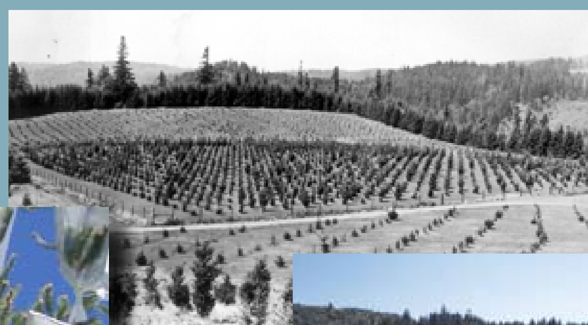
Oregon State University College of Forestry

Northwest Tree Improvement Cooperative

Annual Report

July 1 2006 to September 30 2007

February 2008



Members of the Northwest Tree Improvement Cooperative as of June 30 2007

Bloedel Timberlands
Bureau of Land Management
Cascade Timber Consulting, Inc.
Forest Capital Partners
Fruit Growers Supply Co
Giustina Land and Timber Co
Giustina Resources
Green Crow Management Services
Green Diamond Resource Co.
Hampton Tree Farms, Inc.
Hancock Forest Management
Lone Rock Timber Company
Longview Timberlands
Miami Corp.
Oregon State Department of Forestry
OSU College Forests
Plum Creek Timberlands L.P.
Pope Resources
Port Blakely Tree Farms L.P.
Quinault Indian Nation
Rayonier Timberlands Operating Co.
Rocking C Ranch
Roseburg Resources Co.
Seneca Jones Timber Co
Sierra Pacific Industries
Silver Butte Timber Co
South Coast Lumber Co.
Starker Forests, Inc.
Stimson Lumber Co.
The Campbell Group
Timber West Forest, Ltd.
Washington Department of Natural Resources
West Fork Timber
Weyerhaeuser Company

Liaison Members

Pacific Northwest Tree Improvement Cooperative
USFS-PNW Research Station Genetics team

Northwest Tree Improvement Cooperative

Annual Report

July 1 2006 to September 30 2007

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February 2008

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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

Contents

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.

Table 1. Summary of advanced-generation Douglas-fir trials established in 2007

Program	Entries	Number of			Purpose
		Locations	Test Trees	Test Trees + Fillers + Buffers	
WACTIC Phase I (2nd sowing)	158 families +2 woodsrun controls)	4	12,960		• Rank families and parents • Verify breeding zone(s) • Make forward selections
Trask Coast Phase II	91 families +4 woodsrun controls)	5	9,712	13,416	
Trask Inland Phase III	91 families +4 woodsrun controls)	5	9,542	12,789	
ROSETIC Umpqua Phase I	101 families +2 woodsrun controls	5	10,364	13,925	

Puget Sound

The five Puget Sound metacooperative Phase I tests were visited in 2007, and a decision was taken to measure them in fall 2008. Puget Sound intends to sow the Phase II tests in early 2008, and the form and emphases of 3rd cycle programs in Washington are being discussed. Some rearrangement compared to the current configuration is possible.

Washington Coast

Crossing continued for the Washington Coast program. The Phase I tests were sown in the winter of 2006-7, with 106 crosses to be planted in spring 2008 on five sites covering the range from near Raymond to Forks. All sites have been selected and prepared.

Washington Cascades (WACTIC)

Crossing continued for WACTIC; 14 crosses were attempted at each of the two USFS orchards (Cispus and Planting Creek), eight crosses at DNR's Meridian orchard, seven Skagit crosses at Hampton's Olsen Creek orchard, five crosses at Bloedel's orchard, and 42 crosses at the Lebanon Regeneration Center (a total of 90 crosses). One interesting development has been the use of a tow-behind, battery-powered lift capable of reaching to 25 feet. Such devices are available for monthly rental, and are very useful for operating at remote facilities without on-site lifts.

WACTIC planted the second four of eight Phase I sites. The two low-elevation sites were planted shortly after lifting, while seedlings for the two high-elevation sites were frozen and planted in May. All sites have been visited regularly and carefully maintained.

West Fork Timber, Bloedel Timberlands and Pope Resources decided to join WACTIC. With these membership changes, WACTIC gained further strength, serving over 700,000 acres of productive Douglas-fir timberland.

Vernonia/Ryderwood and NOCTIC

The five Vernonia/Ryderwood Phase I sites were measured and the data analyzed during this period. Data from the Vernonia, Vernonia SE and Ryderwood first-generation programs were included for a cross-generation analysis. Forward selections from the second-cycle tests were grafted in one production orchard and one breeding orchard in spring 2007.

There was some mortality at the Vernonia/Ryderwood clone banks established in spring 2006; this is being addressed by planting new rootstock and grafts. Discussions began on progressing Vernonia/ Ryderwood to a third cycle of breeding and testing; four cooperators showed interest in moving forward. Rootstock were planted in spring 2007 for a breeding orchard.

NOCTIC Phase I sites were measured and the data analyzed during this period. Data from the Snow Peak and Molalla programs (which each contributed substantial numbers of crosses to Phase I) were included for a cross-generation analysis. Forward selections from the tests were grafted in one production orchard and one breeding orchard in spring 2007.

There was minimal mortality at the NOCTIC clone banks established in spring 2006; this is being addressed by planting new rootstock and grafts. Discussions began on progressing NOCTIC to a third cycle of breeding and testing; three cooperators showed interest in moving forward. Rootstock were planted in spring 2007 for a breeding orchard. It is likely that strong emphasis will be placed on wood quality (especially wood stiffness) in this 3rd-cycle "CASTIC" program, and there may be a smaller satellite high-elevation program. Giustina Resources joined NOCTIC during this period.

TRASK

Five Coast Phase II and five Inland Phase II sites were planted in February 2007. These Phase II sites were visited, maintained and tagged during the summer. Following a site tour, the decision was taken to postpone measurement of Coast Phase I sites to fall 2009 (age-7 from seed); overall growth was judged too low on a couple of sites for measurement in fall 2008. Two or three of these sites are being impacted by Swiss Needlecast.

Discussions began on progressing TRASK to a third cycle of breeding and testing; several cooperators showed interest in moving forward. It is quite possible that TRASK will be merged with Vernonia/Ryderwood when progressing to the 3rd cycle. Rootstock will be sown in winter 2007-8 for a breeding orchard.

South Central Coast

The SCC Phase I tests (Mainline, Needlecast and Family blocks) are in the process of being measured at age-7 from seed; Plum Creek's CL98 tests, which have been merged with SCC, are also to receive their age-10 measurement. The combined measurement of these programs is a very large project, with over 70,000 test trees. We can anticipate that the final measurement of the Phase I sites, in a few more years, will be an even larger project and will require careful planning. As trees grow bigger, measurement becomes ever more expensive and there are fewer contractors available for such work.

Needle retention was assessed in the Needlecast sites in spring 2007 and in the same families in three mainline sites. This was funded by the Swiss Needlecast Cooperative (SNCC) as part of a joint project between SCC, SNCC and NWTIC.

Dead trees were replanted in several Phase II test sites. Rootstock have been established for a 3rd-cycle breeding orchard.

