Tree Improvement in the Pacific Northwest

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Abstract

Advanced-generation tree breeding programs are underway for Douglas-fir and coastal western hemlock. These programs will continue to improve growth rates and other traits. Regardless of whether seed is from a seed orchard or natural collection, it must be used in its appropriate breeding zone or seed zone. These zones vary by species. Breeding programs are underway for other species as well, with many of these programs emphasizing disease and insect resistance. Absolute gains at rotation are still an unknown, but absolute (not percentage) gains observed early in the rotation should increase to some degree with time.

Keywords

tree breeding, genetic gain, genetic diversity, disease resistance

History of Forest Tree Breeding in the Pacific Northwest

Operational forest tree breeding programs in the Pacific Northwest began in the 1960's. Douglas-fir (*Pseudotsuga menziesii*) received most of the attention in western Oregon and Washington because of its importance to the timber industry. Weyerhaeuser Company and the British Columbia Ministry of Forestry programs pursued a traditional approach of intense plus-tree selection, followed by progeny testing with control-pollinated families (Stonecypher et al. 1996, Woods 1993). However, most organizations in the region pursued an approach proposed by Silen and Wheat (1979) which involved field testing many wind-pollinated families from less intensively selected roadside selections.

In all of these programs, breeding zones were kept small to ensure that all planting stock would be locally adapted. The complex environmental patterns of the region does not provide large areas of a uniform climate to allow for the large breeding zones that are found in most other breeding programs in the United States. By the 1980's, 125 separate Douglas-fir breeding programs were in existence for western Oregon, Washington, and British Columbia (Table 1). Collectively, these programs tested over 30,000 selections, thus providing an opportunity to make substantial gains by selecting only the best parents and progeny to put into seed orchards and to use in advanced-generation breeding programs.

Most of the first-generation breeding programs were local breeding cooperatives formed under an umbrella organization known as the Progressive Tree Improvement Cooperative. From 1967 to 1985, this organization was jointly run by the US Forest Service Pacific Northwest Research Station (Roy Silen) and the Industrial Forestry Association (Joe Wheat). In 1985, both these organizations had to withdraw their support. To fill the void, the Northwest Tree Improvement Cooperative (NWTIC) was founded by a group of industry and government agencies and was run by contractors. In April 2000, the organization moved to Oregon State University.

Weyerhaeuser initiated second generation programs in the 1980's and NWTIC followed suit in the 1990's. Because research had suggested that first-generation breeding zones were conservative in size (Stonecypher et al. 1996, Johnson 1998), second-generation programs have expanded to incorporate numerous first-generation programs into single breeding programs. Each NWTIC second-generation program (meta-coop) has between 250 and 400 selections in its breeding population. These selections were drawn from a selection base of between 420 and 3,208 tested first-generation families. This resulted in high selection intensities and sizable potential gains.

Table 1. Number of first-generation Douglas-fir breeding programs in the Pacific Northwest.

Program Category	Number of breeding programs	Selections tested
NWTIC Cooperatives	70	19,516
Industry	23	3,419
USDA Forest Service	11	3,661
BLM	12	2,419
Washington DNR	6	720
Oregon Dept. of For.	1	150
BC Min of For.	2	650
TOTAL	125	30,535

Seed Zones

Seed zones are geographic units within which seed presumably can be transferred without impacting productivity. Original Forest Tree Seed Zones (Western Forest Tree Seed Council 1966, revised 1973) were established because of plantation failures, but without the benefit of research information. Original zones were geographically small. Subsequent research confirmed local adaptation, the presence of adaptive variation across the landscape (e.g. Campbell 1986), and established that adaptive gradients in western Oregon were steeper east-west and in elevation than they were north-south (Campbell and Sugano 1993, Silen and Mandel 1983, Sorensen 1983). Seed transfer zones for field collected seeds recently were revised using all currently available information (Randall 1996). Zones have been enlarged primarily in the north-south dimension. For both field-collected seed and orchard seed it is important that it only be used in the appropriate seed zone or breeding/testing zone.

