Proceedings of the 3rd Western White Pine Management Conference

Compiled and edited by:

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BC Ministry of Forests and Range
Southern Interior Forest Region
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Allan Brooks Nature Centre
Vernon Seed Orchard Company
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PROGRAM AGENDA

Tuesday, June 17, 2008

7:30-8:30 Conference Registration Diane Douglas, TIB

8:30-8:45 Welcome & Opening Remarks & Meeting Objectives Michelle Cleary, Pathologist, SIFR Stefan Zeglen, Pathologist, CFR

SESSION 1: THE RUST (Moderator: Stefan Zeglen)

8:45-9:15 The History of Rust in British Columbia Rich Hunt, Research Scientist Canadian Forest Service Pacific Forestry Centre

9:15-9:45 The History of Rust in the United States Det Vogler Research Geneticist Pathologist USDA Forest Service, Placerville, CA

9:45-10:00 Question Period

SESSION 2: THE HOST (Moderator: Michelle Cleary)

10:20-10:40 Ecological Suitability of Western White Pine Dennis Lloyd, Research Ecologist, MFR, SIFR


11:20-11:50 U.S. resistance breeding program, history, current and future directions Mary Frances Mahalovich Regional Geneticist US Forest Service, Moscow ID

11:50-12:00 Question Period
### SESSION 3: MANAGEMENT OF WHITE PINE IN B.C.  
**(Moderator: Michelle Cleary)**

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<td>13:00-13:25</td>
<td>Field Resistance observed in U.S. and Canadian provenance trials</td>
<td>John King</td>
<td>Research Geneticist MFR, Research Branch</td>
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<td>14:15-14:30</td>
<td>Question Period</td>
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<td>14:30-16:00</td>
<td>Field Tour to Allen Brooks Nature Centre and the Bailey Seed Orchard (South of Vernon).</td>
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18:00 Banquet dinner at Kalamalka Forestry Centre

**Wednesday, June 18, 2008**

08:00-15:00 All-day Field Trip

*Stop One:* Vlem Creek – White pine blister rust trial/demonstration (planted 1984).  
Speakers: Michael Carlson, Rich Hunt, and Vicky Berger

*Stop Two:* Baird Lake - Western White pine Realized Gain Trial  
Speakers: Michael Carlson

*Stop Three:* Western white pine management area (pruning) & species trial  
Speakers: Stefan Zeglen and Michelle Cleary
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Opening Comments

Michelle Cleary

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Good morning! On behalf of the organizing committee I would like to welcome you to Vernon for the 3rd Western White Pine Management Workshop. Today, this meeting marks a special occasion of a follow-up to the White Pine Management Workshop that was first held in Revelstoke back in 1979, and the second workshop held in Nakusp in 1988. We have a total of 95 meeting participants today, which is quite comparable to the attendance 20 years ago. It’s very encouraging and exciting to see so many people interested in white pine as a species to manage!

I’d like to extend a special welcome to everyone – we have participants from all over the southern interior of BC, from the coast, and from as far north as Burns Lake —that person must be thinking about climate change!— some who travelled from as far away as California and our neighbours to the south that are joining us from Idaho.

The planning committee has done an excellent job of putting together this event and I just want to take this opportunity to thank some individuals up front who put a tremendous amount of time and effort into making this meeting happen:

First and foremost, Stefan Zeglen, Forest Pathologist from the Coast Forest Region (and otherwise known as “The Alternate Host!”) who spearheaded the idea of hosting this meeting.

Michael Carlson, Forest Geneticist with Research Branch who will be hosting you on the field tours today and tomorrow showing off many of the demonstrations he’s been involved with throughout most of his career. Mike was also instrumental in making these lovely name tags made out of white pine, wood-burned with your name and affiliation, for the meeting.

In commemoration of this meeting we had the idea of presenting gifts to the guest speakers in the form of wood turned bowls made out of western white pine. Michael took on the task of going out to the forest, selecting the appropriate white pine tree for falling, and relied on the much needed support and assistance of his
two pups Sasha and Charlie, and the strength of Keith Cox to haul the logs back to the office. The logs then made their way up to Prince George where the skilful woodturner, Ron Malek, produced these beautiful vases.

This meeting has also been ably supported by Vicky Berger and Diane Douglas. Diane took care of all arrangements for the meeting, the speakers, accommodations, registration and catering. Thank you so much Diane, for making this task so easy for the rest of the organizers.
Western white pine has been decimated throughout its natural range since the introduction of white pine blister rust to western North America. For several decades now, the selection and breeding of white pines resistant to blister rust has remained a high priority for pathologists, geneticists, and forest practitioners.

The program agenda is broken down into three sessions. The first session will focus on the rust itself, covering historical aspects of the pathogen following its introduction to western North America. The second session will focus on the host as a species; its’ ecology and silvics, wood properties, and the initiation and development of the western white pine resistance breeding program in Idaho. The third session focuses more on the management of white pine in British Columbia with presentations related to the species’ performance in provenance trials, growth and yield, long-term survival rates of local and Idaho-resistant white pine, and silvicultural use of and utilization of white pine from an industry perspective.

As far as the objectives set out for this meeting: first and foremost is to present some background information about the pathogen and then about the host as it pertains to its ecological and commercial values and the practical aspects of managing white pine. Western white pine was, at one time, one of the most sought after conifer species in the Pacific Northwest. Historically, in the southern interior of BC it comprised a significant component in stands located in the Interior Cedar Hemlock biogeoclimatic zone. Despite the high ecological and commercial values to forestry in BC and the fact that we have for many years had available resistant stock for planting, use of white pine as a species choice in reforestation plans has declined which may be due to the lack of knowledge of its long-term performance, planting costs, and also because of the large-scale planting of other conifers like Douglas-fir and lodgepole pine, in large part because of the species’ ability to achieve the minimum height requirement for free-growing quite rapidly.

However, these conifers appear to be plagued with other forest health issues of which in many cases, often don’t become fully expressed until after the free growing window.

More than two decades of blister rust research has been carried out in this province as part of the Tree Improvement Program and there’s been demonstrated good success with managed stands and the establishment of resistant stock which now warrants us to ‘rethink’ our desire to manage this species. The driver behind this meeting today is really, a success story for white pine and should be celebrated as such!

Our second objective is really just to stimulate some thought and discussion around planting genetically improved, rust resistant seedlings and managing those stands to promote high survival and growth to restore white pine back into these ecosystems. There is a lot of discussion these days about species selection and managing for resilience by increasing tree species diversity on the landscape. With all the uncertainty associated with climate change, as professional foresters practicing good forest stewardship, we should be thinking about establishing ecologically suitable species, including white pine, in order to increase stand productivity as well as help diversify managed stands and make them more resilient or better capable of coping with the indirect effects of climate...
change. To do this means to plant rust resistant stock broadly, actively, and perhaps more aggressively than in years past.

In closing, I’d like to encourage everyone over the next two days to enjoy the presentations and partake in the exchange of ideas and information surrounding western white pine and opportunities for increasing management of white pine, now and for the future.
History of western white pine and blister rust in British Columbia

Richard S. Hunt

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ABSTRACT:
Blister rust (Cronartium ribicola) entered Europe about 300 years after eastern white pine (Pinus strobus) was first planted in Europe. North America imported millions of infected seedlings after blister rust was firmly established throughout Europe. Blister rust probably entered into western North America on multiple occasions and spread throughout British Columbia (BC) by about 1930. Two large saw mills solely cutting western white pine (P. monticola) started in the 1920s with the main production for matches. Blister rust surveys in the 1940s painted a poor picture for the future of western white pine in BC, so it was discriminated against in forest management plans. Harvest volumes declined and the two mills ceased production about 1960. Selection of resistant clones from mature parents occurred between 1948 and 1960, but when it was evident that mature tree resistance was not likely to be in their seedlings the program was terminated. A program based on screening seedlings was started in 1983. The selected seedlings are hypothesized to possess age-related resistance that is being expressed at an early age. These and the better parents are incorporated into orchards.

INTRODUCTION:
White pine logging started on the east coast, moved to the Great Lakes Region, then to Idaho and British Columbia (BC). By the time logging started in BC, a disease caused by a putative Asian fungus, Cronartium ribicola J.C. Fisch. in Rab., already had been introduced to North America. This rust pathogen produced cankers that were readily invaded by a host of secondary insects (Furniss et al. 1972) and other fungi (Williams 1972) that caused die-back and extensive mortality (Byler et al. 1972). It had been previously determined that C. ribicola was obligated to alternate between currants or gooseberries (Ribes spp.) and white pines, such as eastern white pine (Pinus strobus L.) and western white pine (P. monticola D. Don). Also the infection in the currants was limited to the leaves, so infection ceased in the fall, while in pines it was perennial in cankers. C. ribicola could spread from Ribes spp. to Ribes spp. or white pines, but it could not spread from pine to pine.
A BRIEF HISTORY OF CRONARTIUM RIBICOLA AND EASTERN WHITE PINE IN EUROPE:

Although eastern white pine first arrived in France (Moir 1924) and Britain (Carroll 1973), in 1553 and 1605, respectively, it was not until about 1705 that Britain established the first plantations. These produced copious seed by 1726, which was used to start additional British plantations (MacDonald et al. 1957). Because seed was readily available plantations were established throughout northern Europe from about 1750 to 1810 (Spaulding 1929). At the same time black currants (R. nigrum L.) were commonly grown (Hedrick 1919) and C. ribicola was first recorded on them in 1830 from Austria (Unger 1836; Poelt and Zwetko 1997) and again in 1846 from the Crimea (Peterson 1973). Normally, we would attribute these collections to C. ribicola that originated in Asia on the assumption that C. ribicola was not endemic to Europe (Spaulding 1922; Gäumann 1959). However, because eastern white pine plantations had already been established for 50 to 100 years without any reports of cankering, it can be argued that these collections on Ribes spp. are of a rare, and relatively benign, European strain of C. ribicola (Gäumann 1945; 1959). Dietrich’s 1854 collection in Estonia (Spaulding 1922; Leppik 1970) is the first European report on white pine. Subsequently, reports of cankers on eastern white pine show the rust spreading westward from country to country across Europe (Spaulding 1922; Gäumann 1959). The spread rate calculates to 36 km/year against the prevailing winds. Spread was aided by infection on nearby black currants and by pine seedling sales throughout Europe from infested nurseries in Germany and Belgium (Spaulding 1922; Moir 1924). Some believe this epidemic was caused by a C. ribicola strain newly introduced from Asia, which was more severe on eastern white pines and black currants than the European strain (Gäumann 1959). An endemic European strain of C. ribicola would certainly explain why native European pines are regarded as blister rust resistant (Søoegaard 1972; Blada and Popescu 2004). The rust arrived in Britain in 1892 (Hunt 2003). Consequently, we can be reasonably certain that by 1895 white pine seedlings over 1-year in age growing anywhere in continental Europe likely would be exposed to C. ribicola. The most commonly imported stock was 2-year-old seedlings. Surveys of these imports into the eastern USA in the early 1900s revealed that some lots were so infested that they were destroyed. In contrast, retained lots only averaged about 1% infection (Spaulding 1914).

HISTORY OF CRONARTIUM RIBICOLA IN WESTERN NORTH AMERICA:

Because Mielke (1943) produced a thorough history of blister rust in western North America, general texts and forestry schools have perpetuated his view of C. ribicola arriving in western North America. He attributes all the C. ribicola in the West to a single importation of 1000 eastern white pine seedlings from France into Vancouver in 1910. Additionally, he shows the rust spreading both 200 km north and south (southern Washington State) by 1913, and 500 km south into Oregon by 1917 or 1918 on pine. This calculates to a spread rate of 66 to 71 km/year against the prevailing winds with little or no aid from black currants and without any known pine infection between Vancouver and these southern points. This shot-gun spread seems strange compared to the slower and
more contiguous spread in Europe. To account for this long distance spread the inoculum density must have been massive at this point source in 1913. But, subsequently to Mielke’s (1943) publication we know from resistance screening programs that if the inoculum density was high, the survival of the young imported stock would be near zero within 6 years (Patton and Riker 1965; Gremmen 1972; Heimburger 1972). However, when found after 12 years, 18% of the stock was still alive even with black currants on site (Davidson 1922)! To account for such high survival the inoculum density must have been very low. Thus, it would appear that the Vancouver importation was not responsible for infection in southern Washington and Oregon. Evidently the imports were 1-year-old seedlings (Davidson 1922), so it is possible that they were lifted prior to basidiospore release and were shipped free of infection. Possibly they were infected in Vancouver later than 1910 from some other importation, thus accounting for the high survival observed in 1922. Shortly, after the initial discovery of blister rust in BC in 1921 (Eastham 1922; Güssow 1923), Pennington (1925) reported a P. strobus importation into Victoria prior to 1910. Metcalf (1929) was convinced that many other importations provided inoculum sources. Certainly, Güssow (1923) could not rule out this possibility. In BC, importation records were not kept prior to 1910 and the quarantine of 1914 (Güssow 1916; Eastham 1923) stopped importations (Güssow 1923). During that 4-year window, 27 importations were recorded, but by the time of the first surveys in the 1920s most of the stock had already been sold off and distributed throughout the province, or possibly destroyed (Davidson 1922). These other importations totalled at least 350 seedlings (Güssow 1923). If we conservatively estimated that there were equal importations prior and post 1910 then there would be an additional 53 potential foci in BC contributing to the epidemic in the west. At the same time similar imports were possibly sent to Seattle, Fort Vancouver, Portland, Coos Bay, Corvallis, San Francisco and perhaps other points in the western USA, but apparently no records were kept. However, unknown to Mielke, Joy (1939) recorded, but did not publish, that a nursery in Washington State had ignored the 1914 quarantine (Spaulding 1922). It imported eastern white pine from known infested sources in eastern North America (Van Ardel et al.) – a few in 1913 from Ohio and 50 from Illinois in 1915 (Joy 1939). It is much easier to explain the early disjunct distribution and apparent rapid spread of C. ribicola in western North America by acknowledging that there were multiple introductions at several different points, rather than a single point source for all western North American infections.