Roseburg-Umpqua (ROSETIC)

The first group of ROSETIC tests were established in February 2007; 101 crosses were planted on five sites. Over 90 crosses were attempted, mostly at BLM's Tyrell orchard and some at GLT's Parvin orchard; 150 pollens have been collected (at the orchards mentioned above and at BLM's Provolt orchard) and 330 ramets stimulated for the 2008 crossing season.

Table 2. Status of / plans for cooperative second-generation Douglas-fir breeding populations as of 2007.

Location	Status	Number of Crosses			Test Establishment			
		Total Popu-lation Size	Planted or Sown	Local or Elite Crosses w/ Sufficient Seed1	Target Number	Number Established	Start Planting in Spring Of	Complete Planting in Spring Of
Washington Cascades	Planted 4 sites (first sowing of Phase I), seed sown for second set of 4 sites	300	160	300[1]	16	8	2006	≈2011
Puget Sound	Planted 5 sites in 2003 (Phase I, 143 crosses)	276	143	90[1]	10	5	2003	≈2009
Washington Coast	Sowed first Phase in winter 2005-2006	160	-0-	137[1]	5	-0-	2008	≈2012
Vernonia/Ryderwood	Test establishment completed	404	416	325[2]	10	10	2001	2005
North Oregon Cascades	Test establishment completed	414	399	350[2]	11	11	2001	2005
Trask (*Coast + Inland*)	Test establishment completed	550	500	427[1]	21	21	2004	2007
South Central Coast	Test establishment completed	760[1]	604	604[2,3]	20[3]	20	1998[3]	2006
ROSETIC- Umpqua	Planted 5 sites in winter 2006-2007	160	100	250	10	5	2007	2011
ROSETIC-Roseburg Low	Crossing	200	-0-	-0-	8	-0-	2011	2011
ROSETIC-Roseburg High	Crossing	100	-0-	-0-	4	-0-	2011	2011
TOTAL		2,658		≈2,268	346	80		

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

Technical Updates and Developments

As expected, the draft 3rd-cycle breeding strategy presented in 2006 evolved, was expanded and discussed during this year. While several aspects of the strategy have gained general acceptance (especially increasing the number of crosses per parent while decreasing the number of progeny planted per cross), changes suggested by various individuals and cooperators included (1) More emphasis on wood properties (e.g. stiffness) than in the second cycle (2) Modifying the testing strategy to position co-operators for possible climate change (3) A separate small subprogram for high-elevation land (e.g. for the Oregon Coast Range or the Oregon Cascades). However many cooperators have affirmed their interest in continued genetic gain in volume, tree form and adaptability, while maintaining wood quality -i.e. a similar direction to the 2nd-cycle- as their highest priority. Ultimately the nature and emphasis of each 3rd-cycle program will be decided by the organizations involved. It will be interesting to see how these various scenarios unfold.

Traits to be measured and the specifications for 2nd-cycle tests were further refined. The suite of traits under consideration are budburst, height, dbh, incidence of forking, incidence of ramicorns, sinuosity, crook/sweep, needle retention, wood specific gravity, and accoustic velocity (or other indirect measures of stiffness). Not all of these traits will be measured in each program.

There has been progress on starting a "Seedlot Rating System" in the US PNW. Paul Chapman of The Campbell Group chaired the NWTIC subcommittee formed to work on this. Building on an initial draft by Randy Johnson, NWTIC has formulated a set of tables, data-entry forms and views in MS-Access that generates a seedlot rating (height gain, dbh gain, volume gain and effective population size). In the process, NWTIC also generated age-5 predicted gains for a number of programs, and developed an age-age gain regression equation to adjust early (e.g. age-9) gains to age-15 gains, since most existing orchards were largely established based on age-15 data. The system has provisionally been named DFISR (Douglas-fir Improved Rating System).

The simulation study on combining 1st and 2nd cycle data into a combined analysis was published in Tree Genes and Genomics. A second paper on spatial analysis was submitted to the same journal and is close to being accepted for publication (a summary is provided in this annual report).

NWTIC has researched, developed and written up a standard data analysis protocol for co-operative 2nd-cycle programs, in much the same way as a protocol was developed for first-generation programs. As part of this process, we obtained comments on the protocol from three outside reviewers.

On behalf of its members, NWTIC is staying abreast of current research on wood stiffness and strength, especially studies conducted in the PNW (by the Pacific Northwest Tree Improvement Research Cooperative, the Stand Management Cooperative and other work at OSU), and work in Australasia. It is likely that non-destructive stiffness testing will be incorporated into operational tree improvement of Douglas-fir (and perhaps western hemlock as well) in the near future. A review and synthesis is also under preparation on this topic.

Genetic Gain Trials Demonstration Plantings

Herbicides were applied at NWTIC expense and under NWTIC direction on the six Grays Harbor Genetic Gain / Type IV trials in April and June 2007.

Regrettably, the age-10 (from planting) measurement of the Molalla Genetic Gain trial did not go as planned, and useable data were only obtained from one site during this period. The new plan is to measure the other four sites in fall 2008 (12 years from planting, 15 years from seed). It is also apparent that considerable investment will be needed to retag the sites within the next few years.

Genetic gain demonstrations were established using overrun seedlings from Trask Coast and Inland Phase II, and ROSETIC phase I. This brought the total of NWTIC-led demonstration plantings to 16.

Data Management, Analysis and Reports

Work has continued on updating the database. The NWTIC directory now holds 35,285 files. Of the 32,567 parent-tree records expected, the database contained complete data for 31,643 records by June 2006. There were also data on 1,851 cross-tested parents involving 94 programs; a minority of first-generation parents were tested in two (or perhaps three) programs; cross-testing was generally in adjacent breeding zones.

In addition to continued work loading progeny measurement files into SQL server, and making them available through views that could be called up in Microsoft Access or on the member-access website. By June 30, 2006 3,623,227 records had been loaded (355,618 for 2nd-generation programs), and 1,112 views (92 of which were 2nd-generation) had been created.

Information on full-sib and polymix crosses were updated as information was received. These were mainly crosses made by the advanced-generation Douglas-fir and western hemlock metacooperatives, but also included crosses sown in the first generation tests. By September the database contained records on 5,793 full-sib and polymix crosses (4,803 of which were made for the 2nd-generation testing effort).

The member-access secure website has been updated and improved. It is now set up to allow viewers to view and download Excel datasets, meeting notes, progeny data files etc. NWTIC also filled over 40 individual requests for data, analyses. As mentioned previously, NWTIC also developed a system to generate Seedlot Ratings for the "Douglas-fir Improved Seedlot Rating" system.

NWTIC maintained a strong emphasis on data analysis, completing genetic gain predictions and reports for 17 first-generation breeding units and one advanced-generation programs.