Genetic Gains

In order to pick the families that will absolutely be the best at rotation, it is necessary to wait until rotation age. Fortunately, family rankings at younger ages are reasonably correlated with rankings at later ages. This allows tree breeders to select good families at young ages instead of having to wait until rotation age. The problem with selecting a parent or family at age 12 is that the percent improvement at age 12 is not likely to be the improvement at rotation; i.e. a 10% increase in height at age 12 does not translate to a 10% increase in height at rotation.

As an example, I will use data from three first-generation local NWTIC cooperatives that have progeny test data up to age 20 or age 25. Seventy-five to 150 families were assessed in each trial series. Heights (in cm) of the overall population and the best 10% of the families selected at age 15 were examined (Table 2). This was done by averaging all families at each site, then averaging over sites.

The absolute height difference between the population and best 10% increases with time, but the percentage gain in height decreases. Carson et al. (1999) found that, for Pinus radiata, the best way to model this increase in growth rate was to use a growth multiplier in their existing growth models. In other words, improved stands appear to have normal stand dynamics, but progress at an increased rate. A regression of height on age for the three NWTIC programs showed that the average population and top 10% had significantly different growth rates. After adjusting for differences in intercept due to breeding programs the ht/age equations for the two populations were:

height average population (cm) =
-467 + (91.488*age) r-square=0.995

height of top 10% (cm) =
-447 + (94.413*age) r-square=0.995

If these populations continue on these trajectories until age 40, the best families will be 1.4 m taller than the population average; or in other words, the better families will be roughly 1.5 years more advanced. Using DF-sim and a 150 site index, this translates to approxiamately 6.7% more volume at age 40 for this subset of families. Calculation of estimated genetic gains must consider the accuracy of the genetic tests, the pollen contamination in the seed orchards and the selection intensity with which the parents are selected. Second-generation orchards (and some first-generation orchards) can use selection intensities greater than the 10% used in these examples.

Table 2. Average height at different ages for all families and the best 10%, selected at age-15, for three breeding programs in Oregon.

	Vernonia		Burnt Woods		Umpqua Coast		Average			
Age	Pop.	Best	Pop.	Best	Pop.	Best	Pop.	Best	Difference	% increase
7	127	136	221	240	195	212	181	196	14.9	8.2
10	296	318	487	518	538	577	440	471	30.7	7.0
15	753	794	980	1032	961	1016	898	947	49.3	5.5
20	1234	1279	1491	1560	1410	1477	1378	1438	60.3	4.4
25	1678	1726								

Selection for improved stem form and reduced forking can also increase the value obtained from breeding. In a study with Pinus radiata (Johnson et al. 1992) examining paired plots in a 17-year old stand, volume-per-acre gain was 11%. More importantly, the improved growth and stem form of the genetically improved trees resulted a higher percentage of sawlogs recovered from the improved (85%) versus unimproved trees (65%).

Other traits targeted for selection in some programs include: diameter, wood density, stem form and foliage health. While it is possible to select for more than growth, the addition of other traits will decrease the gain one can achieve in growth rate. This is because the best trees for any one trait will not be the best trees for another. In the case of wood density and diameter growth, the best trees for one trait will be below average for the other. Most breeding programs in the region choose to improve growth while maintaining the current level of wood density. Potential changes in adaptational traits (e.g., cold hardiness, phenology) should also be considered when selecting seed orchard candidates.

For a number of species growth rate is a secondary trait. The western white pine (*Pinus monticola*) and sugar pine (*Pinus lambertiana*) breeding programs in the region emphasize resistance to white pine blister rust (*Cronartium ribicola*) (Sniezko 1999). Improved seed is available from many of these programs. British Columbia's Sitka spruce (*Picea sitchensis*) program is primarily concerned with resistance to weevil (*Pissodes strobi*) damage (King et al. 1997). The most recent breeding effort for disease resistance is a cooperative program involving the USDA Forest Service, the BLM and Oregon State University aimed at improving resistance of Port-Orford-cedar (*Chamaecyparis lawsoniana*) to *Phytophthora lateralis* (Hansen et al. 2000).