**HISTORY OF RUST DISTRIBUTION SURVEYS AND WHITE PINE UTILIZATION:**

The early surveys in the 1920s were carried out by the BC Forest Service, Ministry of Agriculture, the federal Division of Botany and the US Forest Service. The US Forest Service established white pine species trials (Childs and Bedwell 1948) and disease intensification plots (Lachmund 1934) near Whistler. The rust had spread throughout BC by the 1930s so surveys stopped, and the Americans went home as there was plenty of it within the western USA.
Most early inventories show western white pine at about 1% of the total timber volume in both the BC Interior and on the Coast (BC Forest Service Ann. Rept.). Most of the concentrations were on Vancouver Island, the Fraser Valley and the West Kootenays. Western white pine grew mainly with Douglas-fir at the coast and was harvested in clear cuts. The usual practice throughout the interior was to selectively cut western white pine from mixed stands of Douglas-fir, western hemlock, and western redcedar, as pure western white pine stands did not exist as they did in Idaho.

White pine has always commanded premium prices (BC Forest Service Ann. Rept.), and because the logs were valuable, loggers in the west Kootenays went out long distances for individual trees. They were cut in special runs, or mills, for paneling, furniture, pattern stock and match blocks. In the interior, the WW Powell Co. Ltd. opened in Nelson in 1921 cutting only white pine with their major volume being in match blocks sent to Quebec. Similarly, The Canadian White Pine Company was established in Vancouver in 1923 and they bought logs from various coastal operators. In Mission, the Eddy Match Co. opened in 1947 and the Dominion Match Co. operated in Victoria. Shortly thereafter the need for matches started declining as wood stoves were replaced by electric ranges. There was a major mountain pine beetle outbreak in 1957/1961 (Collis and Alexander 1966), and at the same time white pine inventories were declining throughout the province from aggressive salvage harvesting. There was no re-planting of white pine. In the 1960s the match factories and the Nelson sawmill closed, while the Vancouver sawmill converted to cut western redcedar (Heal 2002). However, export to the east of rough 1-inch boards continued at past volumes until 1990; since then, even bolstering the depleting volumes with white bark pine, the volume of white pine cut has continued to decline (BC Forest Service Ann. Rept.).

HISTORY OF DAMAGE SURVEYS:

In 1946, Buckland, and in 1947, Thomas and Roff, surveyed white pine stands for blister rust incidence. As a result, salvage logging was recommended for severely damaged stands, while for less severely damaged stands maintaining crown closure by replacing selective cutting with clear cutting at normal rotation was recommended. Crown closure was thought to discourage Ribes growth and lessen the impact of blister rust. However, in general, Ribes were abundant, the terrain rough, and most white pines scattered, making Ribes eradication too expensive (Porter 1948). Even in the less severely attacked stands “the situation appears to be beyond hope of survival”, for the next crop (Thomas and Roff 1947). Thus, western white pine was cut without re-planting white pine, and because natural young growth was not counted towards a successfully regenerated stand, it was frequently spaced out during pre-commercial thinning operations. Consequently, volumes declined, and at the coast some white pine stands no longer exist (Hunt et al. 1985). Policies that eliminated white pine remained in effect until the early 1980s when it was demonstrated that most cankers are close to the ground so pruning would permit trees to grow to a harvestable size (Hunt 1982). However, the former volumes of white pine will not be restored until resistant stock is routinely planted in high numbers.
HISTORY OF RESISTANCE PROGRAMS TO 2004:

The first screening of BC western white pines occurred in Ontario in 1946/48 (Heimburger 1972) from seed collected in the BC interior and sent by Dr. C.D. Orchard, the chief forester for BC (Heimburger 1948; Heimburger per. com.). Six selected clones were eventually established at the UBC forest at Haney, BC but these were subsequently culled. In Wisconsin, Riker et al. (1943) discovered resistance in a few clones of mature eastern white pine inoculated with C. ribicola. Following Riker’s methods, Porter (1948) initiated a resistance program in BC. He rated clones for blister rust resistance after inoculation for several years in a Ribes garden. Shortly after the program started, Riker et al. (1949) reported that seedlings were more susceptible than their parents. Later, by using a range of clone ages, Patton (1961) clearly demonstrated that resistance increased with age. He explained his results by observing C. ribicola basidiospores failing to develop in needles of mature pines, but readily developing in seedlings (Patton 1967). Thus, inoculated mature trees will have fewer needle infection spots and subsequently fewer cankers than inoculated seedlings. Porter’s (1960) program was terminated in 1960 because it seemed that his resistant clones would produce susceptible offspring (King and Hunt 2004).

It was not until 1983 that a resistance program based on screening seedlings was jointly established in BC by the Canadian and BC Forest Services. The results of this program are summarized in Hunt (2004). The program started out trying to select for the five main traits reported in seedlings from Idaho, i.e., “reduced spotting,” “early shedding of spotted needles”, “fungicidal short shoot”, “bark reactions” and “no spots”. Reduced spotting was found in a few families, but this did not correlate to less cankering in field plots (Hunt 2002). Making this correlation was further compounded by having the current needles frequently more resistant than older needles, but only on older trees (Hunt and Jensen 2000). At an informal meeting “rust busters” in 1990, Bro Kinloch, (emeritus research geneticist, US Forest Service) challenged the western white pine resistance programs to demonstrate that the “early needle shed” and “fungicidal short shoot” resistance traits were reproducible when re-inoculated. When confirmed, the selected materials should be made available for other programs to evaluate. Since then, the BC program spent many years trying to find “early needle shed” and “fungicidal short shoot” resistance in BC test materials and in materials already selected in Oregon and Idaho without any success. In fact, research found that the timing of the reported “early needle shed” was actually happening after the stems were already infected (Hunt et al. 2007). Most early “bark reactions” observed on BC test seedlings were not reproducible on re-inoculation, and were attributed to attack by secondary fungi, or other primary fungi (Hunt 1997). Slightly later “bark reactions” were called “slow-canker-growth” (SCG) resistance and it usually was reproducible on re-inoculation. This was further sub-divided into four sub-types based on morphology (Hunt 1997; 2004). Re-inoculating “no spot” seedlings in a disease garden usually resulted in spotting and copious cankering, while a few had considerably reduced cankering. These few were marked as resistant and called “difficult to infect” or “DI” for short. It was hypothesized that this is the trait described by Patton; i.e., having reduced spotting and cankering because of mature tree resistance, but in these particular cases it was occurring at an early age. There is a tendency for both
SCG resistance and DI resistance to be found in the same families. It is hypothesized that all these seedlings are displaying the phenomenon known as age-related resistance (ARR), but at an early age. Age-related resistance is also called ontogenetic resistance because it is a developmentally regulated defence response as clearly demonstrated in Arabidopsis (Kus et al. 2002). The defence proteins involved contribute to both developmental functions and to non-specific resistance. Although the inheritance and age of onset are little known in conifers, it is believed that AAR in western white pine is genotype specific. It is hypothesized that some pathogenesis-related proteins (PR proteins) are regulated as a tree ages. It is further hypothesized that PR proteins such as PmPR10 (Liu et al. 2003) and anti-microbial peptide (PmAMP1) (Ekramoddoullah et al. 2006) are responsible for this effect in western white pine (Liu et al. 2004). For instance, older needles and twigs contain more PmAMP1 than younger tissues during the late summer. PmPR10 has ribonuclease activity and this inhibits fungal growth. There are at least 19 isoforms of this protein in western white pine (Liu et al. 2003) so the effectiveness against C. ribicola may vary by isoform and the relative amount of the better isoform types, plus the quantity of the protein produced. It has been demonstrated that the quantity of PmPR10 may increase by pathogen attack and by dormancy (Liu et al. 2003; 2004). Selections of BC trees are more resistant at high-elevations test sites where the dormancy is longer than that at low-elevation sites (Hunt 2005). Also, Idaho orchard stock is highly resistant in the BC interior and less so in southern Idaho, and very susceptible at the BC coast where the dormancy is shorter. A long dormancy would favour the production and retention of PmPR10 compared to locations where the growing season is long.

In British Columbia, we have established orchards with seedlings selected for DI and SCG resistance and from parents that produced seedlings with these traits.

ACKNOWLEDGEMENTS:

I am grateful to Thomas Kirisits, University of Natural Resources and Applied Life Sciences, Vienna, Austria, for copies of publications by Unger, Gäumann, and Poelt & Zwetko, and discussions regarding these works. I thank Vern Wellburn, retired western director of FERIC (For. Eng. Res. Inst. of Canada), for his historical knowledge of forest logging and manufacturing in British Columbia. I thank Otis Maloy, retired pathologist US Forest Service, for bring to my attention E.L. Joy’s records.
REFERENCES:

http://www.for.gov.bc.ca/hfd/pubs/docs/mr/annual/ar_1911-2001/annual


Heimburger, C. per. comm. He verbally told me that he started in 1946; however, the 1948 Heimburger reference above would suggest he started in 1948, or possibly in 1947.


[Victoria, B.C., Department of Agriculture, Dominion Laboratory of Forest Pathology]. Typescript. 19 p. Available at: Library, Pacific Forestry Centre.


Van Arsdel, E.P. et al. undated. unpub. Draft manuscript “History”.

Resistance: What is it?

Detlev R. Vogler¹ and Annette Delfino-Mix²

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ABSTRACT

We discuss modes of susceptibility/resistance to disease-causing organisms in plants, with particular reference to forest trees. We define and illustrate four terms used to describe host interactions with pathogens—escape, susceptibility, tolerance, and resistance—but do not address host phenotypes of resistance or how these phenotypes are inherited. We emphasize the importance of carefully defining the terms we use to ensure our communications with fellow researchers and land managers are coherent and effective.

ACKNOWLEDGEMENTS: Brian Geils, Patricia Maloney, and Kathie Jermstad, for comments on a draft of the manuscript.

In the realm of science, what we see—our observations of organisms in nature and how they behave—and what we say about what we see—the language we use to describe the appearance and behavior of organisms—are critically important. This should be obvious, for these habits of observation and reporting must be exercised in most aspects of life. However, unless we are like Darwin, who penned thoughtful, painfully honest lists of the pros and cons of marriage¹, we tend to be less systematic than he about how we approach our personal decisions. And, even in our scientific lives, we are sometimes careless about the observations we make and the language we use to describe them.

In studies of resistance to blister rust in the white pines (Pinus subgenus Strobus), this injunction is critical, for what we see is the behavior of two distinct organisms—host and pathogen—involved in an intimate association in a shared environment, over several to many years; and, what we say about these observations should be informed by an acute

¹ Darwin, C. R. 1838. 'This is the Question Marry Not Marry' [Memorandum on marriage]. (7.1838) CUL-DAR210.8.2 (Darwin Online, http://darwin-online.org.uk/).
awareness of the dual nature of such interactions. Susceptibility is susceptibility to an organism that is attempting to infect a plant, and resistance is likewise a response to invasion by a pathogen.

By nature, susceptibility and resistance are highly contingent biotic phenomena. Although the design and conduct of resistance experiments are also important, what concerns us here is the language with which we describe the outcome of the host-pathogen interaction. We assert that, as scientists, we should be fastidious in the language we use to describe these critical events. If not careful about how we describe disease resistance, we risk misinterpreting the relevance and consequences of what we observe.

In finding a suitable definition for resistance, we follow the lead of Agrios in the 3rd edition of his textbook, Plant Pathology (1988). There, he coined the somewhat unfortunate term *true resistance*, which he defined as,

“… resistance that is genetically controlled by the presence of one, a few, or many genes for resistance in the plant…. In true resistance, the host and the pathogen are more or less incompatible with each other, either because of lack of chemical recognition between the host and the pathogen or because the host plant can defend itself against the pathogen by the various defense mechanisms already present, or activated, in response to infection by the pathogen.” (p. 125).

In other words, a resistant plant is able to recognize that it is being invaded by a pathogen and therefore responds to prevent the pathogen from establishing, ramifying, and reproducing. By implication, then, susceptibility may be characterized as the inability of a plant to recognize the presence of an invader, thus rendering it unable to mobilize a suitable defense, and allowing the pathogen to ramify and grow within host tissues without hindrance.

Agrios also coined a second term, *apparent resistance* (he might have more aptly and logically termed it *false resistance*), within which he included *escape* and *tolerance*. He defined escape as occurring,

“… whenever genetically susceptible plants do not become infected because the three factors necessary for disease (susceptible host, virulent pathogen, and favorable environment) do not coincide and interact at the proper time or for sufficient duration” (p. 127).

It is worthwhile to add that genetically resistant plants are also subject to escape, the consequence being that their mechanisms of resistance remain untested, since, without a pathogen, there can be no resistant response, and thus no evidence can be gained about a genetic trait that has not been mobilized.
Agrios defined *tolerance* as,

“… the ability of plants to produce a good crop even when they are infected with a pathogen. Tolerance results from specific, heritable characteristics of the host plant that allow the pathogen to develop and multiply in the host while the host, either by lacking receptor sites for, or by inactivating or compensating for the irritant excretions of the pathogen, still manages to produce a good crop. Tolerant plants are obviously susceptible to the pathogen but they are not killed by it and generally show little damage from the pathogen” (p. 129).

For the purposes of this paper, we use these terms somewhat differently from Agrios, primarily because we believe that lumping escape and tolerance under the vaguely labeled “apparent resistance” misrepresents the significance of and differences between these two potent mechanisms. We reject the dichotomy of true and apparent (or false) resistance, as we believe that “resistance” should be as unambiguously defined as possible, without excessive qualification.

For our purposes in understanding and interpreting the white pine blister rust pathosystem, we define and rank these terms in the following manner:

**Escape**

Pathogen and host *do not encounter* each other, and thus the pathogen has no opportunity to infect and the host has no opportunity to resist the pathogen. Escape may occur when host and pathogen are geographically separated, or when host and pathogen are out of sync phenologically, preventing the pathogen from making successful entry into a host. Regardless of whether a pathogen is pathogenic (capable of causing disease in a host), or whether the host is actually susceptible or resistant to a pathogen, as long as host and pathogen fail to encounter each other, there is no interaction and thus no evidence for susceptibility or resistance and thus no disease. Escape is the most likely explanation of “apparent (or false) resistance”—i.e., when lack of challenge results in *neither* a compatible (susceptible) or incompatible (resistant) interaction. Escape provides an explanation for those situations where resistance is hypothesized because of an absence of infection or disease in nature, but, when controlled experiments are carried out, putatively resistant plants prove to be susceptible. *Passive* resistance mechanisms that prevent a pathogen from invading and establishing within a host are a form of escape, for the pathogen is prevented by physical barriers from penetrating the host, and thus no genetic or biochemical interaction occurs because there is *no encounter*. 
**Susceptibility**  Pathogen and host *encounter* each other, but the host presents *no barriers*—either *active* (genetically-mediated recognition of and response to an invader) or *passive* (existing, constitutive physical barriers that prevent a pathogen from gaining entry to a host)—to pathogenic invasion, and thus the pathogen is able to penetrate, establish, and sporulate within a host unhindered, thereby leading to disease. Essentially, the host is incapable of responding to or biochemically “recognizing” an invader, and thus cannot mobilize defense reactions that would prevent inoculation, establishment, disease, and sporulation.