Table 3. Summary of genetic gain predictions using BLUP, and reports, completed July 2006 through September 2007

First-Generation Analyses	
Age-5 heritabilities + breeding values for 6 programs: Burnt Woods II, Snow Peak High, BLM Lorane, Snoqualmie BU1 & BU2, Forks	D-fir
Age-age predicted gain regression for Seedlot Rating Protocol age adjustment	D-fir
Medford Evans Elk BU-1	D-fir
Medford Evans Elk BU-2	D-fir
Grays Harbor	Hemlock
Medford Jacksonville BU-1	D-fir
North Umpqua BU-5&6	D-fir
Plum Creek Coos Bay Coastal	D-fir
Plum Creek Coos Bay Inland	D-fir
Plum Creek Coos Bay Plus	D-fir
Reedsport Age 15/18 DBH, combined analysis of Reedsport and Umpqua Coast programs	D-fir
Submit manuscript on spatial analysis	D-fir
Second-Generation Analysis	
Vernonia Age-7 data + Age-7/10 First-generation data	D-fir
NOCTIC Age-7 data + Age-7/10 First-generation data	D-fir
Puget Sound Phase I Age-4 budburst data	D-fir
Cascade Timber High-Elevation full-sib program Age-23 data	D-fir
Write up detailed standard protocol for analysis of 2nd-cycle tests (spatial detrending, combining appropriate 1st-cycle data, and a selection index to combine with age-15 1st-cycle data), obtain reviews and comments, modify protocol as appropriate.	D-fir

Incorporating Genetic Gain into Regional Growth Models

This has been clearly identified as a priority for most NWTIC members. The report on the Agenda 2020 project formulated by the USFS PNW Research Station is shown elsewhere in this report. There has also been some progress in two growth models used in the region (*NOTE: This growth model development was not funded or co-ordinated by NWTIC, but is reported for the information of members).* For both models, the following is true: 1) Multipliers have been built for both ht and dbh and 2) Growth equations are not modified, the multipliers are applied to the results.

ORGANON

Mark Hanus has developed a database interface for the Bureau of Land Management which allows the use of Genetic Growth Multipliers to adjust for different levels of Genetic Gain. He is also working on a Windows shell that will be available from the ORGANON page of the College of Forestry web site at Oregon State University.

1. Since ORGANON is a stand simulator (i.e. it runs on sample data), the effects start when the user tells them to and stop when the user tells them to.

2. The user controls the values of the multipliers; he/she may change them at every cycle, keep the multipliers constant over time, or build in a decay function. For example, if the user "believed" that the multiplier decreased by 0.1x each five years, they could input a multiplier x @ 15, 0.9x at 20, 0.8x at 25 etc.
3. Mortality is a function of tree and stand conditions, so if the trees are projected to grow faster due to the growth multiplier, mortality may also increase. Larger diameters cause an increase in mortality to keep the size density in line. This is balanced (mortality decreases with increasing crown ratio) by the potential increase in crown ratio caused by the height growth multiplier. If the diameter growth multiplier is much larger than the height growth multiplier then mortality may increase. This will probably differ based upon the data set.
4. At present it is possible to start a run at age-5, age-10 or age-15 (typical ages at which we can expect to have gain predictions and growth multipliers) if one can generate tree lists for stands at those ages.
5. Documentation on ORGANON is available at: http://www.forestry.oregonstate.edu/cof/fr/research/organon/

CONIFERS

1. The user will put in a single "genetic worth value." The multiplier for different ages is calculated as a function of that. The simulator grows in annual increments and will make the age transition on its own.
2. There is currently no age or size restriction on CONIFERS. The developers suggest running it to age 10 to 20 depending on stand conditions, and not beyond age 25.
3. The version currently being developed is partially supported by the Stand Management Cooperative (based at the University of Washington) for western Washington and NW Oregon. It has not been released yet; anticipated release is in early 2008.
4. If the trees are projected to grow faster due to the growth multiplier, there could possibly be an increase in mortality in extreme conditions. It depends on assumed maximum SDI, site index, plantation spacing, and the age to which the stand is projected.
5. Developers anticipate that most users will use CONIFERS to simulate very young stands, and input the resulting tree list to ORGANON by say age 15 (or thereabouts).
6. Some documentation on CONIFERS is available at: http://www.fs.fed.us/psw/programs/ecology_of_western_forests/projects/conifers/

Getting Genetic Gain In Operational Plantations

2007 was a heavy seed producing year for coastal Oregon, Washington and BC, with even unstimulated trees in the woods bearing cone crops. The recently rogued orchards (the Skagit orchard on Whidbey Island and the orchard near Bellingham, Guistina Land and Timber's Parvin orchard) were among those producing seed, along with an orchard in Washington which produced about 12 lbs/acre/year only six years from grafting. There were some Controlled Mass Pollination (CMP) projects undertaken, both at Schroeder and at CTC's Mason orchard.

There was further progress on establishing cooperative orchard blocks to serve the ROSETIC area. Three blocks are being established: "Roseburg Low", Roseburg Cascades", and "Elk Creek". A co-operative "South Central Coast" orchard is also being established. Other new 1.5-generation orchard blocks are being established (by individual cooperators) for the high-elevation North Oregon Cascades area, the McKenzie area, the South Central Coast area, the Roseburg breeding zones, and the Mid-Columbia area.

There has been little progress on a cooperative orchard for the Washington Cascades area, but Plum Creek's Whidbey Island seed orchard was finally sold (to Longview Timberlands). An interesting aspect of this last-mentioned sale was the involvement of organizations which saw the value of the property remaining in forestry / agricultural use, and not being converted to real estate. With the growth of suburbs and population in western Oregon, Washington and coastal British Columbia, many orchards once in rural and agricultural settings are now surrounded by houses and development; while such settings are desirable in many ways for orchards - e.g. less pollen contamination, ease of operation, availability of labor - high population density imposes its own challenges (such as conflicts over use of pesticides).

With the emphasis on shortening the delay to obtaining seed from high-gain 1.5-generation orchards, some co-operators have tested the use of large container stock such as 815A or 1015A seedlings, with the objective of field grafting no more than one year after planting the rootstock. In some cases the objective has been achieved, but not in others. Conditions that favor seedling establishment (especially warm soil temperatures in spring, abundant soil moisture in spring and summer, control of rodents) will increase the likelihood of reaching graftable size in one growing season.

NWTIC again attempted to collate the number of coastal Douglas-fir and western hemlock seedlings planted by members, since there are no other published reports on the number of seedlings derived from orchard seed planted in Oregon and Washington. While data were not provided by non-members (some private companies and non-industrial woodland owners), the figures in Table 9 provide some idea of the impact of the tree improvement programs in the region.

Table 4. Survey response on the number of coastal Douglas-fir and western hemlock planted by NWTIC members in 2007

Year	Coastal Douglas-fir			Western Hemlock		
	Clonal/seedling orchard	Rogued progeny test	Woodsrun	Clonal/seedling orchard	Rogued progeny test	Woodsrun
2005	53,737,985	1,469,000	7,292,511	5,342,251	-0-	1,437,774
2006	56,437,587	1,595,000	6,994,261	4,775,327	-0-	1,771,017
2007	59,375,026	957,443	9,564,035	3,981,237	-0-	1,711,605

Celebrating Milestones

2006 marked two important milestones: **40** years since the launch of the "IFA-Progressive Tree Improvement System", and **20** years since the founding of NWTIC. A special, memorable Anniversary meeting was held (at a unique and fitting Oregon forestry location, Camp 18 Restaurant on Hwy 26) in September 2006. We were fortunate to have several individuals (including Mike Bordelon, Bob Campbell, Don Copes, Jess Daniels, Howard Dew, Bob Lee and Nancy Mandel) whose involvement in the programs dated back to the 1980s, 1970s and even the 1960s, and anecdotes related, humorous and otherwise, of people, events, how things used to be and how they became what they are now.