Tree Breeding in the Future

Tree breeding programs in the Pacific Northwest will continue to increase growth rate, especially in Douglas-fir and western hemlock (*Tsuga heterophylla*) where advanced-generation breeding programs are underway. There is interest in Oregon and Washington to breed weevil resistant Sitka spruce for use on the coast because of the impact of Swiss needle cast on Douglas-fir. Some interest has also been expressed for noble fir (*Abies procera*) in both the Coast range and Cascades. Swiss needle cast resistance has also been added as a selection trait in some coastal Douglas-fir breeding programs. Unimproved orchards are underway for western redcedar (*Thuja plicata*) in the region and Ponderosa pine (*Pinus ponderosa*) in the Willamette valley.

Commonly Voiced Concerns

Using genetically improved seed will reduce the variation in our forests.

Plantations regenerated from seed orchard seed have essentially the same variation in tree size as plantations regenerated from field collected seed (Carson and Hayes 1998). Most of the tree-to-tree variation seen in a stand is due to environmental differences, usually only around 20% of the variation is influenced by the genetics of the trees. The reduction in genetic variation is a function of the number of seed orchard parents and is theoretically estimated as 1/(number of parents) (see Johnson 1998 for details). A typical seed orchard seed lot has between 20 and 150 parents, thus the genetic variation is reduced by 1/20th in the worst case scenario. Reducing 20% of the variation by 1/20th results in a loss of 1% of the total variation.

Seed orchard seed does not have enough rare genes (alleles) for use against unknown diseases and for overall genetic conservation purposes.

Maintenance of rare alleles and genetic variation for the long-term is done in the breeding population (from where we select only the best for the seed orchard) and in gene resource populations. The Pacific Northwest Forest Gene Conservation Group is presently assessing the adequacy of the region's gene conservation populations, both in situ and ex situ. Ex situ resources of Douglas-fir include over 30,000 families in the region (see Lipow et al. in mans.).

Rare genes are valuable in breeding populations but have limited benefits in plantations unless they have been intentionally selected upon for use in seed orchards. Low-frequency neutral genes in the native population will be at a low frequency in both the breeding population and in a seed orchard. As a result rare genes will be at low frequencies in both a naturally regenerated forest and in artificially regenerated plantations. Theoretical calculations have shown that a mix of 30 to 40 clones (or families) provides essentially the same protection against catastrophic failure as extremely large numbers of clones (Roberds and Bishir 1997).

Shouldn't breeding for fast growth result in increased disease and insect susceptability? The governing principle of most evolutionary defense theories is the physiological trade-off between growth and defense (Herms and Mattson 1992).

Results of most forest genetics research demonstrates just the opposite. The faster growing families tend to be the healthier families. Numerous studies bear this out. In Douglas-fir, favorable genetic associations have been shown for growth and resistance to Swiss needle cast (Johnson and Temel 1998), and for growth and terpine content (Kimball et al. 1999), a deterrent to bear damage.

Other favorable genetic associations include: foliage disease and growth in Pinus radiata (King et al. 1998), fusiform rust and height in loblolly pine (McKeand and Bridgwater 1995), and weevil resistance and height growth in a British Columbia population of Sitka spruce (King et al. 1997).

Conclusions

Tree breeding programs will continue to provide genetic gains in important economic traits. Growth rate will continue to be improved as programs progress. New species and traits are becoming important as pest problems alter our silvicultural practices. Gains from tree improvement take time because of the time needed to test parents, establish seed orchards and bring them into production. Gains from tree improvement are easy for a forest manager to utilize; all that is necessary is that they use the best stock in the appropriate places.

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