**Tolerance**  Pathogen and host *encounter* each other, pathogenic invasion proceeds as in a susceptible host—often resulting in extensive colonization of the host and sporulation of the pathogen—but the nature of the disease is such that the host survives and reproduces, albeit with some reduction in growth or seed crop and possible deformity. When forestry is practiced as an economic enterprise, the costs of tolerance are likely to be intolerable, but in forests managed for ecosystem and esthetic values, these costs may be acceptable, perhaps even desirable, for enhancing genetic diversity, species heterogeneity, and landscape-scale evolution.

**Resistance**  Pathogen and host *encounter* each other, pathogenic invasion begins, and the early stages of pathogenic growth are similar to a typical susceptible interaction. However, usually within a few hours, days, or weeks, depending upon the aggressiveness of the pathogen, the receptivity and vigor of the host, and the nature of tissue initially invaded, the pathogen elicits a genetic and biochemical response in the host that causes it to sequester the pathogen within a barrier of necrotic host cells from which the pathogen cannot escape. If the tissue invaded can be sacrificed (a leaf or needle, preferably, or even a twig or minor branch), the pathogen, though alive, may be unable to flourish or sporulate, and will die along with the invaded plant part. If a tree stem is invaded, either from infection in a leaf or small branch, a necrotic lesion may develop, preventing the pathogen from penetrating further into uninfected tissues. The stem may be wounded or deformed by the resistant host’s response to invasion, but in a perennial plant stem growth may relatively quickly encapsulate the wound, rendering the pathogen innocuous and incapable of further growth or sporulation.
All of this may be illustrated graphically for greater clarity and comprehension (Figure 1, below). The image depicts relationships among the four modes by which plants interact with and respond to pathogens: escape, susceptibility, tolerance, and resistance.

**Fig. 1.** Illustration of relationships between modes by which plants respond, or appear to respond, to disease-causing organisms. Direction of solid blue arrows designates increasing effectiveness against pathogens. Dashed black arrow: although differing in robustness and underlying genetics, these two modes are indistinguishable in the forest since, in either case, hosts appear unaffected. Dashed yellow arrows: although these responses differ dramatically in disease effects and in subsequent host survival, all three depend upon inoculation and incubation to express differentially. Horizontal blue line: differentiation between modes in which disease is evident, and those in which no disease occurs.

Escape, though it may appear to be a significant mechanism, is actually absence of encounter with a pathogen; whether a plant is susceptible, tolerant, or resistant, if it escapes encounter, it is really only *apparently* resistant, although in fact it may be any of the above. We just don’t know. Still, if neither powerful nor especially useful, escape may be one of the more common modes by which plants evade infection; nevertheless, since individual trees cannot move, they can only *passively* escape their pathogens.
As noted above, escape and resistance do share a common feature: host plants appear identical in the field because of a lack of disease symptoms, in the former case because of a passive mechanism and in the latter because of an active mechanism. This is denoted by the dashed black, double-headed arrow at the bottom of the graphic.

Situations under which disease will be apparent are at the top of the figure, susceptibility and tolerance. Differentiation of these two categories will be made in the field by the professional land manager and his or her field assistants. In most cases, susceptibility will be viewed as unacceptable because infected hosts are deformed, rendered incapable of reproduction, or at risk of dying before they reach a desired size and maturity.

As to tolerant hosts, disease will be evident and may reduce the productivity or appearance of a host so greatly that the tree must be harvested for wood products or removed for esthetic or disease-sanitation purposes. Depending upon management goals, land managers may also judge infected but tolerant trees as likely to survive and produce wood products or provide esthetic and ecosystem benefits. Although susceptibility is unacceptable in many situations, tolerance may provide adequate protection to be beneficial to land managers.

Yet tolerance is not without risks: over the life of a stand, initially tolerant trees may become more susceptible because of genetic changes in the pathogen, changes in the environment, or by actions of other pathogens and insects over time. Tolerance is essentially living with disease, with all the inherent problems that accrue thereto. Nevertheless, many land managers may judge it the most feasible long-term choice for forest sustainability.

Resistance can be either complete (preventing any further growth or sporulation of the pathogen) or partial (allowing some growth of the pathogen, but substantially limiting the ravages of disease so that infected trees may survive and regenerate). In our terms, however, resistance as denoted in Figure 1 is defined as complete, and partial resistance is viewed as a form of tolerance.

One drawback to resistance (i.e., “complete” resistance) is that virulent pathogen genotypes may arise that are capable of bypassing host resistance, thereby rendering formerly resistant host genotypes effectively susceptible. This phenomenon has been demonstrated and extensively reviewed in agricultural pathosystems (Flor, 1971; Robinson, 1987; Keen, 1990; Crute et al., 1997; Barrett et al., 2009) and has been reported twice in the white pine blister rust/white pine pathosystem (Kinloch et al., 1970; Kinloch et al., 1999).

Nevertheless, mutation to greater or lesser virulence can occur in all three modes by which a plant directly interacts with a pathogen. Generally, increased virulence is only reliably detectable in those instances when the mode of inheritance is simple (involving one or very few genes, and thus simply inherited) and the hosts are planted in such a manner that the onset of virulence is readily detectable because the expected frequency of resistance is already known and any deviations from this frequency can be easily
observed in the field.

Although land managers and researchers practice distinct and often mutually-incomprehensible disciplines, they share a need to understand clearly what they are talking about and what the consequences of their decisions will be. The study of disease resistance often employs words and phrases that are opaque or inconsistent, preventing adequate communication between researcher and practitioner. What we have attempted here is to bring some clarity to what disease resistance research can offer in the way of resistant plant materials that may help prevent or reduce the damage that diseases cause to individual trees, to stands, and to forests.

Research cannot offer silver bullets or magic wands, but it can provide insight, information, and genetic materials that benefit the forester or other biologist who is attempting to manage wildlands for the long term, both for commodity and ecosystem values. This can only happen successfully, however, if both researcher and practitioner understand clearly and precisely the words they use to describe plant disease resistance and related phenomena. We hope to have made some progress in this endeavor.

REFERENCES


The Distribution and Ecology of Western White Pine (*Pinus monticola*)

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Western white pine, (*Pinus monticola* D. Don), also known as silver pine, soft pine, fingercone pine, mountain pine, Idaho pine, or little sugar pine, is a conifer species that is widely distributed across western North America. It occurs west of the Rocky Mountains from northern California to southern British Columbia, and occupies parts of Washington, Oregon, Idaho, Nevada, and California. In British Columbia it ranges from 0-1200m along the coast and 300-1600m in the interior. In California it occupies an elevation range of 2000-2500m in the Sierra-Nevada’s and occurs up to 3500m in the San Bernardino Mountains. Along the coast of Washington and Oregon it ranges from 500-1500m, while inland it is restricted to 300-1900m. It is the state tree of Idaho.

White pine characteristically has straight blue-green needles, which are approximately 4-10 cm long and 0.4 to 1 mm wide, and bundled in fascicles of five. The margins of the needles are minutely serrated, the tips are broadly to narrowly acute and have a 1-1.5 cm sheath. Needle retention of white pine is typically about 3-4 years. The bark of the tree is grey in colour, smooth with distinctive pitch pockets when young. As the tree ages, its bark develops distinctive rectangular or hexagonal scaly plates which give way to an increasingly furrowed appearance in older individuals. The bark thickness of white pine is intermediate when compared to other conifers growing in western North America. As a consequence, white pine is more susceptible to wildfire than Douglas-fir (*Pseudotsuga menziesii* (Mirb. Franco)), western larch (*Larix occidentalis* Nutt.), and Ponderosa pine (*Pinus ponderosa* Douglas ex C. Lawson).

Western white pine staminate cones are yellowish and ellipsoidal, approximately 10-15 mm long. Ovulate cones are 10-25 cm long, resinous, green with grey and purple tints when young, at maturity cones are brown. Cone production can occur as early as seven years into the tree’s life and mature two years after fertilization. Seeds are shed shortly after maturation. Cone production appears to be unaffected by irrigation or fertilization, although thinning combined with fertilization has been shown to increase cone crops. Initial viability of seeds is moderate (approximately 40% in year 1), but declines to only a
1-2% chance for germination after 3-4 years. Despite this, western white pine is one of the most consistent seed-producing conifers, with seeds fairly resilient to temperature extremes and therefore easy to store. This benefit however is offset by poor natural dispersal due to the heavy nature of the seeds, generally falling within 120 m of a parent. It is commonly slow to germinate and prefers a mineral soil seedbed.

Genetic variation within populations of western white pine is generally low, with little apparent differentiation due to ecological factors throughout its geographic range. As a consequence, seed can be transferred with little regard for local geographic conditions including elevation, latitude, longitude, and habitat type. It is genetically distinct from eastern white pine (*Pinus strobus* L.), but physically very similar.

In British Columbia western white pine is most commonly associated with the Interior Cedar-Hemlock (ICH) and Coastal Western Hemlock (CWH) Biogeoclimatic Zones (Meidinger and Pojar 1991; Lloyd et al. 1990) but is restricted to latitudes south of about 52 degrees. Small localized stands of white pine can also be found at lower elevations of the Mountain Hemlock (MH) and Engelmann Spruce-Subalpine Fir (ESSF) Zones, and climatically wetter portions of the Interior Douglas-fir (IDF) and Montane Spruce (MS) Zones, more specifically the coast-interior transition and in the interior wetbelt-drybelt transition areas. It’s occurrence in the Coastal Douglas-fir (CDF) Zone is relatively minor, with drought being a limiting climatic factor.

The climatic profile for western white pine shows the species to be intolerant of extended periods of drought, and is likely restricted from higher elevations and northern latitudes by temperature regimes that result in a shorter growing season, fewer frost free days, and colder winter extremes. It grows in areas with the mean annual precipitation between 270-1800 mm and with the growing season precipitation between 80-460 mm. The mean annual temperatures range is from 2.5-7.9˚ C. It is best suited to sites that are well drained with good exposure.

White pine is typically found on soils with morainal, colluvial, eolian, lacustrine and fluvial parent materials. Soil development tends to be podzolic in nature, but at the drier climatic range of its distribution, it may also occur on Brunisols. It is also found locally on Gleysols and Regosols. It rarely occurs on Organic soils. Soils are generally acidic with pH’s ranging from 3.5-6.5, but more typically it grows on soils with pH’s ranging from 4.0-5.0.

White pine tolerates a range of soil moisture conditions (Figure 1). It favours intermediate conditions in the IDF and MS Subzones that have climates that are transitional between coastal and interior conditions and in areas that are transitional between the interior “drybelt” and interior “wetbelt” climates. In the ICH and CWH Zones, it seems to grow on all but the wettest (subhydric, wetlands) and the driest (very xeric, rocky outcrops) sites. It occurs widely on intermediate sites but it is most productive on subhygric, seepage sites.
Western white pine is relatively intolerant of drought, but moderately tolerant of flooding and poor drainage conditions. The species is moderately shade and frost tolerant when compared to other conifer species with which it is commonly associated. It is generally considered to be a seral species, requiring wildfire or harvesting to remove competing trees and vegetation for it to become established. The species is relatively windfirm, but can be prone to snow breakage in young pole-sapling stands.

With respect to stand composition, western white pine occurs almost exclusively in mixed stands. A GIS query of the provincial forest cover inventory, indicates that of the stands containing any white pine, 86% of the stands contained less than 20% white pine. In other words, white pine generally makes up only a minor component of most stands. This inventory also showed that white pine was most commonly associated with Douglas-fir (*Pseudotsuga menziesii* Mirb. Franco), western hemlock (*Tsuga heterophylla* Raf. Sargent) and western red cedar (*Thuja plicata* Peattie); the latter two species defining the location of the ICH and CWH zones. In order of dominance, other commonly associated seral tree species include hybrid spruce (*Picea engelmannii* x *pilungii* Perry ex Engelm.), lodgepole pine (*Pinus contorta* Dougl. ex Loud.) western larch, paper birch (*Betula paperifera* Marsh.), and trembling aspen (*Populus tremuloides* Mich.).

Western white pine exhibits rapid growth potential. Under ideal conditions, it can achieve a site index exceeding 45 m in height at 50 years of age (Figure 2). In young stands, white pine is generally several meters taller than other adjacent tree species. It has also demonstrated excellent performance where planted on a trial basis on sites beyond its natural distribution. Unfortunately, most naturally regenerated stems are quickly infected by white pine blister rust and rarely reach rotation age.
**Fig. 2.** Site index height growth curves based on breast height ages for white pine (Curtis et al. 1990).

Figure 3 illustrates the relationship between site index and soil moisture regime across a range of Biogeoclimatic Subzones in British Columbia’s southern interior. The growth potential is greatest on seepage sites in the ICH. While the average site index is upward of 35 m, individual trees in excess of 40 m in height have been observed. When found in the ESSF, the shorter growing season is responsible for reduced growth and many trees have reduced top heights due to snow breakage. Reduced growth rates in the IDF and on dry rocky sites can be attributed to inadequate soil moisture or drought.

**Fig. 3.** Site index of western white pine across a moisture continuum for biogeoclimatic subzones in the British Columbia’s southern interior.
Historically, although white pine has been known to live in excess of 400 years, the mean age of white pine in the provincial inventory is currently 60-80 years, with less than 1% exceeding 300 years (Figure 4). At least 85% of the stands containing white pine are less than 120 years old. This in part reflects the seral nature of the species. However, this skewed age class distribution also reflects the impacts of white pine blister rust (*Cronartium ribicola* J.C Fisch), the consequences of forest harvesting and to lesser extent, the natural wildfire disturbance regime. Seedlings, saplings and immature trees with a canopies extending to or near the soil surface appear most susceptible the blister rust and this likely contributes to the sharp decline in abundance after 60-100 years. Much of the CWH and ICH where white pine is most common, has a natural wildfire return interval in excess of 250 years. Hence, these old growth climax stands may have historically had a white pine component, but natural forest succession has resulted in its replacement by western red cedar and western hemlock. In these areas, logging may benefit western white pine by creating early seral sites where western white pine may become established provided it is planted or a local seed source is present. Use of genetically rust resistant planting stock should also contribute to an increase in the abundance of white pine found in late seral stands.