Membership Changes

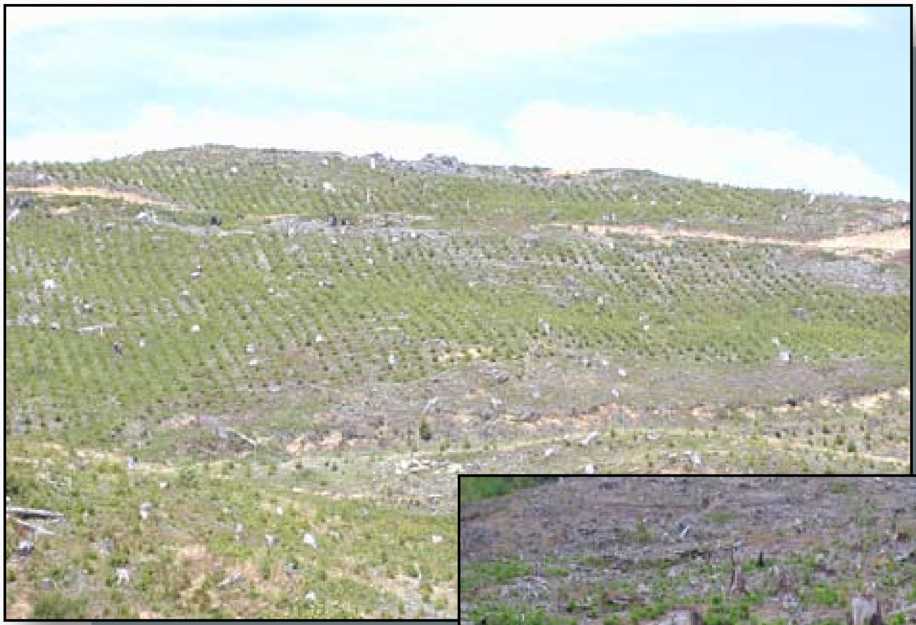
West Fork Timber and Bloedel Timberlands joined NWTIC in late 2006, and Giustina Resources and SDS Lumber Co joined NWTIC in 2007. With the purchase of Swanson Group lands by Plum Creek, nearly 100,000 acres were added to NWTIC. NWTIC is pleased to welcome all these organizations!

Pacific West was sold in late 2007, with implications for NWTIC, Vernonia/Ryderwood, NOCTIC and South Central Coast. The effects of that land sale on the various cooperatives are currently being worked out. Last but not least, Weyerhaeuser announced its withdrawal from NWTIC, and the second-generation cooperatives it was involved in, at the end of 2007.

Puget Sound Phase I Test site.

NOCTIC Phase I: forward selection at CTC's McDowell Creek site. (Photo courtesy of Bill Marshall, CTC)

NOCTIC Phase II: Port Blakely's site in 3rd growing season.



TRASK Coast Phase I: Plum Creek's Bull Run site.

TRASK Coast Phase I: Stimson's Stock Tank site.

Tow-behind lift used in WACTIC crossing at USFS orchards. (Photo courtesy of Karen Blair, WA DNR)

ROSETIC Phase I site.

SCC Phase 1: Big Rush site.

WACTIC Phase I site. (Photo courtesy of Karen Blair, WA DNR)

Grays Harbor Genetic Gain / Type IV site: Donkey Creek (Rayonier)

Puget Sound genetic gain demonstration: DNR NW site (elite cross on left, woodsrun in middle)

NOCTIC Genetic gain demonstration: CTC Jack32 site (elite seedlot on right, woodsrun on left)

Table 5. Status of Overall Douglas-fir breeding population including cross-testing of second-generation crosses as of September 2007

	First Generation Program	Elevation	# of 1st Gen Parents	(# crosses used by) Second Generation Meta-coops											
									Trask		South Central Coast				
				WA Coast	Puget Sound	ROSETIC	WA Cascades	Vernonia/Ryderwood	Coast	Inland	Main	Family Blocks	SNC	Coost Bay CL98	NOCTIC
NOCTIC	BLM McKenzie	800 - 4,050'	576					1		1	3				19
	BLM Molalla BU-30	600 - 3,000'	188				3	2		3					23
	BLM Snow Peak BU-33	700 - 2,640'	198				4	2		1					26
	USFS Blue River McKenzie Mid	2,300 - 3,000'	211												3
	USFS Detroit Sweet Home 18032	2,050 - 2,920'	209					1							6
	USFS Estacada 202-06013	2,000 - 3,000'	358												11
	Molalla	920 - 2,780'	376				4	2							97
	USFS Oakridge Ridgon Lowell Low	1,280 - 2,500'	159					1							8
	USFS Oakridge Ridgon Lowell Mid Series 2	1,790 - 3,270'	185					1							6
	Snow Peak High	1,200 - 4,000'	198					3		3					52
	Snow Peak Low	480 - 2,450'	186					3		4					41
	Snow Peak Wiley	0 - 1,800'	120					1							4
							10	13		10	3				294
ROSETIC	BLM Lorane	600 - 1,950'	224			13				2	5				
	Umpqua Noti	400 - 1,900'	330			20				5					
	Umpqua Elkton	400 - 2,400'	297			11				4					
	Umpqua Wells Creek	560 - 1,280'	216			12				4					
	Coquille Inland	120 - 2,800'	287			9				4					
	Roseburg N. Umpqua 5 & 6	1,241 - 5,260'	717								4				
						65				19	9				
SCC	Coos Bay CL 98	300 - 1,900'	28						8		10			48	
	Coos Bay Inland	1,450 - 3,100'	39											12	
	Coos Bay Plus	100 - 1,850'	89								1			103	
	Coos Bay Coastal	400 - 800'	18											8	
	Gold Beach Zone 1	50 - 1,840'	276						1		1			99	
	Gold Beach Zone 2	160 - 2,300'	345						1		3				
	Coquille Coastal	20 - 1,650'	374			3			4		45	19	10		
	Mapleton High	250 - 3,300'	240			2			5		34	14	5		2
	Mapleton Low	70 - 1,200'	257						3		42	22	7		1
	Reedspoort Coastal	50 - 1,860'	235			7			7		49	27	10		
	Umpqua Coast	500 - 1,600'	600			5			6		63	28	11		
	Umpqua Swisshome	310 - 2,600'	270								67	28	10		2
						17			33		313	136	51	270	5
Trask	Alsea Waldport High	800 - 2,250'	153					1	4	3	2				1
	Alsea Waldport Low Series 1	250 - 1,000'	132					4	8	6	1				1
	Alsea Waldport Low Series 2	80 - 1,548'	157					1	2	2	1				1
	BLM Alsea	700 - 2,550'	224		1	6		2	19	21					1
	BLM Nestucca	600 - 3,000'	295			4		2	23	20	1				3
	BLM Yamhill	500 - 2,750'	228			1			8	9					
	Burnt Woods Phase 1	525 - 1,700'	161			4		2	13	11					
	Burnt Woods Phase II	400 - 2,500'	300			3		7	37	8					
	Plum Creek Toledo Plus	250 - 2,000'	103						9	6	1				
	Toledo Roadside High	1,250 - 2,250'	101						6	1					
	Toledo Roadside Low	150 - 1,000'	147						16	6					
	Hebo Low Series 1	400 - 2,160'	176					6	16	4	1				
	Hebo Low Series 2	350 - 1,450'	105					2	4	1					
	Nehalem	100 - 2,450'	386	17	1			6	66	34	7				
	Dallas High	860 - 3,100'	206			1		6	8	25	1				6
	Dallas Addition	360 - 1,560'	77					1	1	9					
	Dallas Low	400 - 2,100'	229			2		8	9	19					
	Vernonia Sunday Creek	970 - 3,170"	89		1			3	4	13					2
				17	2	20		48	249	192	14				13
Vernonia/ Ryder-wood	Ryderwood I.P.	320 - 2,000'	338				3	49	3	3					3
	Vernonia	260 - 2,600'	909				3	254	7	3					3
	Vernonia Southeast	420 - 1,960'	169				1	23		3					3
							7	326	10	9					9
WA Coast	DNR Coast	200 - 1,400'	84	14	8			4	4	1					
	DNR Forks	200 - 1,600'	112	14	5				5						1
	Forks	100 - 3,000'	211	14					5	1					
	Grays Harbor	30 - 1,200'	501	33	9			7	7	3					
				75	22			11	20	4					1
WACTIC	Cowlitz BU-1	500 - 1,880'	259		7		14	4							6
	Cowlitz BU-2	1,500 - 3,350	356		2		8	3							2
	Cowlitz BU-3	1,500 - 2,600'	210				2								2
	Cowlitz BU-5	2,500 - 3,500'	200				3								
	DNR Northwest	200 - 2,300'	98				13								
	DNR Southwest	400 - 1,800'	127				11								
	DNR Central	200 - 2,000'	138				11								
	DNR South Sound	300 - 1,900'	66				11								
	Skagit	230 - 2,700'	322		12		29								9
	Snoqualmie BU-1	300 - 2,100'	240		7		17	2							6
	Snoqualmie BU-2	1,700 - 2,800'	319		11		22								
				-0-	39		141	9							31
Puget Sound	DNR Northwest	200 - 2,300'	98		5										2
	DNR Southwest	400 - 1,800'	127	10	10			4	2						3
	DNR Central	200 - 2,000'	138	10	10			4	1						1
	DNR South Sound	300 - 1,900'	66		9			4	1						1
	Port Gamble	0 - 1000'	134		20			4	1						3
	Simpson Puget Sound	40 - 1,900'	306		21			3	2						5
				20	74		-0-	19	7						15

