the US PNW, the sum of those two gains could be very large (if we are very selective when establishing orchards) since a very large number of families were tested. For the second cycle, we would get gains from two cycles of testing and a subsequent "creaming off" step; the sum of those three gains will be larger than (but not double) the gains from an elite 1.5 generation orchard.

It is worth comparing these results with the publications referred to previously. Hodge and White (1993) found the top ranking parental selections to have higher breeding values than the top ranking offspring selections (from full-sib crosses) with populations of 201 and 2001. One difference with their study was that the full-sibs were random crosses, with no selection of the parents (unlike the BZERC model in which only the top 10% were crossed). Ruotsalainen and Lindgren (1998) similarly showed that where one exerts a high selection intensity, the best parents will beat the best open-pollinated progeny. For example, with a heritability of 0.2 and a selection intensity of 1 in a 100, the backward selection had a higher breeding value than the highest-ranked open-pollinated family selection in 25% of the families. Burdon and Kumar (in press, modeling a situation with 300 tested first-generation parents) found results very similar to ours. In their case, the best 15 (of 300) first-generation parents beat the best 15 forward selections from the 300 open-pollinated families, but were in turn beaten by the best 15 progeny in full-sib trials.

Reference to the southeastern USA (where an extra cycle of breeding and testing has been completed) can be instructive. For example, the third cycle slash pine breeding population of 466 selections is to contain 71 backward selected first-generation parents, 95 backward selected second-generation parents and 300 untested third-cycle selections (White et al. 2003).

We have a chance to further boost the gain from the second cycle of testing by doing everything possible to increase the heritability in the tests being planted. We assumed an individual heritability of 0.25, but with good site selection, preparation and maintenance we may hope to increase that. Some within-site heritabilities of 0.5 were obtained in the best first-generation tests, although such within-site estimates are potentially biased upward by genotype x environment interaction.

Implications

Most cooperative 1.5 generation seed orchards (such as the Interim Dallas orchard grafted in 2002) recruit from many first-generation open-pollinated testing programs and have lots of parents from which to choose. In these cases, using parental selections would give more gain than all-progeny orchards and is essentially equal to the gain from selecting both progeny and parents. With small number of starting parents, a progeny orchard may be superior.

However, progeny will be more important in achieving gain after the second cycle of breeding and testing. Combined orchards will be the norm, and in many cases progeny will have the highest expected gain.

Gains from the second cycle of breeding and testing (200 full-sib families + orchard selection) of approached gains from the first cycle (as defined by testing 200 open-pollinated families and selecting the best progeny from 200 families) at 18% compared to 21%. This is reassuring given that the second cycle would cost only around 10% of the first cycle, if costs per planted tree remain constant.

There appeared to be good justification for selecting based on age-6 data, establishing an orchard, and roguing based on age-12 data rather than waiting for age-12 data to begin orchard establishment.

NWTIC cooperators have an opportunity to further boost the gain from the second cycle of testing by doing everything possible to increase the heritability in the tests being planted (with good site selection, preparation and maintenance).

Caveats and Context

As in many simulations, the main benefit is to compare the relative merits of different options, rather than to predict the absolute values. Thus we can infer the relative gain from backwards vs. forwards selections from this exercise, but it is not designed to give an accurate estimate of gain for a given second-generation breeding program or orchard.

As in many simulations, changing the assumptions and input parameters would impact the results. For example, increasing the individual heritability from 0.25 to 0.50 would increase the gain from forward selections faster than it would increase the gain from backward selection.

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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