![Age Class of Stands with White Pine](image)

**Fig. 4.** The age class distribution of stands containing white pine in British Columbia.

White pine is susceptible to a number of disturbance agents, including fire, bark beetles, and most notably white pine blister rust. White pine blister rust was introduced from France into British Columbia around 1910. This disease has resulted in a major decline in western white pine throughout its range. The species is also susceptible to Armillaria root disease (*Armillaria ostoyae* Romagn. Henrick); although it is often more tolerant than other conifer species. White pine has also been considered to be resistant to
Phellinus root disease (*Phellinus sulphurascens* Pilát) and has been proposed as an alternative for planting sites infected with this disease. White pine is attacked by the mountain pine beetle (*Dendroctonus ponderosae* Hopkins), but considerably less frequently than lodgepole pine or Ponderosa pine and is sometimes susceptible to attack by red turpentine beetle (*Dendroctonus valens* LeConte). It is also prone to attack from foliar diseases, such as red band needle blight (*Dothistroma septosporum* Dorog.) and *Lophodermella arcuata* (Darker) and *Lophodermium nitens* (Darker) which have shown to cause needle cast on isolated trees.

Climate change is an undeniable global event. Projected climate warming will potentially have profound effects on the earth’s biota, including the distribution of tree species. Current models that predict rising temperatures and changes in the precipitation regime for British Columbia indicates a likely expansion of the climatic envelop which corresponds to the CWH and ICH zones (Hamann and Wang, 2006). Since the range of white pine is strongly correlated with these zones, it seems fair to anticipate that the distribution of white pine will expand.

A Canadian Natural Resources Ministry web site shows the results of climatic models aimed at predicting the implications of climate change on white pine distribution (Figure 5). The climatic models project changes in the temperature and precipitation and then assess the results in concert with known ecological temperature and moisture requirements and the limitations and tolerances of white pine.

Numerous analytical and modelling approaches have been taken in both Canada and the United States. While the results are locally variable, the trends are similar. Most sources conclude that the range of white pine will expand significantly northward, that it will move up in elevation, and that its distribution will be reduced throughout its southern geographic range.
Fig 5. Prediction changes in the distribution of western white pine based upon the Canadian general circulation model CGCM2 A2 Scenario 2. (Source: Natural Resources Canada web site).

While there is considerable speculation about the nature of global warming and the predicted results, additionally, there are questions about the ability of tree species to migrate at a pace which corresponds to a changing climate. This will be particularly true for a tree species like white pine whose mobility may be compromised by large seed that generally disperses only a short distance. Successful expansion of populations will also be compounded by the impact of white pine blister rust on natural regeneration. If white pine is to achieve its migration potential, it’s clear that silviculturalists must be vigilant in planting significantly more blister rust resistant stock than what has historically been planted.

In summary, in British Columbia, the current distribution of western white pine is primarily restricted by drought and winter extremes. There is a strong correlation with white pine distribution and the ICH and CWH Biogeoclimatic Zones, south of 52 degrees latitude. It seems to grow on a wide range of soil moisture regimes within the ICH and
CWH zones but its maximum growth tends to occur on seepage sites. White pine blister rust combined with forest harvesting and wildfires have had a strong cumulative impact resulting in the reduction of white pine across BC’s landscapes. However, the introduction of white pine blister resistant planting stock, increased removal of old growth stands in the ICH and CWH, and global warming bows well for recovery of white pine populations. If this species, with valuable wood qualities, is to play a more prominent role in future forestry markets, then silviculturalists must take responsibility for planting significantly more blister-resistant stock throughout its potential range.

REFERENCES:


Wood Properties Of Western White Pine

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INTRODUCTION

Canada has eight forest regions, each with a characteristic mix of tree species. We also have a vast range of climate, soils, aspects, and elevation. Western white pine is one of the 22 common commercial softwood species in Canada (and there are 14 common hardwood species as well). Each of these species can grow in a mixture with others, while some can grow in pure stands. All of these species will respond in their own way to a variety of silviculture treatments. The proper choice of stand treatment will depend on stand condition and the desired end product.

Forest management professionals are trying to do the best they can to supply their operations, while dealing with the forest, blister rust, wood supply, mill configuration, market situations, and public expectations.

BACKGROUND

The pines, which comprise the genus Pinus, in the family Pinaceae, include a very diverse group of species, which can be separated into two major subgroups, soft pines and hard pines.

The qualities of the wood of these two subgroups can be summarized as follows:

Soft pines; Medium-low density (less than 0.40 on average)
  Fairly soft
  Even-grained
  Gradual earlywood to latewood transition
  Non-dentate ray tracheids (a microscopic feature)
  Large, window-like ray-cross-field pits (another microscopic feature)

The three principal soft pines include eastern white pine (P. strobus), western white pine (P. monticola), and sugar pine (P. lambertiana). These pines can be recognized by the fact that their needles are borne along the twig in groups of five.
**Hard pines:** Medium to high density (greater than 0.40 on average)
- Moderately hard to hard
- Uneven-grained
- Abrupt earlywood to latewood transition
- Dentate ray tracheids
- Smaller window-like or pinoid (football-shaped) cross-field pits

This group includes trees whose needles are generally borne along their twigs in groups of two or three. Woods in this group include the southern yellow pines, red pine, Scots pine (*P. sylvestris*), ponderosa pine (*P. ponderosa*), lodgepole pine (*P. contorta*), jack pine (*P. banksiana*), and radiata pine (*P. radiata*).

**GROSS FEATURES OF WESTERN WHITE PINE WOOD:**

The wood is moderately soft, even-textured, straight-grained, and light-weight, and slightly resinous with a characteristic pine-smell. Bending strength in the air-dry condition is medium. It is weak in compression parallel to grain. The sapwood is nearly white to pale yellowish white, narrow to medium wide. The heartwood is cream colored to light brown or reddish brown, becoming darker with exposure. The earlywood zone is several times wider than the latewood. Latewood bands are distinct to the naked eye, but the end-grain is not pronounced. The transition from earlywood to latewood is gradual. In cross-section the rays are very fine and are not distinct to the naked eye, unless they include a horizontal resin canal. On the radial surface (edge-grain) the rays form a fine, close, inconspicuous fleck.

Both longitudinal and horizontal resin canals are normally present. The numerous longitudinal resin canals, which appear as white flecks to the naked eye, are confined mainly to the central and outer portions of the growth ring (Figure1). They are solitary or rarely 2-3 contiguous tangentially, forming more or less prominent streaks along the grain. The horizontal canals are smaller than the longitudinal ones, and appear as white, rather prominent wood rays spaced irregularly on the cross-section, scarcely visible with a hand-lens on the tangential surface (flat-grain).
Fig. 1. Western white pine wood showing longitudinal resin canals as white flecks in the central and outer portions of the annual growth ring.

Western white pine is indistinguishable from eastern white pine, and the two species are interchangeable for use. In addition, some ponderosa pine, with non-prominent latewood, can be a western white pine substitute.

Appendix I shows a key for identifying stumps of B.C. tree species based on macroscopic features of wood.
MICROSCOPIC STRUCTURE OF THE WOOD:

*Tracheids:* On average, 2.9 mm in length and 35-45 microns in diameter. Fiber coarseness is 24 mg/100m. Bordered pits are present mostly in one row (or occasionally in two) on the radial walls; tangential pitting is present in the last few rows of latewood tracheids. Pits leading to ray parenchyma are very large, window-like, 1-4 (generally 1 or 2) per ray-cross-field. Ray tracheid pits are present, and appear as small bordered pits on ray margins.

*Resin canals:* longitudinal resin canals are 135-150 micron in diameter, horizontal less than 80 micron, with thin-walled epithelial cells.

*Rays:* Numerous uniseriate and scattered fusiform rays, the latter with horizontal resin canals. Ray tracheids are present in both types of rays, with non-dentate inner walls. Volume occupied by all rays is approximately 6.5%.

GROSS FEATURES OF THE BARK:

Smooth bark, gray to light gray in color, and less than 1.0 cm thick on young trees. On older trees the bark breaks up into nearly square or rectangular plates, giving the impression of paving stones, dark grey in color, still relatively thin, less than 2.0 cm thick. Figure 2 shows the appearance of bark on the lower part of the stem western red cedar, western white pine, subalpine fir, and Douglas-fir. The dead outer bark of western white pine has fine cork-tissue layers, visible with an unaided eye, especially if the cross-sectional surface is cut with a sharp knife (Figure 3).

![Fig. 2. Appearance of bark on stems of western red cedar, white pine, subalpine fir and Douglas-fir.](image)
Appendix II shows a dichotomous key for identifying stumps of B.C. softwoods, based on bark morphology.
PHYSICAL PROPERTIES OF WOOD

Western white pine wood density is 0.36 (this value is based on oven-dry weight divided by green-volume, and one could convert this to 360 kilos/cubic meter; of course, water would weigh 1000 kg/ m3).

Heartwood moisture content averages 62%, and sapwood moisture content 148%, on the oven-dry weight basis.

Shrinkage of wood, when dried from sopping wet to oven-dry (0% moisture content) radially 3.7 %, tangentially 6.8 %, longitudinally 0.1-0.2 %. Volumetric shrinkage is 10.7% from wet to oven-dry, and only 6.0 % from wet to air-dry. Once installed, the wood moves very little in response to changing relative humidity conditions.

UTILIZATION OF WESTERN WHITE PINE WOOD

Western white pine wood is famous for its workability across or with the grain. The wood is straight-grained, and can be kiln-dried with no difficulty. The wood is used extensively for architectural detailing, furniture building, matches, boxes, crates (because of its light weight), does not split when nailed (has very little latewood, it is almost entirely earlywood), the wood has no taste, but does smell like pine. Higher grades are used for sash, doors, and window frames, patterns, paneling and interior trim. Lower grades are used for siding and sheathing. The wood takes and holds paint well. Wood cutting is easy in any direction, and it is an excellent choice for wood carving. Figure 4a) shows an example of carved eastern white pine in the Library at the Parliament Buildings in Ottawa, Ontario. Figure 4b) shows a western white pine wood carving by the author. This one-by-six-foot piece was carved entirely by hand, using a carving knife. Because of exterior installation, the wood was pressure treated in an industrial plant with chromate copper arsenate (CCA), hence the green color of the piece.
In general, pine furniture is usually made from knotty wood (with ingrown live knots), because this gives character to the piece. Second-growth western white pine wood is used extensively in veneer slicing for the furniture industry.

Based on western white pine wood’s density and stiffness, clear wood has excellent acoustical (resonating) properties, as the following table illustrates. The “ability to resonate” is calculated as the square root of Modulus of Elasticity (MOE)/relative density cubed. Please note, the higher the number, the greater the ability to resonate.
**Table 1.** Old-Growth Relative Density and Modulus of Elasticity Reference Values for some British Columbia Softwoods (Jessome 1977) and their Ability to Resonate.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>No. of Trees Tested</th>
<th>Relative Density (Oven-dry)</th>
<th>Modulus of Elasticity (Mpa)</th>
<th>Ability to resonate</th>
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<td>Cedar, western red</td>
<td>Thuja plicata</td>
<td>12</td>
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<td>344</td>
</tr>
<tr>
<td>Larch, western</td>
<td>Larix occidentalis</td>
<td>17</td>
<td>0.640</td>
<td>14,300</td>
<td>234</td>
</tr>
<tr>
<td>Pine, lodgepole</td>
<td>Pinus contorta var. latifolia</td>
<td>13</td>
<td>0.455</td>
<td>10,900</td>
<td>335</td>
</tr>
<tr>
<td>Pine, western white</td>
<td>Pinus monticola</td>
<td>17</td>
<td>0.398</td>
<td>10,100</td>
<td>400</td>
</tr>
<tr>
<td>Pine, Ponderosa</td>
<td>Pinus ponderosa</td>
<td>17</td>
<td>0.489</td>
<td>9,510</td>
<td>313</td>
</tr>
<tr>
<td>Spruce, black</td>
<td>Picea mariana</td>
<td>32</td>
<td>0.445</td>
<td>10,400</td>
<td>343</td>
</tr>
<tr>
<td>Spruce, Engelmann</td>
<td>Picea Engelmannii</td>
<td>11</td>
<td>0.425</td>
<td>10,700</td>
<td>373</td>
</tr>
<tr>
<td>Spruce, Sitka</td>
<td>Picea sitchensis</td>
<td>14</td>
<td>0.394</td>
<td>11,200</td>
<td>428</td>
</tr>
<tr>
<td>Spruce, white</td>
<td>Picea glauca</td>
<td>43</td>
<td>0.393</td>
<td>9,930</td>
<td>404</td>
</tr>
</tbody>
</table>

**WOOD MORPHOLOGY RELATED TO VENEER-PEELING EFFICIENCIES**

1) With smaller logs there is more waste left behind in the peeler core;
2) With smaller logs there is more fish-tail (that part of the veneer that is produced during roundup, until there is a continuous sheet coming from the log being peeled);
3) With smaller logs more time is spent on de-barking;
4) With smaller logs the lathe is spending more time in the non-productive phase.

For example, when we consider log size, and 1/10-inch-thick veneer, a 15 cm (6") diameter log will yield only 2 full sheets of veneer. A 20 cm (8") log will yield 5 sheets, a 25 cm (10") log will yield 10.5 sheets, and a 30 cm (12") log will yield 16 full sheets of veneer.

As peeler block small-end-diameter increases from 15 to 30 cm (6 to 12 inches), the percentage of volume lost to round-up and the peeler core as low-value pulp chips drops from 48% to 24%. Over the same diameter range the % of block volume manufactured into the highest value product (full veneer sheets) increases from 33% to 63%.
APPENDIX I. DICHTOMOUS KEY FOR IDENTIFYING STUMPS OF B.C. SOFTWOODS, BASED ON MACROSCOPIC FEATURES OF WOOD.