Efficiency of using spatial analysis in first-generation coastal Douglas-fir progeny tests in the US Pacific Northwest

Terrance Ye and Keith Jayawickrama

Summary of paper submitted to Tree Genetics and Genomes

Single-trial and across-trial spatial analyses using autoregressive error structures were conducted for growth traits based on 1,146 data sets from 275 Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) progeny trials in 45 first-generation breeding zones in the US Pacific Northwest. The breeding zones encompassed a wide range of latitude, longitude and elevation. Efficiency of using spatial analysis in controlling site heterogeneity, estimating genetic parameters, and increasing prediction accuracy was compared among different experimental designs, traits, assessment ages, and tree spacings.

More than 97% of the data sets showed significant model improvement with spatial analysis, and height showed greater improvement than diameter or volume. The mean AIC reduction in spatial models compared to base models was usually large (AIC > 120), except for a few data sets of diameter at age 20 where the improvement was relatively small. Strong spatial patterns of variation were shown in most cases. Over 95% of data sets had autocorrelation coefficients () 0.6 or above and 11% of them were larger than 0.9, the average being 0.75.

Using the base model, 909 of the 1,135 data sets had significant replicate effects. The replicate effect decreased markedly after conducting spatial analysis, and remained significant in only 161 data sets. In those data sets, spatial models specifying replicates were better than models not specifying replicates (AIC=1.0~18.7).

Estimates of individual-tree heritability (h2) generally increased with age. They also increased from base models to spatial models for most data sets. Out of 1,135 individual data sets, seven had 0.20 to 0.28, 192 had 0.10 to 0.19, and 697 had 0.03 to 0.09 increase in h2. For the remaining 73 data sets, changes in h2 fluctuated between -0.029 and 0.029. Overall, height received a slightly higher amount of increase in h2 than diameter and volume.

The changes in accuracy of breeding value estimates (rgg) varied between experimental designs and among traits. In sets-in-reps design, 98% (131/133) and 100% of datasets showed increases in rgg for parents and offspring respectively. In comparison 87% (876/1,002) and 88% (878/1,002) of data sets had rgg increase in reps-in-sets design, for parents and offspring, respectively (Figure 2). Overall, changes in rgg ranged from -0.1 to 0.4, with an average increase of 0.04 for both parents and offspring. Height had slightly higher increase in rgg than diameter or volume.

Spatial analysis on average removed 14~34% of residual variance due to spatial heterogeneity, which resulted in an up to 20% increase in accuracy of breeding value estimates. The coefficient of variation decreased substantially due to spatial adjustment. Height showed more improvement than diameter by removing spatial heterogeneity. Of 166 trials where both height and diameter were measured at age 15, 138 showed much larger AIC reduction (> 20%) for height than that for diameter. Diameter had larger AIC reduction (< 15%) than height in only seven cases.

Rank correlation between predicted gains before and after spatial analysis was about 0.96, and spatial analysis had little effect on the average predicted gain of the top 20% of parents. We did not observe substantial geographic trends in improvements due to spatial adjustment. Across-site spatial analysis had almost no effect on genotype-by-environment interaction, but tended to increase among-trial heterogeneity of residual variance. Two different methods for across-trial spatial analysis were compared and discussed.

Based on a large amount of growth data from Douglas-fir progeny tests in the US Pacific Northwest, the results clearly demonstrated how spatial heterogeneity can be effectively reduced by adding a spatial component to the design model. Thus, we agree with the suggestion made by many authors that spatial analysis should be conducted routinely in forest genetic trials. NWTIC now includes spatial analysis as routine analyses for second-cycle tests.

Gain Prediction For Third-Cycle Cooperative Douglas-fir Breeding Based On Computer Simulation

by Terrance Ye and Keith Jayawickrama

Simulation Procedure and Parameters

First-generation testing and 1.5-generation seed orchard

1. Select 2,000 trees as the 1st-generation parents.
2. Generate 2,000 open-pollinated families with 120 trees per family for progeny test based on the following genetic parameters : (1) additive variance , (2) family-mean heritability .
3. For the 1.5-generation seed orchard – select the top 20 parents or progeny (limited to 1 selection per family) based on the estimated breeding values (BLUPs) to establish a 20-clone seed orchard. The gain from the seed orchards is then scaled to 30% or 50% gain . All subsequent gains are scaled accordingly.

