Breeding for Growth Improvement and Resistance to Multiple Pests in *Thuja plicata*

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Introduction

Western redcedar (*Thuja plicata* Donn ex D. Don), a member of the Cupressaceae, is an important commercial species in British Columbia (BC) and the Pacific Northwest (PNW), which is prized for its heartwood and its performance as a naturally durable outdoor building material. Although a genetic improvement program has been ongoing for only 15 years in BC, substantial progress has been made owing in part to its unique genetic and biological properties. These include early precious flowering and short generations (Russell and Ferguson 2008), the ability to self with minimal inbreeding depression (Russell et al. 2003), and ease of vegetative propagation and clonal deployment.

Initial population improvement focused on growth and adaptability as well as heartwood durability–an important wood quality trait for second growth western redcedar. The heartwood of this species contains secondary extractives implicated in rot resistance to a number of fungal species (Daniels and Russell 2007, Maclean and Gardner 1956). Tropolones are a group of extractives that are present in relatively small concentrations, but are highly fungitoxic to a suite of fungal rot species in living trees. These extractives are readily leached out of wood in service, but lignans, another group of secondary compounds (e.g., plicatic acid) are not. Lignans are mildly fungitoxic as compared to the tropolones, but are in greater concentrations in the heartwood (Morris and Sterling 2010). Individual tropolone and lignin compounds have moderate to high heritibilities (h^2_{ns} = 0.25 to 0.58) and additive coefficients of variability (CV_{add} >68 percent) (Russell and Daniels 2010).

In addition to fungal rots, black-tailed deer (*Odocoileus hemionus columbianus*) and cedar leaf blight (*Didymascella thujina*) have increasingly caused western redcedar plantation failures and reduced growth, and resulted in longer times to reach free to grow status. Black-tailed deer have been shown to avoid browsing trees that are high in volatile foliage monoterpenes (Kimball et al. 2012, Vourc'h et al. 2002). Similar to heartwood secondary extractives, foliage monoterpenes have moderate to high heritibilities (h^2_{ns} = 0.48 to 0.60) and additive coefficients of variability (CV_{add} 24 to 66 percent) (Russell, unpublished data)

Cedar leaf blight (CLB) occurs throughout western redcedar's range, but is especially virulent in humid, warm environments typical of the highly productive maritime ecosystems for western redcedar (Kope and Trotter 1998). There is significant genetic variation in resistance to CLB across moderately to heavily infected sites (h^2_{ns}=0.18; CV_{add}=14 percent) (Russell et al, 2007) and this variation is strongly correlated to population-origin climate with parents from wetter, milder sites having greater resistance.

As climates change and pests, known and unknown, become more abundant, breeding strategies need to adapt to better accommodate shifts in environmental stresses. Developing breeding populations that are resilient to multiple pests, as well as maintaining adaptability and growth, is imperative to ensure current and future forest health.

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Initial Population Improvement

Western redcedar has been under domestication since the late 1990s. Two main populations were used for initial selections and breeding: 1) 1,000 wildstand parent trees selected from throughout the species coastal range from northern California to northern BC, and grafted into clonebanks at Cowichan Lake Research Station (CLRS), and 2) BC range-wide provenance trials with open-pollinated family structure. The four main traits described above had the following improvement to date:

1) Growth and CLB resistance. The above wildstand parent trees were polycrossed with a common 20 parent mix, and progeny established in 45 field tests across seven annual series throughout BC between 2000 and 2008. Top breeding value parents for predicted volume production at 60 years varied from 18 to 35 percent, over wildstand seedlots based on 7 to 10 year heights. On individual sites highly infected with CLB, an increase in the disease impacted height and diameter growth significantly with genetic correlations from -0.58 to -0.88 at age 10 years (fig. 1); however, type B genetic correlations between CLB and height on sites with no CLB are not significantly different from zero. Backward selections that are both CLB resistant and high volume producers have been established in a breeding orchard and are currently being mated using partial diallels with assortative mating. Approximately 350 full-sib families have been completed to date with an anticipated 700 families in total when completed.