Developed in 2007 by Les Jozsa, Research Scientist Emeritus, FPInnovations, Forintek

Note; all features are to be seen at 15-times magnification on smoothly cut clean cross-sectional surfaces

<table>
<thead>
<tr>
<th>Step</th>
<th>(a) Resin canals present</th>
<th>Go to Step:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(a) Resin canals normally absent</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>(b) Resin canals normally absent</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>(a) Latewood prominent, easy to see</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>(b) Latewood is not prominent, wood has a light color</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>(a) Resin canals are large, easy to see, relatively frequent</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>(b) Resin canals are very small, hard to see even with loupe, and they are relatively infrequent</td>
<td>Douglas-fir Western larch</td>
</tr>
<tr>
<td>4</td>
<td>(a) EW-LW transition gradual, wood is easy to cut</td>
<td>Ponderosa pine</td>
</tr>
<tr>
<td></td>
<td>(b) EW-LW transition abrupt, wood is dimpled on the flat grain (tangential surface)</td>
<td>Lodgepole pine</td>
</tr>
<tr>
<td>5</td>
<td>(a) Resin canals are large and they are the easiest to see as distinct pin-prick cavities</td>
<td>White pine Spruces</td>
</tr>
<tr>
<td></td>
<td>(b) Resin canals (RC) are very small, and they are hard to see even with the loupe, RC occurring in multiples of 2-3 tangentially in the latewood, often no more than “white dots”</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>(a) Latewood brown and prominent</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>(b) Latewood pale and narrow, wood smells like raw potato</td>
<td>Yellow cedar</td>
</tr>
<tr>
<td>7</td>
<td>(a) Latewood about 1/3 or more of the ring width</td>
<td>Western hemlock Grand fir Amabilis fir Subalpine fir</td>
</tr>
<tr>
<td></td>
<td>(b) Latewood is 1/4 or less of ring width on average, wood smells very fragrant (like cedar)</td>
<td>Western red cedar</td>
</tr>
</tbody>
</table>
APPENDIX II. DICHOTOMOUS KEY FOR IDENTIFYING STUMPS OF B.C. SOFTWOODS, BASED ON BARK MORPHOLOGY

Developed in 2007 by Les Jozsa, Research Scientist Emeritus, FP Innovations, Forintek

Note; bark features described are visible on surface topography and on cross-sectional surfaces. Thick bark is where bark thickness is more than 2-cm, thin bark is where bark thickness is less than 1-cm.

Step:                                                                                              Go to Step:

1   (a) Thick bark, with prominent cork tissue (easy to see)........................................2
     (b) Thin bark without well developed cork tissue....................................................4

2   (a) Cork tissue in arching lenses....................................................................................3
     (b) Cork tissue in straight lines, like stacked plates..............................ponderosa pine

3   (a) Bark brown when cross-cut, beige cork plates.............................. Douglas-fir
     (b) Bark turns beet-red when cross-cut (axe or saw)..........................western larch

4   (a) Thin bark is fragmented with ridges or scales.......................................................5
     (b) Thin smooth bark, not fragmented even on old stumps..........................8

5   (a) Bark turns beet-red when cut...........................................................western hemlock
     (b) Bark does not turn beet-red color when cut........................................6

6   (a) Bark fragmented like paving stones, cork tissue visible..............white pine
     (b) Bark is fragmented, cork tissue thin and hard to see........................7

7   (a) Bark in thin loose scales.................................................................spruce
     (b) Bark has resin pockets, cork tissue undeveloped............................lodgepole pine

8   (a) Grey bark with evidence of resin blisters.............................. amabilis fir
     ..................................................................................................grand fir, subalpine fir
     (b) Fibrous bark in long vertical interlocking strips..............................western red cedar
         ..................................................................................................yellow cedar

REFERENCES

ABSTRACT

The genetics program follows a recurrent selection program for general combining ability, screening for seven, rust resistance traits. Family selection is based on a weighted index for spots per meter, early stem symptoms, bark reactions, and canker tolerance. Elite trees are assigned to sublines in rank order to facilitate positive assortative mating within a circular half-sib mating design. About 535 controlled crosses have been made since 2000. Within-family selections, based on the presence of no-spot, needle shed, short shoot, and bark reaction traits, are deployed to the Phase II/III seed orchards. There are 39 rust screening trials, performance tests, and realized gain trials in the program. In situ gene conservation involves four clone banks and 3,811 plus trees among cooperators. About 256 lbs of individual-tree and bulked seed and 15,770 gm of pollen are part of the ex situ efforts. Phase I (F2) and Phase II/III (F1) USFS orchards annually produce about 1,316 and 215 bushels of cones. Approximately 170,780 acres (69,112 ha) of rust resistant seedlings have been planted on federal lands in Idaho, Montana, Oregon, and Washington. Overall the western white pine blister rust resistance program is sitting on the cusp between the first and second generations of genetic improvement.
INTRODUCTION

Western white pine (\textit{Pinus monticola} Douglas ex. D. Don) is a seral component of the majority of community types. In the Northern Rocky Mountains it occurs in associations on moist sites with fir (\textit{Abies} spp.), western hemlock (\textit{Tsuga heterophylla} (Raf.) Sarg.), western redcedar (\textit{Thuja plicata} Donn ex. D. Don) and spruce (\textit{Picea} spp.), on drier sites with ponderosa pine (\textit{Pinus ponderosa} C. Lawson var. ponderosa) and western larch (\textit{Larix occidentalis} Nutt.), and under cooler conditions and higher elevations with whitebark pine (\textit{Pinus albicaulis} Engelm.). Western white pine in the interior has a distribution spanning 44º to 52º N latitude, 113º to 121º W longitude and elevation 400 to 1,900 m. Disjunct populations occur in northwestern Montana, eastern Oregon and southeastern Washington. Western white pine uses include building construction, framing, doors, interior paneling, match wood, and toothpicks (Harvey et al. 2008, Graham 1990). Though more tolerant to Armillaria root disease than Douglas-fir (\textit{Pseudotsuga menziesii} (Mirb.) Franco) or Ponderosa pine, it is highly susceptible to the introduced pathogen, white pine blister rust (\textit{Cronartium ribicola} J.C. Fisch) (Fins et al. 2002, 2001, Harvey et al. 1995). Western white pine is estimated to occupy 5 to 10% of the original 5 million acres (2,023,428 ha) of cover type that existed in the Inland Northwest at the time white pine blister rust was introduced (Fins et al. 2002). It is largely represented by widely scattered trees with limited natural regeneration potential in areas it formerly dominated (Harvey et al. 2008).

The first phenotypic selection in the Inland Northwest was made in 1946 (Bingham 1983). USDA Forest Service Research initiated the Phase I selective breeding program in 1950 (Hoff and McDonald 1980a), which was later transferred to the USDA Forest Service Northern Region in 1971, which coincided with the formation of the Inland Empire Tree Improvement Cooperative (IETIC). Since 1971, Phases II and III have been a collaborative effort of the USDA Forest Service Northern Region (84%) and Inland Empire Tree Improvement Cooperative (16%) (2008 IETIC Annual Report). Rust resistant selections from Phases I and II have also been included in IETIC orchards, Colville National Forest and Dorena Genetic Resource Center orchards and breeding program, British Columbia Ministry of Forest and Rangeland Kalamalka Research Centre orchards, and Klamath National Forest blister rust resistance field test site at Happy Camp (Kinloch and Byler 1981). After 30 years in the field, western white pine full-sib families from Idaho performed the best overall (44 to 64% rust-free) as compared to full-sib families from the Cascade Range of Oregon and Washington (Kinloch et al. 2007).

Concurrent with the establishment of the blister rust resistance selective breeding program was genecological research to establish patterns of genetic variation among and within seed sources. These endeavors also involved characterizing a model to describe patterns of genetic variation across environmentally heterogeneous landscapes from Idaho, Montana, and eastern Washington using geographic variables and elevation to establish seed transfer guidelines in key adaptive traits. Rehfeldt et al. (1984) concluded adaptations to heterogeneous environments in western white pine were likely achieved through phenotypic plasticity rather than through natural selection. Similar results were
obtained by Steinhoff (1979) and Townsend et al. (1972) where western white pine seedlings representing the various elevation and latitudinal collection areas did not differ significantly. These findings culminated in the delineation of one breeding zone (Figure 1) for the Inland Northwest selective breeding program (Mahalovich and Eramian 1995, Franc 1984). The genecological research to-date may only be part of the explanation for adaptive response in western white pine, as genetic differentiation with respect to blister rust resistance has not been reported in western North America, but studies since 1996 (Cycles 14-22) are underway. The latter is critical in reassessing the breeding zone boundary in conjunction with climate data, to establish the breeding zone(s) for the second-generation program. Within the current selective breeding program, there is an emphasis on establishing estimates of additive genetic variation, narrow-sense heritabilities, genetic correlations among rust resistance, survival, and growth, and evaluating potential genotype-by-environment interactions.

The scope of this paper involves selective breeding and genetic conservation by the USDA Forest Service Northern Region, the eastern portion of Washington (USDA Forest Service Pacific Northwest Region through a Memorandum of Understanding), and membership within IETIC, with an emphasis on Phases II and III of the first generation program. Information on blister rust resistance work for USDA Forest Service Pacific Southwest Region Placerville Nursery and USDA Forest Service Pacific Northwest Region Dorena Genetic Resource Center are discussed in McDonald et al. (2004).
Fig. 1. Western white pine breeding zone USDA Forest Service Northern Region and the Inland Empire Tree Improvement Cooperative.
RECURRENT SELECTION PROGRAM FOR GENERAL COMBINING ABILITY

The selective breeding program for western white pine is based on a recurrent selection program for general combining ability (Mahalovich and Eramian 1995, Namkoong et al., 1988, Shelbourne 1969) (Figure 2). The four main components of the program in order of decreasing size \((n)\) and increasing selection intensity \((i)\) are the testing, conservation, breeding, and production populations.

![Diagram of the recurrent selection program for western white pine.]

**Fig. 2.** Western white pine recurrent selection program for general combining ability in the Inland Northwest.

**Testing Program**

The majority of the phenotypic selections originate in natural stands. Selection criteria in Phase I \((n=400)\) emphasized rust resistance (1946-1971) (Table 1). Due to concerns over a low effective population size \((N_e)\) and interest in growth (volume) by IETIC, Phase II selections \((n=3,098)\) favored both rust resistance and height growth (1971-1995). Some of the Phase II selections were made in plantations rather than natural stands and are predominantly located on the Lolo National Forest in western Montana. The Phase III portion introduced in 1996, emphasizes rust resistance in areas not previously sampled.
(for example, the Flathead and Nez Perce National Forests, Inland Empire Paper Company), but also includes selections from areas with little or no rust infection to broaden the genetic diversity in the program. A secondary goal of Phase III is to ensure at least 50 live, leave (plus) trees per ownership. As of 2009, 343 Phase III plus trees have been designated. The approximate total number of phenotypic selections made in the first generation program is 3,841 plus trees.

Each plus tree is monumented in the field with a 4x4” orange metal USFS Genetic Resource tag or a 4x4” blue plastic IETIC tag and three horizontal bands of paint around the bole at breast height. Some trees may also include a tree number embossed on a separate metal tag. Efforts to relocate the plus trees in the field to meet the goal of 50 live, leave trees per ownership is on-going. As a result of these relocation efforts, 24% of the 3,841 plus trees have been lost due to fire, harvesting, rust, beetles, road construction, and road obliteration (Mahalovich, unpublished data).

The goals of the testing population are to challenge the phenotypic selections to blister rust in a controlled environment in order to make selections for the breeding and seed orchard populations and to provide rust resistant seed for reforestation and restoration. The objectives of each artificial inoculation or rust screening trial are to:

1. Identify rust-resistant individuals for the development of seedling seed orchards for reforestation and restoration (forward selection),
2. Identify rust-resistant families for inclusion in the breeding population (backward selection),
3. Study patterns of genetic variation and estimate heritabilities and genetic correlations for rust resistance and growth in the host,
4. Monitor changes in the rust population (virulence) through controls (seven, full-sib standard crosses),
5. Compare Phase I elite trees alongside Phase II and III selections, and
6. Evaluate the effectiveness of upgrading artificial inoculation procedures over time.

The rust screening environment involves artificial inoculations at the USFS Coeur d’Alene Nursery, Coeur d’Alene, Idaho. Due to the large number of phenotypic selections in Phases II and III, open-pollinated (o-p) offspring from 200 plus trees and associated control lots enter a testing cycle approximately every year. Retesting of plus trees from light inoculations (Cycles 14-18) has resulted in a total of 23 cycles. Seven, full-sib crosses from Phase I (17x293, 19x70, 20x21, 208x314, 220x221, 222x225, and 347x348), a woodsrun bulked lot, and several Phase I and II seed orchard lots serve as controls. Currently, Cycles 20-22 are being screened at Coeur d’Alene Nursery. The nursery handles four cycles in various stages of rust screening in any given year, comprised of upwards of 800 families, 30 bulked lots, and 18 control lots, across four species (western white pine, whitebark pine, limber pine (P. flexilis James), and southwestern white pine (P. strobiformis Engelm.)).
Table 1. Western white pine traits of interest.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Acronym</th>
<th>Description</th>
<th>Selection Emphasis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spots per meter</td>
<td>SPM</td>
<td>Reduced needle spot frequency (Meagher and Hunt 1996, Hoff and McDonald 1980a 1980b, 1975); total number of spots on one upper fascicle/average needle fascicle length.</td>
<td>X</td>
</tr>
<tr>
<td>Bark reactions</td>
<td>BR</td>
<td>Increased number of callus formation, walling off cankers, and thereby preventing further infection (Hoff 1986).</td>
<td>X</td>
</tr>
<tr>
<td>Early stem symptoms</td>
<td>ESS</td>
<td>Reduced number of early stem symptoms (cankers); slow fungus growth in the needles (Hoff and McDonald 1972, 1980b)</td>
<td>X</td>
</tr>
<tr>
<td>Canker tolerance</td>
<td>TOL</td>
<td>Persistent survival and seedling growth with active cankers (Hoff 1984, Hoff and McDonald 1980b).</td>
<td>X</td>
</tr>
<tr>
<td>No-spot</td>
<td>NO</td>
<td>No spot symptoms on needles, no canker development; only trait to infer immunity (McDonald and Hoff 1971)</td>
<td>X</td>
</tr>
<tr>
<td>Needle shed</td>
<td>NS</td>
<td>Seedlings drop their infected (spotted) needles less than 12 months after inoculation and before the mycelium reaches the stem (McDonald and Hoff 1971, 1970).</td>
<td>X</td>
</tr>
<tr>
<td>Short shoot</td>
<td>SS</td>
<td>Seedlings retain their infected (spotted) needles beyond 12 months after inoculation, but never develop a canker; mycelium do not enter woodier bark tissue at the base of the needle fascicle of junction of the short shoot and needle fascicle bundle (Hoff and McDonald 1971, McDonald and Hoff 1971).</td>
<td>X</td>
</tr>
<tr>
<td>Total height</td>
<td>HT</td>
<td>Fifth-year total height</td>
<td>X</td>
</tr>
</tbody>
</table>
Aeciospores used to inoculate the *Ribes* spp. gardens at Lone Mountain Tree Improvement Area (TIA), Idaho Panhandle National Forests, are a dynamic sample collected from 10 areas throughout northern Idaho and western Montana (Figure 1). The older garden is comprised of *Ribes* spp. used to inoculate western white pine: western black currant (*Ribes hudsonianum* Richardson var. *petiolare* (Douglas) Jancz.), European black currant (*R. nigrum* L. ‘Heimburger’ clone, Patton (1972)), and another European black currant (*R. nigrum* ‘Blackdown’ L. cultivar). The newer garden is comprised of *Ribes* spp. found in whitebark pine habitat types: wax current (*R. cereum* Douglas), whitestem gooseberry (*R. inerme* Rydb.), prickly currant (*R. lacustre* (Pers.) Poir.), European black currant group (*R. nigrum* L.), and sticky currant (*R. viscosissimum* Pursh). The rationale for using a dynamic spore sample and *Ribes* spp. from western white pine habitat types (Graham 1990) is to challenge the two-year old seedlings to contemporary spore populations and potential changes in virulence in the rust population. Other rust screening facilities primarily focus on the Heimburger clone (*R. nigrum* L. ‘Heimburger’) and a single isolate of rust spores. The latter strategy is useful in research to study a specific response in the host by controlling an additional environmental variable in the experimental design.