Second-cycle testing and seed orchard

4. Select the top 216 parents or progeny (limited to 1 selection per family) as the 2nd-cycle breeding parents based on their BLUPs.
5. Construct 18 sublines with 12 parents per subline. Within each subline we make 12 pair-crosses using disconnected 2×2 factorial mating design.
6. Generate 216 full-sib families which are tested at 6 sites with 20 trees per family per site. The genetic parameters used are: (1) individual-tree heritability , (2) dominance variance , (3) genotype × environment variance .
7. For the 2nd-cycle seed orchard – select the best progeny from each subline based on BLUPs to establish an 18-clone seed orchard. The seed orchard gains are calculated over either the 1st-generation seed orchard or the 2nd-cycle breeding population.

Third-cycle testing and seed orchard

8. Select the top 12 parents or progeny (limited to 3 selections per family and 4 selections per parent) from each subline as the 3rd-cycle breeding parents based on their BLUPs. All related materials resided within sublines.
9. Make crosses within each subline using a circular mating design (see Appendix 4 in "Draft 3rd-cycle breeding strategy, making selections from 2nd-cycle Douglas-fir progeny tests"), assuming no inbreeding within sublines.
10. Generation 432 full-sib families which are then tested at 6 sites with 10 trees per family per site. The genetic parameters used are: (1) individual-tree heritability, (2) dominance variance, (3) genotype × environment variance .
11. For the 3rd-cycle seed orchard – select the best progeny from each subline based on BLUPs to establish an 18-clone seed orchard. The seed orchard gains are calculated over either the 2nd-cycle seed orchard or the 3rd-cycle breeding population.

The above simulations (i.e., steps 1~11) were run 200 times, and the average gains for 2nd- and 3rd-cycle seed orchards were calculated.

Costs and relative gains

Costs for the 1st-, 2nd- and 3rd- cycles were estimated using the spreadsheet and assumptions routinely used for NWTIC testing programs. We assumed that the total duration of these three cycles would be 30, 25 and 20 years, respectively. These assumptions and estimated costs were used together with the assumption of 50% age-15 volume gain in the first cycle, and a heritability of 0.20.

Simulation Results

Gain for 18-clone 2nd- or 3rd-cycle seed orchards

Table 6. Gain for 18-clone 2nd-cycle and 3rd-cycle orchards: Assume gain from the 1.5-generation seed orchard = 30%, scale accordingly

Individual-tree h^2		Gain over previous-generation/cycle seed orchard		Gain over current-cycle breeding population	
2nd-cycle	3rd-cycle	2nd-cycle	3rd-cycle	2nd-cycle	3rd-cycle
0.20	0.20	14.87%	13.39%	24.66%	23.85%
	0.25	14.44%	14.10%	24.40%	24.30%
	0.30	15.02%	16.31%	25.02%	26.69%

Table 7. Gain for 18-clone 2nd-cycle and 3rd-cycle orchards: Assume gain from the 1.5-generation seed orchard = 50%, scale accordingly

Individual-tree h^2		Gain over previous cycle seed orchard		Gain over current-cycle breeding population	
2nd-cycle	3rd-cycle	2nd-cycle	3rd-cycle	2nd-cycle	3rd-cycle
0.20	0.20	24.87%	22.31%	44.10%	39.75%
	0.25	24.07%	23.50%	40.67%	40.50%
	0.30	25.03%	27.18%	41.70%	44.48%

Table 8. Relative age-15 volume gains and costs for 1st-, 2nd-, and 3rd-cycle programs, (scaled to 50% predicted age-15 volume gain in a 1.5 generation orchard

Individual-tree h^2		Predicted age-15 volume gain over previous cycle seed orchard	Cost (in milions of $)[1]	Total time in years for testing cycle (assumed)	% Age-15 gain/ (million $ x years of testing cycle)
1st cycle		**50.00%**	2.150	30[2]	**0.78%**
2nd cycle	0.20	**24.87%**	0.373[3]	25[4]	**2.67%**
3rd cycle	0.20	**22.31%**	0.364	20[5]	**3.06%**

[1] Calculated using the spreadsheet and cost assumptions typically used to estimate costs in NWTIC programs.

[2] Typical duration between start of 1st-generation testing and establishment of elite 1.5-generation orchards: in some cases this duration was shorter. 1.5-generation orchards were mostly established afer the year 2000.

[3] See previous footnote on the number of 2nd-cycle crosses. In some meta-cooperatives, the cost of 2nd-cycle testing could be twice as high as this figure.

[4] Typical duration of a 2nd-cycle program, from inception of program to the end of the age-12 measurement.

[5] Estimated duration of a 3rd-cycle program, from inception of program to the end of the age-12 measurement, assuming efforts are taken at each stage to maintain rapid progress.

Discussion

1. The largest gains expected in the cooperative Douglas-fir programs in the US PNW will undoubtedly be from the first generation. However, due to the size and cost of that first cycle, and its long duration, [gain / (cost x time)] is likely to be higher in the second and third cycles compared to the first cycle. The long duration is partly due to adjacent first-generation programs starting over a period of time (10-15 years in some cases).
2. Gains (over a high-gain orchard of the previous cycle) and costs for the second and third cycles are expected to be more or less equal; in other words, these results indicate substantial gains going from the second to the third cycle. Previous simulation studies also show gains continuing for many cycles of breeding with no appreciable decline (e.g. Mahalovich and Bridgwater 1989, McKeand and Bridgwater 1998).
3. One unknown regarding gains in the second cycle is "seed source" or "provenance" gains due to finding superior first-generation breeding zones ("genetic hotspots") within second-cycle metacooperatives. At this point we cannot factor in the likely gains from identifying such superior programs, so we assumed that all first-generation programs within second-cycle metacooperatives would have equal gain. This may result in underestimating second-cycle gains.
4. Predicted gains for the second-cycle breeding from this simulation is fairly comparable to that reported by Johnson and Jayawickrama (2002), with similar (but not identical) genetic parameters and assumptions.
5. All gains reported are predicted age-15 gains. We expect the realized gains of seed orchard in each cycle to be lower than the predicted gains due to pollen contamination and non-random mating etc. Methods to predict gains at rotation are still being developed.
6. No adjustment was made for inbreeding depression since it will be possible to construct a third-cycle program without crossing related individuals (or keeping such crossing to a minimum).

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Estimation of Genetic-Gain Multipliers for Modeling Douglas-fir Height and Diameter Growth

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Summary of paper submitted to Forest Science

The widespread use of genetically improved seed sources in the Pacific Northwest and other regions may require revisions to yield tables and growth models that were based on information from wild or "woods-run" stands. Projecting the growth of improved stands is important because genetic gain in traits such as height or diameter growth may lead to greater final harvest volumes and changes in management regimes, such as different thinning strategies and shorter rotations. Additionally, growth projections are needed for organizations to estimate their expected return on investments in tree breeding programs. Genetic-gain multipliers provide an approach for incorporating information on the performance of superior genotypes into growth projections that requires relatively little modification to existing growth models. Genetic-gain multipliers reflect the relative difference between improved seed sources and woods-run populations in a trait such as height growth. They reflect the growth difference between individual trees, or stands, that are identical in all respects other than genotype. First-generation progeny tests coordinated by the Northwest Tree Improvement Cooperative (NWTIC) currently provide the best measure of the performance of superior families based on the growth of individual trees in relative isolation, or in a mix of superior and inferior families. The goal of this study was to develop flexible methods for estimating genetic-gain multipliers for seedlots from parent trees whose breeding values have been estimated from progeny test results. To address this goal, equations were developed to estimate genetic-gain multipliers at the seedlot level based on the breeding values of the parent trees contributing to the seedlot.