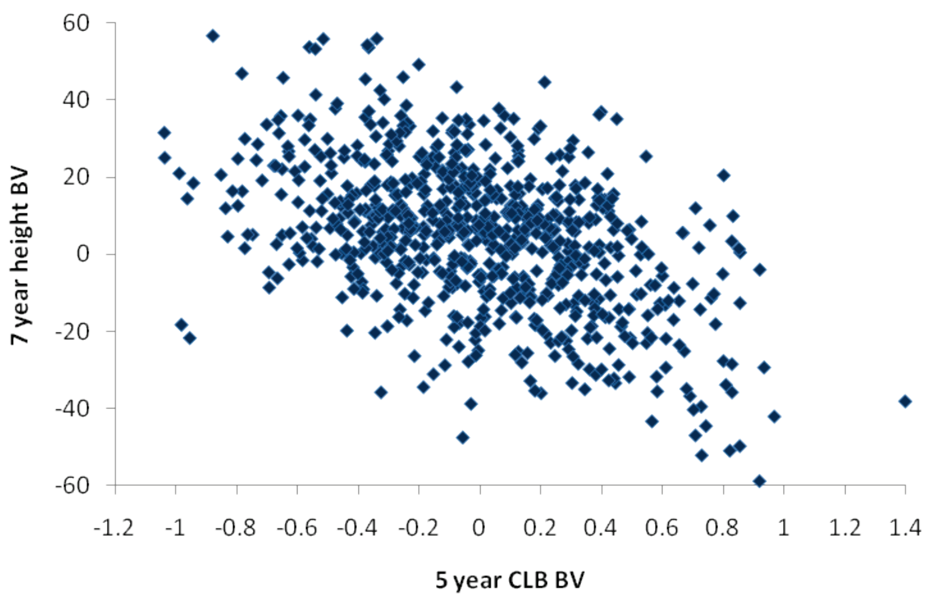

Figure 1—Relationship between western redcedar parental breeding values (BV) for cedar leaf blight (CLB) and height at a British Columbia maritime low elevation test site. Positive CLB BVs indicate susceptibility.

2) Heartwood rot-resistant population. Approximately 350 of the wildstand parent trees were old enough (20 years) to estimate heartwood extractives. Inner and outer heartwood from these trees have been profiled for tropolones (implicated in resistance of living heartwood) and lignans (responsible for durability of wood in service) using multiple ramets from clonebanks and seed orchard trees. Sixty backward selections have been made based on total thujaplicins and plicatic acid. These backward selections are currently in a breeding orchard for advanced generation breeding.

3) Deer browse-resistant population. All 1,000 wildstand parent trees were profiled for individual monoterpene compounds using foliage from multiple ramets in clone banks and seed orchards. In addition, foliar monoterpenes were estimated from 2,200 open-pollinated progeny from the range-wide provenance trial mentioned above, at age 6 years. Approximately 120 clonal and forward selections were made from both populations based on deer browse intensity and total monoterpenes. These parents were bred using partial diallels with assortative mating including selfs. Approximately 400 families were sown and forward selections made based on total foliage monoterpenes from one-year-old seedlings in the greenhouse (target age for deer browse resistance). First generation selections averaged around 35,000 ppm total monoterpenes and second generation selections averaged over 75,000 ppm. These forward selections are established in a breeding orchard and are currently available for 3rd generation breeding.

Advanced Population Improvement

Our objective for western redcedar is to develop a durable advanced generation breeding population with potential cross resistance. Developing breeding populations that are resilient to multiple pests may not only give protection against the current target pests, but potentially against future unknown ones. Selections for both increased volume production and CLB resistance are readily achieved for deployment on sites that have CLB, which is currently the majority of productive western redcedar forests. Genetic correlations between secondary extractives in the foliage and growth rate (fig. 2), and secondary extractives in heartwood and foliage (fig. 3), although not strong, are positively low to moderate. This is a simplistic measure and assessment of complex chemical pathways, but it does give us a potential indication that there is minimal competition in chemical resources between foliage and heartwood extractives. We have no information on CLB resistance mechanisms at this time, but as in many leaf disease studies, foliar monoterpenes have played a significant role (e.g., Wallis et al. 2011).