There are other alternate hosts for blister rust, particularly sickletop lousewort (*Pedicularis racemosa* Douglas ex Benth.) and giant red Indian paint brush (*Castilleja miniata* Douglas ex Hook.) (McDonald *et al.* 2006). The authors were able to transfer urediniospores of *R. nigrum* whose basidiospores were then used to infect western white pine with isolates from *P. racemosa*; however, the number of western white pine seedlings inoculated and their origin were not reported. It is too early in the research stage of exploring alternate hosts to have practical application in the selective breeding program.

In western white pine, there are 14 host rust resistant host responses (Miller 1982) with a genetic basis (Meagher and Hunt 1996, Hoff 1986, 1984, Hoff and McDonald 1980a, 1980b, 1972, 1971, 1970, Bingham *et al.* 1971, and McDonald and Hoff 1971, 1970). Subsequent rust screenings (1990-2009) confirm these traits are repeatable and they present themselves over time in a consistent fashion. The operational program involves screening for seven of those traits (Table 1). Needle spot color data are routinely collected in each cycle to monitor racial differences and potential changes in the rust population (McDonald and Hoff 1975), but is not formally included in the selection strategy. Referencing the bark reaction trait, it is described as the formation of callus effectively walling off and subsequently killing the rust fungus in both branch and stem tissue (Hoff 1986). Monitoring blister rust infection in the field includes this response, as well as: 1) bark lesions reduced both in number and size, 2) bark lesions that are ‘corked out’ and the rust fungus is presumed dead, and 3) relatively slow extension of bark lesions in branches such that the fungus fails to reach the stem. The composite trait, percent rust resistance, is based on the frequency of the four, individual-tree traits (Table 1).

In Phases II and III, two-year old container seedlings are artificially inoculated with blister rust using the detached leaf method, followed by rust inspections (Hoff and
McDonald 1980b). Cycles 1-18 occurred under a double-canvas tent outdoors (Mahalovich and Eramian 1995, Appendix B) and beginning in Cycle 19 (2003), inoculations occurred indoors to better control temperature and humidity. The testing design is a randomized complete block design with four replications. A target of 144 seedlings per plus tree or 36 seedlings per replication are desired to evaluate blister rust resistance traits (no-spot and needle shed) in low frequency (Mahalovich unpublished data, McDonald and Hoff 1971) and to control the standard errors of the o-p family means, estimates of additive genetic variance, narrow-sense heritability, genetic correlations, and genetic gain. Fewer than four replications can lead to standard errors equal to or exceeding the genetic estimates (Mahalovich personal communication). In contrast, Phase I involved 10 replications per inoculation (Lupo 2004, Bingham 1983). A contemporary cycle of rust screening includes 30,384 seedlings (211 entries represented by 144 seedlings among the treatment and control seed lots).

Beginning in Cycle 7 (1990) the target spore load was 8,000 spores/cm², approximately 2.5 times more than spore loads reported in the Pacific Northwest program (Kegley and Sniezko 2004). Actual spore loads from Cycles 7-18 averaged 6,914 spores/cm² and 73.7% germination, with a range of 6,424 to 7,211 spores/cm² and 60 to 86% germination. With the change in indoor inoculation procedures in Cycle 19 and monitoring percent spotting and percent infection, the desired target spore load was increased to 20,000/cm². Cycles 19-21 averaged 37,489 spores/cm² and 84.9% germination with a range of 30,920 to 46,684 spores/cm² and 84 to 86% germination. Germination percentages in the later screenings are more consistent; however, until Cycles 20-21 have been completed, the impact of higher spore loads at the family and individual-tree levels are pending. At least 50% spotting is required to reliably detect family differences and at least 80% spotting is required to reliably assign a rust resistant trait to a seedling.

Percent rust resistance is a variation of the traditional expected gain; represented in its conceptual form as the product of the heritability of the trait and its selection differential (difference between the selected population mean and the overall population mean). Like expected gains, percent rust resistance tends to overestimate actual gains because of:

1. uniform test environments,
2. plot design; competitive effects will be different than those in planting from mixed orchard seed,
3. unbalanced designs due to mortality resulting in a potential increase in error, and
4. low juvenile-mature correlations using young material to predict half-rotation performance.

Expected gain for western white pine in Phase I was based entirely on the number of canker-free F₂ seedlings at 2 ½ years after a single, artificial inoculation in the nursery (1966) and is referred to as the ‘Canyon Creek’ data (Bingham 1983, Bingham et al. 1971). Lupo (2004) evaluated the 1967 nursery rust screening, later referred to as the ‘Hog Meadows’ data, and found comparable percent rust resistance at 60%.
Percent spotting and percent infection began to be tracked by test and by replication in Cycle 7. Percent resistance in rust screening trials with acceptable spotting varies from 10.1 to 43.3%, averaging 33.5%. Percent resistance is expected to be less than the 66% reported in Phase I, since it is directly related to the spore load (spores/cm^2) in an inoculation, nursery cultural practices and changes in stock type (selected F_2 full-sib seedlings from the 1966 and 1967 progeny test vs. o-p seedlings from plus trees in Phases II and III). Percent resistance among the standard cross full-sib lots varies from 14.8 to 82.5%, averaging 48.4%.

The selection strategy involves forward selection for establishing the seedling seed orchards and backward selection for establishing the breeding population. Family selection for both the seedling seed orchard and breed orchard is based on an index of four traits using family mean ranks with the following weighting factors: bark reaction (4), spots per meter (3), early stem symptoms (2), and canker tolerance (1). A comparison of a more typical selection index using breeding values and the same weighting factor for each trait results in almost the same grouping of families for both the breeding and seed orchard populations, just different rankings, due to an emphasis on families with fewer spots per meter rather than bark reactions (Mahalovich personal communication). This is in contrast to the assignment of families screened in the Pacific Northwest program into the following categories: 1) absence of visible stem infections, and 2) presence of visible stem infections (Kegley and Sniezko 2004). Average family heritabilities from Cycles 7-9 are low to moderate (0.23 ≤ h^2 ≤ 0.64) with expected gains ranging from 6.3 to 13% (Table 2) (Mahalovich and Eramian 1995). Negative gains are reported for spots per meter and early stem symptoms, as the goal is to reduce the frequency of these traits in the selected (elite) population. Phenotypic correlations of family means among rust resistance traits and early height-growth are favorable; in particular, rust resistance in western white pine is not at the expense of early height-growth (Mahalovich and Eramian 1995). The top 30 families from each cycle are relocated in the field for collection of scion and pollen for the breeding orchard.

Table 2. Western white pine blister rust resistant family heritabilities and percent gain from Cycles 7-9.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Family heritability h^2</th>
<th>Genetic Gain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spots per meter</td>
<td>0.23</td>
<td>-7</td>
</tr>
<tr>
<td>Early stem symptoms</td>
<td>0.60</td>
<td>-13</td>
</tr>
<tr>
<td>Bark reaction</td>
<td>0.64</td>
<td>6.3</td>
</tr>
<tr>
<td>Canker tolerance</td>
<td>0.55</td>
<td>9.3</td>
</tr>
</tbody>
</table>

^# Half-sib relationship assumed for the open-polliated families.

Within-family or forward selections in the nursery beds are restricted to the top 20 families from each cycle based on family mean ranks discussed above. In addition, the
mechanisms of resistance are sequential, where resistance caused by one mechanism prevents any subsequent mechanisms from acting (Hoff et al. 1980). Due to this sequential nature of infection and expression of resistance, only one resistance type (no-spot, needle shed, short shoot, or bark reaction) can be observed per seedling. Therefore, within-family selection is based on the progeny possessing one of four, individual-tree resistance traits (no-spot, needle shed, short shoot or bark reaction). The selection goal is 10 seedlings per family or 200 rust-resistant elite trees per cycle. When there are an excess number of target seedlings per family, within-family selections are finalized based on total height (cm) rankings in year five.

Phases II and III involve both short (artificial inoculations previously described) and long-term field tests under repeated, natural inoculations. There are 39 active performance (long-term field) tests in the program. These tests are made up of survivors from the artificial inoculations planted in a randomized complete block design, with three replications and approximately 30 trees per family. High rust hazard field locations are preferred for further field evaluation, but a mixture of rust hazard sites are accepted to characterize the types of operational sites the production seedlings will be exposed, and due to the availability of large enough planting units at the end of the nursery test. Unlike other programs (Sniezko et al. 2004, Kinloch and Byler 1981) the performance tests are not inter-planted with the alternate host. Field tested seedlings are comprised of families from highest, lowest, and average rust-resistant rankings, as well as families representing the geography and elevations represented within a cycle. Including controls, the performance tests are made up of 3,500 test trees on 16 acres (6.5 ha). The long-term test objectives are to:

1. monitor resistance under field conditions to
   a. identify the response in the number of families represented over time,
   b. identify the response in the number of blister rust resistance traits represented over time,
2. test for the presence of genotype-by-environment interactions when families are planted in more than one (sister) test (Cycles 14-18),
3. validate the breeding zone boundary (phenological vs. rust resistance data), and
4. compare family performance and correlations between a single intense, artificial inoculation vs. repeated natural inoculations.

Two additional performance tests from Phase I include Canyon Creek (Idaho Panhandle National Forests) and Hog Meadows (Clearwater National Forest), planted as completely random designs. Lupo (2004) found the average percent rust resistance and long-term survival after 31 and 32 years averaged 20% rather than the 66% or 60% predicted from nursery progeny test data. Though both test sites are not strictly realized gain trials, after 30 years they provide valuable insight into the long-term rust performance, family representation, and stability of the individual-tree rust traits over time. While some consider 20% a “failure” taken in context, the selective breeding program is a first generation endeavor based on an undomesticated tree species. This 20% rust resistance is well within the range of first generation expected gains of 3.9 to 34% in loblolly pine
Realized gain trials are the last step in the testing population in a recurrent selection program for general combining ability. Realized gain is actual gain, where selected materials are evaluated alongside woodsrun (unselected) materials in field tests planted in an operational manner.

The objectives specific to the Inland Northwest selective breeding program are to:

1. determine gain for rust resistance under operational conditions,
2. monitor potential impact of nursery cultural practices on family numbers and resistance traits, and
3. formally evaluate an hypothesis of rust virulence at the Merry Creek location.

Key elements of realized gain trials are:

1. replicated tests across a representative range of sites where the species will be planted and managed,
2. treatment lots from reproductively mature orchards or controlled crossing to simulate a fully mature orchard,
3. uniform control lots allowing comparisons among replicated tests, and
4. an experimental design that incorporates block plots.

The experimental design is a randomized complete block design made up of three replications, and 7 x 7 block plots at 10-foot spacing. Treatment lots include bulk collections from Coeur d’Alene Nursery, Lone Mountain TIA, and R.T. Bingham Phase I orchards, and Lone Mountain TIA Phase II orchards, orchard block bulks by no-spot, needle shed, short shoot, and bark reaction traits from the Grouse Creek TIA Phase II orchards, and individual-tree o-p collections from the Coeur d’Alene Nursery Phase I orchard, which are part of the nursery cultural practices administrative study. Control lots include bulk collections from the B1, F1, and F2 lots used at the original Merry Creek test (1970), the operational seed lot 18-0-119-4 from the former St. Joe National Forest (now Idaho Panhandle National Forests) used as a control, and the seven, full-sib standard cross lots used in the artificial inoculations.

The target number of realized gain trials is six: two tests each for sites characterizing low (< 50% infection), medium (50 to 90% infection) and high (> 90% infection) rust hazard. The two, high hazard sites were planted in 2005 at Merry Creek and Cedar Creek, Idaho Panhandle National Forests. The two, low hazard sites were planted in 2007 at Paradise Creek, Idaho Department of Lands and Brickel Creek, Inland Empire Paper Company. Finding two, medium hazard sites was problematic, so the goal was revised to test field performance under operational conditions in western Montana. These tests will be sown in 2010 and will be planted in 2011 on the Lolo National Forest and possibly other IETIC landholdings.
Objective 6 to formally evaluate the presence of potential virulence or changes in the rust population at Merry Creek (McDonald and Dekker-Robertson 1998) involves planting a realized gain trial at this location (planted in 2005) using the same seed lots as the original Merry Creek test (1970) for the B₁, F₁, F₂, and woodsrun control lots in a more robust experimental design (e.g., uniform site preparation within a replication, uniform spacing throughout, and data collected on all test trees). These four lots, as well as the 40 lots mentioned above, will also be evaluated in an artificial inoculation trial using Merry Creek spore samples as the sole source for inoculating the Ribes spp. garden. The artificial inoculation trial is being sown in 2010. Either approach is satisfactory for testing the hypothesis of a virulent race of rust at the Merry Creek location; however, the realized gain trial in combination with the customized artificial inoculation trial will provide the strongest supporting data one way or another.