Data from a subset of the first-generation NWTIC breeding programs in Oregon and Washington were used for the analysis (Tables 1 and 2). Heights and diameters of all trees included in the modeling datasets were measured 10- and 15-yrs after sowing. Heights and diameters in some breeding programs were also measured 5- and 20-yrs after sowing. The first-generation programs tested half-sib families; each family was from seed collected from a single wild mother tree with pollen from the surrounding population. The half-sib families analyzed in this study were considered to be individual seedlots. The genetic value of a seedlot was expressed in terms of its genetic worth (GW). GW refers to the average expected level of gain for some trait (e.g, height or diameter) at a specific age for improved seedlots. GW can be calculated for a seedlot as the weighted average of the breeding values (BV) of parent trees, adjusted for pollen contamination. BV is conceptually similar to GW, but it refers to the value of an individual parent tree for passing on some trait to its progeny. BVs for total tree height and diameter at age 10 yrs had been previously estimated for parent trees by the NWTIC applying the best linear unbiased prediction (BLUP) method to the progeny test results. The seedlots that were analyzed in the present study were half-sib families collected from individual wild parent trees whose BVs have been estimated. Consequently, the GW of a family was calculated as one-half of the estimated parental BV; this assumes that the pollen was representative of the woods-run population and had a BV of zero.

A two-stage modeling approach was used to develop equations to calculate genetic-gain multiplier (M) from a seedlot's GW. In the first stage, nonlinear mixed-effect models were fit to produce woods-run models to predict height or diameter growth for individual trees ignoring family differences. This assumed that the expected growth across families represented the mean growth potential of trees within the breeding zones prior to selection (i.e., the woods-run average). The woods-run models did not explicitly account for important factors that influenced growth, such as site productivity and stand density; however, the random effects captured the aggregate of effects

that are attributable to differences between stands. Thus, the addition of stand-level variables, such as site index and stand basal area, would not have improved the models. In the second stage, M was calculated for each family to reflect the ratio between the family's mean observed growth and its mean predicted growth under the woods-run model. On average, Ms for top families (i.e., those with progeny of high GW) were expected to be > 1.0, indicating higher than average growth. The family-level estimates of M were then modeled as a function of the family's GW using a linear model. Equations were fitted separately for the 5-yr, 10-yr, and 15-yr periods. The final equations were validated using an expanded form of the "holdout data" approach. Under this approach, genetic gain multipliers were applied to 1000 random samples of families (with each sample equal to one-third of the total dataset) to estimate the likelihood that applying multipliers would improve the estimation of growth over the woods-run models alone.

The final coefficients of the equations to predict M from a seedlot's GW were estimated using ordinary least-squares regression, weighted least-squares regression, and method-of-moments estimators to account for uncertainty in the estimation of the independent variable (GW in this case). Given the purpose of the equations and form of the data, the weighted least-squares regression coefficients were most appropriate.

For height growth the final equations were:

$M = 1.000 + 0.0062770 \cdot GW$ at 5 yrs
$M = 1.000 + 0.0031119 \cdot GW$ at 10 yrs
$M = 1.000 + 0.0041740 \cdot GW$ at 15 yrs

For diameter growth the final equations were:

$M = 1.000 + 0.0101054 \cdot GW$ at 5 yrs
$M = 1.000 + 0.0033696 \cdot GW$ at 10 yrs
$M = 1.000 + 0.0029435 \cdot GW$ at 15 yrs

For a seedlot with a GW of 10 percent for height at age 10 yrs, the genetic-gain multiplier for projecting a stand from age 5 yrs to 10 yrs would be 1.062770, which means that height growth would be about 6.3 percent greater than predicted by the woods-run model. The coefficient estimates for the 10- 15-yr equations were not significantly different for either height or diameter growth, suggesting that genetic gain is approximately constant during these periods. The 10-yr coefficient estimates were based on much larger datasets than the 15-yr estimates, so they should be considered more reliable. Assuming that the 10-yr model is appropriate for projecting growth from ages 10 yrs and beyond, a genetic-gain multiplier of 1.031119 would be used for height growth if the seedlot's GW for height was 10 percent.

The results of this study indicate that the height and diameter growth of Douglas-fir seedlots with high genetic worth for these traits is faster than what would be predicted by woods-run models, even when prior growth up to age 15 yrs is considered. The period spanned in the present study represents approximately one-third to one-half of a typical rotation for a productive site managed to maximize financial return. Our results indicate that a single genetic-gain multiplier is not appropriate for both early growth (e.g., the 5-yr period) and later growth (10 yrs and beyond). For a seedlot with a specific GW, the estimated genetic-gain multipliers would be greater for the 5-yr period than for subsequent periods. The primary cause of the change appeared to be a decrease in the relative difference in growth between the woods-run population and the top families. The trend in genetic-gain multipliers over time presents a challenge to modeling early growth. A workable approach may be to integrate genetic gain into stand establishment models or submodels based on the GW of seedlots. The model output would then be used to project future growth using an individual-tree model with genetic-gain multipliers. Changes in M beyond the study period are also important. Since predicting volume at the end of the rotation is the goal of many growth projections, model users will routinely extrapolate these results beyond the period examined in this study. We recommend that modelers assume that M remains constant for stands beyond age 10 yrs. Caution is warranted, however, particularly for longer rotations. Additional data should be analyzed as it becomes available to determine whether this assumption hold 's true.

The equations developed in this study provide the best available estimates of genetic-gain multipliers for height and diameter growth of improved Douglas-fir in the Pacific Northwest. The genetic-gain multipliers can be incorporated into regional individual-tree growth models such as FVS and ORGANON. Because the progeny test data used to develop the equations were based on individual-tree plots, important questions remain unanswered regarding how improved seedlots will develop in uniform stands. Additional block-plot trials are urgently needed to test and refine our results; particularly for later stages of stand development where competition is more important. In addition, block-plot trials are needed to better understand other differences between genotypes, such as differences in maximum density, asymptotic height, and stand volume.

Table 9. Summary of the height-growth datasets. Mean initial heights ($\overline{H}$) are height-growth increments are shown for trees in all families and those in the top 25 families with one standard error.

Period (yrs)	Breeding Zones (N)	Families (N)	Site-Set Comb. (N)	Obs (N)	$\overline{H}$ (m)	
					All	Top 25
5	14	1802	381	166,870	1.10 (0.001)	1.19 (0.003)
10	16	2485	521	222,818	4.28 (0.003)	4.58 (0.008)
5	1	90	15	7,571	9.60 (0.020)	9.99 (0.036)

Table 10. (manuscript Table 5). Summary of the diameter-growth datasets from first-generation progeny tests. Mean initial diameters ($\overline{D}$) and diameter-growth increments ($\overline{AD}$) are shown for trees in all families and those in the top 25 families with one standard error

Period (yrs)	Breeding Zones (N)	Families (N)	Site-Set Comb. (N)	Obs (N)	$\overline{D}$ (m)	
					All	Top 25
5	1	145	20	7,704	1.84 (0.007)	1.96 (0.018)
10	7	1178	213	83,072	5.41 (0.009)	5.90 (0.022)
15	2	321	48	20,396	12.14 (0.019)	12.79 (0.050)

High-elevation Douglas-fir: testing programs, seed orchards and potential future developments

In addition to the large north-south extent of Douglas-fir natural distribution, the species also typically extends over a large elevation spread at a given latitude and longitude. In the western slopes of the Cascades or in southern Oregon, it is not uncommon to traverse several thousand feet elevation traveling through only a few miles of planted or natural forests. Douglas-fir is usually the dominant species (especially in plantations) from as low as 500 feet to about 3,000 feet, after which the proportion of western hemlock, mountain hemlock, noble fir, Pacific Silver fir and other species increases, and Douglas-fir becomes a minor component of the stands above 6,000 feet.