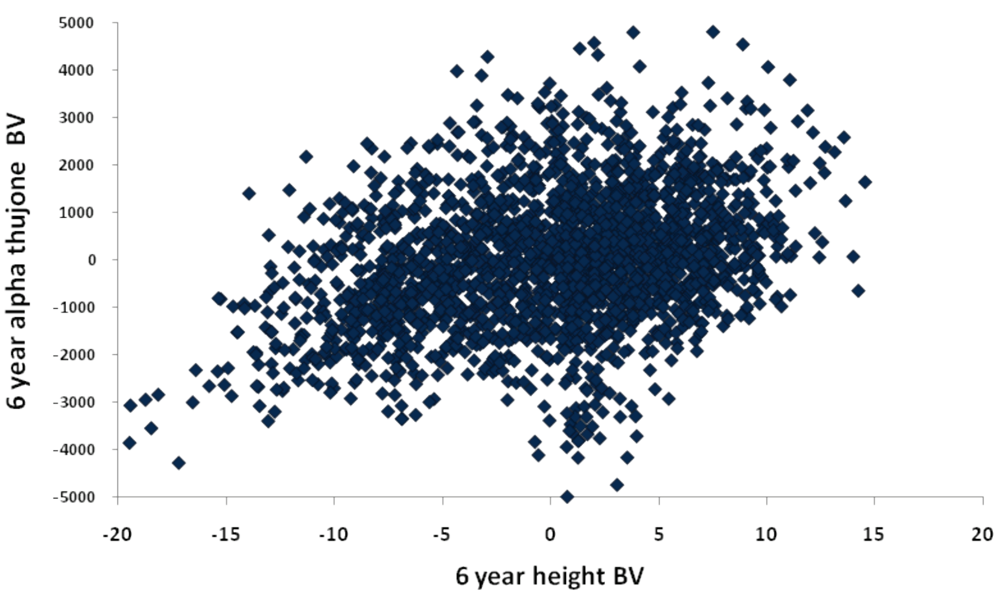

Figure 2—Relationship between western redcedar breeding values (BV) for foliage monoterpene and growth in a BC coastal open-pollinated progeny trial.

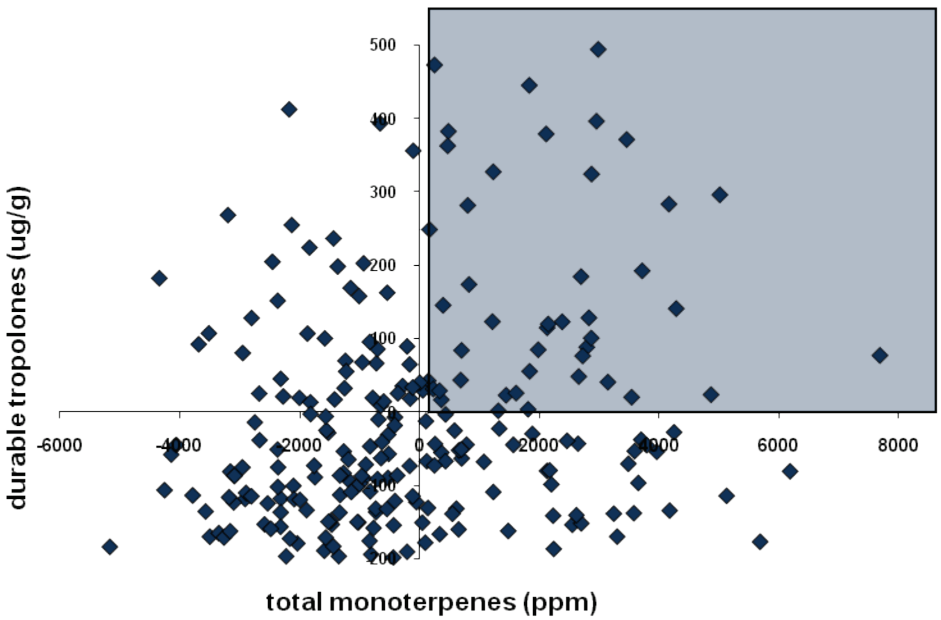

Figure 3—Relationship between western redcedar clonal values for foliar monoterpenes and heartwood tropolones in a 20-year-old clonal trial (blue box = independent culling).

Advanced generation breeding strategy will involve breeding groups by traits and matings performed within and between groups using partial diallels (fig. 4) with assortative mating within groups.

	Growth			CLB			Foliage terpenes			Hdwd extractives		
Growth	X	X	X	X	X		X	X		X	X	
		X	X		X			X			X	
			X									
CLB				X	X	X	X	X		X	X	
					X	X		X			X	
						X						
Foliage terpeness							X	X	X	X	X	
								X	X		X	
									X			
Hdwd extractives										X	X	X
											X	X
												X

Figure 4—Western redcedar advanced generation breeding strategy for multiple pests and growth.

This new population will be tested in environments conducive to the respective stresses. Because of the partial confounding of population with selection objectives in the first generation of screening, we expect it would be beneficial to do further field testing in each of the growth/CLB and the deer resistance populations prior to make final selections for advanced generation breeding population.

For the growth/CLB selections, advanced generation full-sib matings from backward selections have already been done. Seed from these families will be grown in the nursery and tested for foliar monoterpenes at age one year. The top selections for total monoterpenes will then be cloned and tested for growth/CLB in short-term tests. For the deer resistance population, families from second generation breeding have already been tested for foliar monoterpenes and forward selections cloned for production hedges. These clones will be established in short-term tests in environments conducive to good growth and cedar leaf blight infection. Clones from both of these additional trials will be selected based on the respective target traits for the advanced generation durable breeding population.

The final population (Ne~100) will be composed of: 1) 50 third generation forward selections from the deer resistant population further clonally selected for growth and CLB resistance; 2) 50 first generation parental selections based on clonal values for total heartwood extractive content with independent culling for the other target traits; and 3) 50 second generation forward selections for volume further selected for deer resistance. Currently, mechanisms for CLB resistance are unknown, but being researched. It may be appropriate to make additional CLB selections based on future potential resistance mechanisms.

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