In the meantime, 5-year data from the realized gain trail planted at Merry Creek (2005) shows 76.7% survival and 2.2% rust infection. In addition, the Cycle 17 performance test 5-year field data (10 years from seed, located adjacent to the 1970 and 2005 trials) shows 74.5% survival and 19.3% rust infection among Phase II o-p progeny. Data thus far do not support a virulent race of rust at Merry Creek either in the realized gain trial or Cycle 17 performance test. Similarly, aeciospores collected from the Merry Creek area, used in the artificial inoculations beginning in Cycle 7, also do not show higher mortality and percent infection indicative of a virulent rust strain.

Assessments of rust infection in 41 F₂ plantations ranging from 8 to 21 years of age, derived from stock from the R.T. Bingham seed orchard (formerly Moscow Arboretum), varied among sites from 2 to 95%, with a mean infection of 36% (Muller 2002). The robust sampling procedures among operational plantations and genetic tests evaluated in Muller (2002) and Fins et al. (2001) demonstrate rust infection and mortality are substantially lower in genetically improved white pine than in their unimproved counterparts. These findings are in contrast to McDonald and Dekker-Robertson (1998), who generalize rust resistant stock types as suffering high mortality on high-risk sites. Rather than wholesale abandonment of a selective breeding program, if field resistance levels differ from expected gains, which by definition they will, a likely outcome would be for white pine managers to adjust their management plans, restoration strategies, and site-specific prescriptions. For example, if field resistance varies from 20 to 66%, one option might be to plant more trees per acre to attain a desired future condition.

Both short and long-term testing are required to: 1) identify rust-resistant individuals and families for a suite of traits, 2) provide genetic estimates, 3) produce rust resistant stock, 4) assess the stability of family performance and specific traits under field conditions, and 5) monitor changes in the virulence of the rust populations over time. The more popular research trend emphasizing natural inoculation in Phase I field tests or plantations, curtails the development of rust resistance through a selective breeding program. Field monitoring is constrained to observing stem infections at the expense of spotting frequency, no-spot, needle shed, and short shoot traits (Table 1) in artificial inoculation trials specifically designed to identify the genetic basis of rust resistance in the host. Both approaches are needed because of the mutual dependence on the: 1) identification
and development of rust resistant stock, 2) monitoring to provide valuable feedback to the selective breeding program, and 3) subsequent development of forest management policy and practices to restore western white pine cover types.

Gene Conservation

There are four clone banks located at Dry Creek TIA, Idaho Panhandle National Forests. The seed orchard clone bank is made up of one copy of each Phase II/III seed orchard selection and is planted by individual tree, rust-resistance traits (Table 1). The breeding orchard clone bank is made up of two copies of each elite-tree and is planted by its subline assignment. The Vertical Resistance Study clone bank is made up of two copies of each of the study trees planted by individual-tree rust resistance trait. The last clone bank is made up two copies each of progeny of elite trees that are no longer alive in the field predominantly from Cycles 14-18 and to a lesser extent, grafts of plus trees that are slated for removal in the field, or selected trees from the IETIC R.T. Bingham orchard. Collectively, these four clone banks span approximately 30 acres (12 ha).

Other in situ gene conservation includes the long-term performance tests and realized gain trials, which are at risk due to fire, insect and disease damage, changes in ownership, and the production seed orchards and breeding orchard. Lastly, the network of plus trees across the landscape are a component of gene conservation in the Inland Northwest. An unavoidable consequence of a long-term program is the loss of plus trees across the landscape over time. Ex situ conservation includes approximately 256 lbs of pedigreed seed and 15,700 gm of pollen in the testing and breeding program. The pounds of seed and grams of pollen vary from year-to-year due to sowing schedules for artificial inoculation trials and breeding activities.

Breeding Population

The question in 1950 of whether it was more applicable to follow an interspecies (hybridization) or intraspecies approach (Bingham 1983) is as timely today as it was almost 60 years ago. Eurasian species are characterized with slow growth, procumbent habit, rapidly tapering boles, coarse branching, and cold sensitivity. Though seed and pollen may be more readily available today for breeding, it still remains that most hybrids are unsuccessful and difficult to produce. Even if adequate resources are made available and technical difficulties are overcome for a hybrid program, the concerns over adaptation in the progeny or outbreeding depression in interior environments remains a concern.

Screening at three different facilities has not shown any detectable major gene resistance (MGR) for blister rust in interior western white pine. Moreover, the current breeding strategy does not include infusing the interior population with coastal population entries due to differences in terpene (Hunt and Rudloff 1977), early frost hardiness (Rehfeldt et
al. 1984), cp DNA (White 1990), and the coastal region having 20% more cold damage than interior region in cold hardiness tests (Thomas and Lester 1992), even though there are similarities in the two regions for survival and height (Bower 1987, Steinhoff 1981). Though incorporating MGR from the coastal populations into the interior populations has some merit, the Inland Northwest program does not have the resources to follow an agricultural model to release back-crosses for reforestation and restoration. The high sustainable rust resistance gains in the first generation program in a relatively undomesticated tree species doesn’t warrant infusion of new genetic variation, while running the risk of outbreeding depression if F1s rather than B1s are released for reforestation purposes. Similarly, the potential of lowering Ne depending on the number of MGR pollen parents and concerns of using MGR, which may place undo selection pressure on blister rust (Kinloch and Dupper 2002, 1987, Vanderplank 1984, 1975), are further reasons for confining selections within the Inland Northwest breeding zone (Figure 1) under the umbrella of an intraspecies approach.

Concerns of inbreeding among Phase II selections and low Ne in Phase I have guided the choice of replicate breeding populations (sublines) rather than multiple populations (Bulmer 1985, Burdon and Namkoong 1983, Baker and Curnow 1969).

The objectives of the breeding population are to:
1. create a new testing population for second generation of improvement,
2. increase rust resistance gains through positive assortative mating,
3. manage inbreeding, and to a lesser extent,
4. provide an ex situ gene conservation clone bank made up of 10% of the original selections.

The population size among 18 sublines, comprised of 20 elite trees is n = 360. This population size is slightly larger than currently recommended (White et al. 2007, White 1992, Nicolas 1980) in conifer tree improvement. The decision to carry this population size was necessitated to accommodate potential updates in the genetic models for rust resistance, possible patterns of geographic and elevation differences for resistance traits (i.e., more than one breeding unit needed), changes in traits of interest in advanced generations, or a differential response due to climate change.

Designation of an elite tree is based on backward selection (original phenotypic selections have been promoted to elite tree status based on the performance of their progeny in the artificial inoculation trials). Elite trees are assigned in rank order to sublines based on their geographic origin. The role of sublining is to structure the breeding groups within a population to manage inbreeding with the long-term goal of having unrelated entries in second-generation seed orchard (Bridgwater et al. 1993, Burdon and Namkoong 1983). Sublines began to be populated with elite tree selections from Cycle 7 in 1994. Two sublines are reserved for selections from elite trees in the Cycles 4-6 performance tests. The sublines were transplanted to an outdoor orchard setting in 2003 at Coeur d’Alene Nursery with seven ramets per elite tree. So as to not lose the gains made in Phase I, one subline is reserved for the top performing F2
individuals from Hog Meadows and Canyon Creek (Mahalovich unpublished data), with the additional stipulation of equal numbers of no-spot, needle shed, short shoot, and bark reaction entries among the selections.

A circular half-sib mating (Huber et al. 1992, van Buijtenen and Burdon 1990, van Buijtenen and Bridgwater 1986) is the mating design within each subline. The circular half-sib mating design rather than single-pair mating or a complementary testing scheme was chosen to generate families for second-generation selections and estimating genetic parameters for parts of the species’ range that weren’t available from earlier research. Crosses are assigned by an index rank for positive assortative mating to promote additional rust resistance gains (Mahalovich and Bridgwater 1989). Each subline generates 40 full-sib families for subsequent testing. Up to 20 additional crosses may also be made per subline to ensure a sufficient number of full-sib families for second-generation selections in the event some crosses can’t be made due to mortality in the elite trees or some crosses don’t yield sufficient quantities of seed for second-generation testing. Since 2000, approximately 535 controlled crosses have been made. Controlled-crossing continues until enough seed has been generated to proceed with a second-generation artificial inoculation trial (five sublines per cycle).

Concurrent with the development of the breeding population, the Vertical Resistance Study was initiated in 1993. The objective is to test the single-gene recessive model (Hoff and McDonald 1971, McDonald and Hoff 1970) for the short shoot and needle shed resistance types. Parent trees identified as having the bark reaction resistance type were also included in the study design as bark reaction has been referred to as both a single-gene trait in the second rust inspection (Hoff personal communication) and polygenic inheritance (Hoff 1986). The results of this study will be used for potential mid-course corrections in seed orchard design and breeding strategy for establishing the second-generation population. The crossing population is made up of F2s from Phase I planted at Canyon Creek and Hog Meadows. The selected parent trees are survivors from the 1966 and 1967 artificial inoculations, respectively. During those artificial inoculations, the parent trees were ‘genotyped’ by resistance trait based on a 2 ½ year rust screening process, with four inspection periods. Following Allard (1960), data on the percentage of infected plants in the parental types in the F3 progeny will be used in interpreting the inheritance of resistance. There are also two levels of controls to validate the single-gene hypotheses: trait crosses (NS x NS, SS x SS, and BR x BR) and selves (Table 1). A minimum of 20 full-sib crosses per trait and 20 selfs per trait are required to detect statistically significance differences at the 95% confidence interval. Scion was also grafted at Coeur d’Alene Nursery to expedite completing of the controlled-crossing. Since 1993, 73 of the 120 controlled crosses have been completed.

Production Population

Phases I-III seedling seed orchards are based on one breeding zone (Figure 1). There are four active Phase I orchards located at Coeur d’Alene Nursery (low elevation < 3,500 feet), Lone Mountain TIA (mid elevation 3,500 to 4,100 feet and high elevation > 4,100 feet), and R.T. Bingham (formerly Moscow Arboretum and not structured in elevation
bands). All are randomly planted F1s with operational seed lots referred to as F2s. The popularly cited expected gain in rust resistance is 66% based on the nursery portion of Canyon Creek progeny test data (1966). All of these orchards have reached reproductive maturity and are meeting reforestation needs since 1996. The estimated Ne for each orchard is 15 made up of the following grandparents (G) 1, 17, 19, 20, 21, 22, 24, 25, 37, 54, 58, 61, 63, 64 and 109. Among the Canyon Creek and Hog Meadows tests, Ne is 14 (no 109), assuming unrelated grandparents.

One F1 orchard is located at Sandpoint, Idaho. The expected gain in rust resistance is 30% (Franc 1984). Only one-third of the original one-acre orchard is located on USFS ownership and the remainder occurs on Sandpoint, ID School District grounds. The Kootenai National Forest in western Montana was the last cooperator to use seed from this orchard. The number of survivors in these plantations is expected to be higher than 30% due to the low selection pressure by blister rust in this part of the species’ range. The Sandpoint orchard is now managed as a clone bank and it contains ramets of some of the original parents used to construct the seven, full-sib standard crosses. Controlled crossing still occurs at this site to replenish the seed inventory for some of the standard crosses.

Both F2 and F1 Phase I orchards were designed for random mating. As a consequence of this design, susceptible individuals will be a part of the mix in each bulked collection, 34% and 60%, respectively. The deployment strategy for each o-p bulked collection using expected gains in the F2 orchards is that 66% of the seedlings will be resistant (but there will still be some spotting, branch flags and cankers in the plantations due to the sequential expression of rust resistance in western white pine) and the other 34% of the seedlings will be susceptible.

Prior to establishing the realized gain trials, an assessment of the expected gains from the Phase I orchards (36 o-p orchard lots from trees identified as needle shed, short shoot, or bark reaction) was slightly less than 66% with Coeur d’Alene Nursery (63%) performing better than R.T. Bingham (58%) orchard (Table 3). Using the Phase II deployment strategy of an equal mix of rust resistance traits in operational stock, the number of rust resistant individuals produced by each o-p lot showed a more balanced mix at the R.T. Bingham orchard. An average height at age five was 73 cm at both locations. The cut-off for family rankings for Phases II and III selections for constructing the seed orchard population is 20 (Cycles 7 to 23). Both locations met this criterion with Coeur d’Alene Nursery being the 20th ranked entry in the rust screening and R.T. Bingham slightly better at a rank of 17. The Cycle 19 rust screening yielded 33.8% resistance for Coeur d’Alene Nursery and 35.1% for R.T. Bingham orchards. This contrast was chosen to illustrate that percent resistance in artificial inoculations is closely tied to spore loads, nursery cultural practices, and stock type (Cycle 16 7,439 spores/cm² and Cycle 19 10,577 spores/cm²). As a consequence, it should be of no surprise to observe variability in F2 plantation performance, including that which is both below and above 66% resistance; however, the more typical conclusion is that rust resistance has failed under field conditions if it is anything but 66%. Using combined data from artificial inoculation trials, performance tests, realized gain trials, and operational plantations will better reflect
the average percent rust resistance and associated standard errors rather than relying on one test statistic of 66%.

Table 3. Artificial inoculation (Cycle 16) results of 21 open-pollinated seed orchard lots each from the Coeur d’Alene Nursery and R.T. Bingham Phase I orchards using contemporary Phase II analyses, selection criteria and deployment strategies.