First-generation testing of high-elevation Douglas-fir (defined here as above 3,000 feet) got underway in the 1970s. A total of 24 first-generation breeding zones (testing 5,700 first-generation parents) were designed to cover land above 3,000 feet; the highest being Medford Jacksonville Breeding Unit 4 (4,500 to 5,500 feet). A total of 5,058 first-generation parents were selected at 3,000 feet elevation or higher. In practice several of these high-elevation plantations faced difficulty due to severe conditions. The two federal agencies (US Forest Service Region 6 and western Oregon BLM) played a very large role in the high-elevation Douglas-fir testing programs, partly because much of the high-elevation lands were under their management.

High-elevation lands (above 3,000 feet) generally received little emphasis in co-operative 2nd-cycle breeding and testing, on the basis that (A) this was a relatively small part of the landbase and (B) longer rotations made investment in such programs less profitable. However there were three exceptions: (A) a small full-sib second-generation program was established in the Oregon Cascades with sites as high as 4,300 feet due to the efforts of Roy Silen of the PNW Research Station and Cascade Timber Consulting, (B) the Washington Cascades co-operative has aimed to establish some its tests close to 3,000 feet, and (C) the ROSETIC co-op in southern Oregon has a separate breeding and testing program for lands from 2,500 to 4,000 feet.

The high-elevation ROSETIC program was made especially appealing because in the drier areas of southern Oregon, higher-elevation lands may in fact be more productive (mainly from higher rainfall) than low-elevation lands. An example is in Jackson county, where rainfall increases from 20" /yr in Medford/ Grants Pass (at 1,300') to 70-100" / yr at 4,000' in the Galice area west of Grants Pass (where Douglas -fir grows very well in spite of the poor soil and rocky slopes).

Several Forest Service orchards were established in the woods, while the BLM established high-elevation blocks at each of their three large orchards (Horning, Tyrell and Provolt). However with the reduction of harvest from federal lands which took place in the 1990s, federal demand for such seed is nowhere as high as anticipated when the orchards were established. As a result, the Forest Service orchards are rapidly falling into neglect, and the germplasm developed at great cost and effort is in danger of being lost. Efforts have been taken to archive such material at other sites. Two 1.5-generation high-elevation seed orchard blocks (for the Roseburg co-op area and the North Oregon Cascades respectively) are being established.

Today's tree improvers and orchardists wonder about the ideal siting for such orchards, much as their predecessors did in the past. Most modern orchard blocks are sited at fairly low elevations (usually from 500 to 1,500 feet) for very good reasons (ease of management and access, availability of labor, good seed production, moderate climates, established orchard sites etc). However if elevation is a key factor for adaptability, background low-elevation contaminant pollen could be particularly detrimental for such high-elevation orchard blocks. Having accepted that fact, it is also generally recognized that high-elevation orchards free of such contamination would hardly be practical. Access to such orchards could be blocked by snow for several months a year, they would be distant from central operations driving up costs, and female strobili, pollen catkins and developing conelets could be vulnerable to sudden severe weather during pollination and early cone development. The solution seems to lie in suitable pollen management techniques (large orchard blocks, creating a buffer against non-orchard pollen, CMP etc).

Operationally, Douglas-fir is currently a component of the planting mix all the way to 5,400 feet (usually as wild seed); organizations differ in their weighting of Douglas-fir compared to other species (noble fir, western hemlock, Pacific Silver fir) adapted to high elevations. The elevation cutoff is highest in southern Oregon, and is considerably lower in northern Washington. One concern about Douglas-fir at high-elevations is that its long upright branches are not well suited to the heavy, wet snow frequent in western Oregon and western Washington, and make trees susceptible to limb and top breakage. Noble fir has short branches and suffers little damage due to snow; in addition to its moderate stumpage value, noble fir also offers the possibility of bough production. The motivation for growing Douglas-fir are (A) It is a native component of high-elevation forests (B) the volume and value of Douglas-fir wood produced is usually greater than the alternate species for most forest growers and purposes and (C) there can be difficulties establishing the alternate species on some sites (such as south facing slopes).

We can add two other considerations: (A) We can speculate that if significant shifts did occur in the PNW climate, landowners might grow a greater proportion of successful and productive Douglas-fir plantations at such elevations than has been the case in the past (B) The properties of high-elevation wood should be considered; while slower-grown trees grown to longer ages can be expected to have better wood properties as a rule, there is some indication that wood specific gravity decreases as elevation increases (see the USFS's Western Wood Density Survey from the 1960s).

All in all, there appears to be a small but significant need for well-adapted, vigorous, well-formed improved Douglas-fir seed for high elevations. As co-operators consider 3rd-cycle breeding and testing, it seems prudent and necessary to give serious consideration to these higher-elevation lands; while it is not appropriate to put excessive weight on such lands, neither does it seem appropriate to ignore them. One simple step would be to include small satellite tests containing a subset of 3rd-cycle material, in the 3,000 – 4,000 ft range.

Cooperators

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NWTIC representatives for 2006-7:
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Bob Ohrn, Bureau of Land Management

Bill Marshall, Cascade Timber Consulting

Jerry Anderson/Rudy Frazzini, Forest Capital Partners

Rod Burns, Fruit Growers Supply

Mike Tucker, Giustina Land and Timber

Paul Wagner, Giustina Resources

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Randall Greggs, Green Diamond Resource Co.

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Bryan Nelson, Lone Rock Timber

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Jim Carr, Menasha Corp/ The Campbell Group

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High-elevation Douglas-fir testing programs and orchards. Clockwise from top:

- First-generation BLM Breeding Unit-32 site at 3,500 feet,
- CTC's Second-generation high-elevation program at 4,300 feet,
- Roseburg North Umpqua orchard block at BLM's Travis Tyrell seed orchard complex,
- High-elevation Cowlitz breeding zone orchard at USFS Planting Creek seed orchard.

Front Cover – The program of Cascade Timber Consulting (previously the Timber Service Co and later Barringer and Associates) mirrors the evolution of tree improvement in the PNW. Clockwise from top: Starting with an untested phenotypically select plus-tree orchard established in the 1960s (early black-and-white photo and recent color photo), they progressed to an orchard from the Snow Peak co-operative, then to 1.5-generation orchard blocks combining a small group of selections from multiple zones, and most recently to a 2nd-cycle orchard including full-sib forward selections from NOCTIC Phase I. CTC is also testing operational Control Mass Pollination, and is preparing to move to the 3rd cycle of breeding and testing.