<table>
<thead>
<tr>
<th>Orchard Lots</th>
<th>Coeur d’Alene Nursery</th>
<th>R.T. Bingham</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Resistant</td>
<td>63</td>
<td>58</td>
</tr>
<tr>
<td>% Susceptible</td>
<td>37</td>
<td>42</td>
</tr>
<tr>
<td>Horizontal Rust Index</td>
<td>20</td>
<td>17</td>
</tr>
<tr>
<td>5-yr height (cm)</td>
<td>73</td>
<td>73</td>
</tr>
</tbody>
</table>

The early Phase II seed orchards (Cycles 1 and 2 at Lone Mountain TIA and Cycles 3-6 at Grouse Creek TIA, Idaho Panhandle National Forests) are o-p F1s (survivors of the artificial inoculation trials/forward selections) in a random design for wind-pollination and have an expected rust resistance of approximately 50-60%. Seed orchard bulks from each cycle have been evaluated in subsequent rust screenings. Due to their performance as compared to the Phase I orchards, they are currently not used in the USFS reforestation program as their overall ranking based on the horizontal rust index is greater than 20 (or the cut-off for seed orchard selections), with only 24.3% and 22.2% rust resistance, respectively (Cycle 19 artificial inoculation). The best attribute however, of the early Phase II seed orchards as compared to the Phase I orchards, is their higher effective population size.

A change in orchard design and deployment strategy was instituted with Cycles 7 to 23 (Mahalovich and Eramian 1995) for the later Phase II and III selections. These orchards are blocked by the individual traits of no-spot, needle shed, short shoot, and bark reaction. These orchards are made up of survivors of the artificial inoculations (forward selections) and are therefore F1 o-p seedlings. The USFS blocked orchards are at Grouse Creek TIA and include four blocks that are isolated from each other to minimize background pollen contamination. The Phase II expansion of IETIC R.T. Bingham orchard (Moscow, ID) also contains four, individual-trait blocks. For the no-spot, needle shed, and short shoot blocks, with supplemental mass pollination, the theoretical rust resistance is 100%. If pollen contamination occurs or the traits are other than single-gene recessives (like bark reaction which behaves in a quantitative fashion) the percent rust resistance will be less than 100%. The estimated effective population size at Grouse Creek is \( N_e = 340 \). The deployment strategy involves sowing, growing, and lifting by orchard block, then packing and planting with equal numbers of each of the four, resistance types.
Annual cone production in the Phase I orchards using five-year averages is 1,316 bushels (bu) and in the Phase II blocked orchard at Grouse Creek TIA, 215 bu. Yields vary by orchard age, cone crop periodicity, and crown management (topping). Floral stimulation has not been needed due to the number of orchards and demand for seed. The USFS expectation is to have a 7 to 10 year seed supply to meet out-year reforestation and restoration needs.

**SUMMARY AND FUTURE DIRECTIONS**

The Inland Northwest Western White Pine Breeding and Restoration Program emphasizes resistance rather than immunity in its planted stock. The rationale includes maintaining sufficient genetic diversity in the host, while not applying unde selection pressure on the rust. As a consequence, forest managers will continue to observe spotting, cankerings, branch flaking, dead tops, and some mortality in plantations, but not to the extent of unimproved materials. Referencing the sequential nature of rust development, spotting and cankerings must occur for needle shed, short shoot and bark reactions to have an opportunity to be expressed in planted stock. Favoring Phase I orchards (randomly designed orchards) also means accepting the risks of lower genetic diversity and susceptible seed as part of the orchard bulked lots. As the program matures and there are a new group of managers and researchers, continued extension work on expected vs. realized gain and differing reports on rust-resistant performance (i.e., replication among estimates to assess variability) remain critical to adaptive management for restoring western white pine ecosystems.

Following development of the first generation seed orchards, 170,780 acres (69,112 ha) of rust resistant seedlings ($F_1$ and $F_2$) have been planted on federal lands in Idaho, Montana, Oregon, and Washington from 1974-2009, averaging 2,561 ac (1,036 ha) per year over the last five years. Muller (2002) reported approximately 250,000 ac (101,171 ha) have been planted with $F_2$ western white pine from the R.T. Bingham Seed Orchard across all ownerships in IETIC from 1976-1996. Mass selection and natural regeneration are considered additional tools available to managers to restore western white pine. Taken in context, western white pine still only occupies 5 to 10% of its historic range. Survival of unimproved, control seedlings planted at Canyon Creek and Hog Meadows after more than 30 years in the field was only 1% (Lupo 2004). Moreover, genetic diversity and effective population size in naturally regenerated areas are anticipated to be low due to founder effects. The most promising restoration strategy is better focused on artificial regeneration using rust resistant seedlings.

Data from the long-term tests have been under evaluation to ratify the breeding zone boundary as the program transitions into the second generation. These evaluations are focused on field levels of rust resistance, survival, and growth as key adaptive traits to characteristics patterns of genetic variation among and within populations in the Inland Northwest. Models used to characterize patterns of genetic variation using geographic and elevation data are now being re-examined using climate data.
One of the more wide open research areas to explore is the molecular mapping of the recessive genes implicated in rust resistance. Applied technology from this research could potentially lead to the assignment of more than one rust resistant trait to an individual, a more stream-lined screening protocol to identify resistance in field selections, and refining the selection strategy in the second-generation testing population. Woo et al. (2004) points out that if resistance genes can be activated by manipulating phenology, molecular tools might be employed to enhance the understanding of gene regulation.

The success in the western white pine tree selective breeding program has also served as a template to establish rust screenings for whitebark pine (Mahalovich et al. 2006, Mahalovich and Dickerson 2004), limber, and southwestern white pine. Continued refinements in the artificial inoculation protocols and nursery cultural practices will continue to be applied to other five-needle pines.

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Management of White Pine: Assessing the effectiveness of our selection and breeding programs by measuring “field resistance”

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SUMMARY

Results from provenance trials of western white pine show geographic trends to native partial resistance with north and coastal populations having higher levels of resistance; similar results are shown in whitebark pine. However, the progress from operational screening and breeding programs is more striking, indicating significant progress over wild trees by decreasing infections by one half. Site hazard or “rust environment” is still a significant and unfortunately unpredictable factor for partial resistance which has been the major factor that we have selected for in these programs. A combination of partial resistance, major-gene resistance and some very marked and heritable forms of resistance noted in some full-sib families can provide more assured resistant white pine.

BACKGROUND

White pine blister rust (WPBR) caused by Cronartium ribicola (J.C. Fisch. in Rabh.), has been devastating to the North American native white pine species since its introduction a century ago, and although an exotic disease, significant native genetic resistance has been found (Kinloch 2003). Reviewed here are results of what we know about the distribution of this genetic resistance from observations of “field resistance” based on survival in long-term field trials, primarily in western white pine Pinus monticola (Dougl. ex D. Don), but also some of the other western species where work is currently being carried out. Provenance research has always been an important feature in understanding the background genetic variability of our forest species. Western white pine has one of the most comprehensive series of provenance tests for native North American 5-needle pines in both in the US and Canada. This review summarises (1) results from these provenance trials impacted by white pine blister rust and draws some conclusions to the native geographic variability for resistance, and (2) some of the key findings from the operational screening programs.
Although WPBR is an exotic pathosystem in North America, several important inheritable forms of resistance have been noted in our populations: major gene (R gene) and multigenic partial resistance or slow rusting resistance are categories that are broadly recognized (Kinloch 2003). Another identified heritable form of resistance has been through recessive genes particularly for some of the traits (e.g. needle shed) selected for in the Idaho western white pine populations (Hoff and McDonald 1971). These categories may not always be distinguishable in the observed phenotypic distribution of resistance and recessive gene inheritance especially is not easily picked up in the open-pollinated type of screening that has been part of most of the western operational screening programs.

**DISTRIBUTION OF NATIVE RESISTANCE IN 5-NEEDLE PINES**

The distribution of the major gene resistance found in both sugar pine (*P. lambertiana* Dougl.) and western white pine, identified as *Cr-1* and *Cr-2* respectively, and the virulence that has arisen in *C. ribicola* to these genes has been extensively reported (Kinloch et al. 2004). This work shows that these R genes have higher distribution in the south of these species ranges, and in western white pine the *Cr-2* gene is not even present in the northern part of the species distribution, i.e. North of the Columbia River (Kinloch et al. 2003).

Most of the trials reported here deal with partial resistance for western white pine and observe long term field resistance. First of these are the provenance trials that surveys the natural distribution of a native resistance to blister rust. A description of the provenance collection originally made by random population sampling is provided by (Steinhoff et al. 1982). Trials were established with this collection in Washington, Whidbey Island and Idaho. Trials were also established in British Columbia (B.C.) with some of the Steinhoff collection and other material including selected material. These trials are described by Meagher and Hunt (1998, 1999) and King and Hunt (2004). Briefly these trials show the following (King et al.; unpublished data):

- The Northern populations (North and Central Cascades and Interior populations) are superior for growth and resistance over Southern populations (Sierra Nevada and California).

- Interior populations are in general more susceptible but are good overall for vigor and growth.

- On the Coast the North Central Cascades are some of the most resistant populations but taking out high elevation the North Coast (Olympic Peninsula and Vancouver Island) are as good.

Some recent results in whitebark pine (*P. albicaulis* Engelm) also indicate a trend to the distribution of native partial resistance with Northern populations appearing more
resistant (Mahalovich et al. 2006; Sniezko et al. 2007); this trend in whitebark may be even more marked that in western white pine (R. Sniezko pers. comm.).

OBSERVATIONS OF FIELD RESISTANCE FROM THE BREEDING PROGRAMS

More striking than these slight differences in the natural distribution of resistance are some of the results from observations of our field trials from the selection and screening programs that have been carried out (Figure 1). Various reviews of this work, carried out over many decades, are available including: Hunt (2004a), McDonald et al. (2004) and Geils et al. (2010). Carlson et al. (2010, these proceedings), have shown the dramatic effect that the Idaho selection and screening program has brought to the southern interior of B.C. in their realized gain plots. On the coast similar realized gain plots are almost as striking as the Vlem Creek plantation (Carlson et al. 2010, these proceedings) with selected groups showing on average one-half the level of blister rust cankers than unselected material (Figure 2).

Fig. 1. Results from the B.C. provenance trials at Ladysmith and Sechelt showing the slight variation (significant) between native populations but the marked variation in selected populations. The Interior selected are the Westar selections made by Rod Martin; the Coastal selections are the Porter Parents; Dorena has a strong MGR element and P. koraiensis is one of the Eurasian stone pines that are endemic to the WPBR pathosystem (King and Hunt 200).
Fig. 2. Marked Resistance in Coastal B.C. Realized Gain Trials. Boundary is indicated between susceptible (unselected) 8 x 8 tree block and relatively resistant block. Below are the comparisons in replicated blocks between DD (crosses from screened Dorena trees (non-MGR) and wild unselected tree). CF – Canker Free, CD – Canker Dead, SC- Stem Canker, BC – Branch Canker, 999 – Missing Plot Tree

Features of this resistance observed over many of the trials we have put out over the years indicates that:

- Selected populations (those that have been selected and screened in operational programs) are significantly more resistant than the background variability shown in the provenance trials (Figure 1). Over 100% more resistant on average.

- This resistance is not always transferable and there can be an environmental effect. The strongly expressed resistance of the Idaho selection so dramatically expressed in the Southern Interior (Carlson et al. 2010, these proceedings) may not be as well expressed in Coastal environments (Hunt 2004b). Physiological
processes that make traits such as needle-shed effective in the Interior may not work as well on the Coast.

- Partial resistance, for which most of the screening has been done is probably durable and long term but on very high hazard sites, i.e. where the rust is particularly intense, we still may get considerable cankering and mortality.

- Although these intense rust sites may be infrequent it is unfortunately difficult to predict rust hazard for operational management. One safety measure is to add MGR into the orchard mix. MGR although adding a “total resistance” on heavy rust sites, may not be durable in the long term because virulent rust races can arise to overcome this resistance.

- Another feature that has emerged from the observation of long-term field trials with full-sib families is an often marked phenotypic resistance effect in certain specific crosses (Fig. 3, Sniezko et al. 2004, Kinloch et al. 2008). This could point to the expression of specific combining ability (perhaps a demonstration of recessive genes hypothesized earlier in the Idaho program). This type of resistance could provide both the strongly expressed resistance shown by MGR with the durability of the other types of partial resistance.

Fig.3. Surviving full-sib block at Grass Creek trial, Umpqua National Forest, Oregon. Showing marked full-sib effects (Sniezko et al. 2004).
It is obvious that a good deal of progress has been made to date in the selection, screening and breeding programs as indicated by observing “field resistance” in our trials. It is to the point that white pine is starting to make a come-back in the Southern Interior and we hope this enthusiasm may soon be transferred to the Coast. There is still an element of risk but with its fast growth and other attractive features it is probably no more of a risk than any of our species. There is still a lot of information to be uncovered and although we will never get rid of white pine blister rust there is no reason not to believe that one day it will be just another minor pest and disease factor, as indicated in the endemic reaction of Korean pine (Figure 1), and not the calamity has been over the last 100 years since it first arrived.

LITERATURE CITED


Western white pine Growth and Survival in the southern interior Cedar-Hemlock Zone of British Columbia

Alan Vyse

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INTRODUCTION

Western white pine (Pinus monticola Dougl. Ex D.Don) has highly desirable growth and wood qualities but it is not an acceptable species for restocking areas in British Columbia (Ministry of Forests 1993 and revisions) because of the threat of growth losses and mortality caused by white pine blister rust (Cronartium ribicola J.C. Fisch.), an introduced pathogen. Interest in using the species has increased in recent years as a result of tree breeding programs aimed at producing blister rust resistant stock. There is also interest in expanding the range of the species in response to expected climate change. However, there is very little comparative information available on the potential performance of white pine and the risk of its use in relation to the common plantation species (Douglas-fir, interior spruce and lodgepole pine) other than the information presented in the SIBEC tables (Ministry of Forests and Range 2008).

Two species trials were established in the southern Interior in the 1980s may help fill this information gap (see Table 1 and Figure 1 for locations). The oldest trial (Experimental Project 904) was established in the Quesnel Lake area of the Cariboo just beyond the natural range of the species. The second trial (Experimental Project 1153) was established east of Enderby at the western edge of the present range of white pine and compares its performance with eight other species.

EP 904 was established in 1982 to assess the performance of potentially rust resistant western white pine, and to compare performance with three local species: lodgepole pine (Pinus contorta var. latifolia Engelm. Ex Wats.); Douglas-fir (Pseudotsuga menziesii var. glauca (Beissn.) Franco); and interior spruce (a naturally occurring hybrid between Picea glauca (Moench) Voss and P. engelmannii Parry ex Engelm). Two seedlots of white pine were used in the trial. One seed source was obtained from trees the most northerly part of the species range in the Adams river drainage (labelled Pw BC). The seed was taken from parent trees with no more than one canker on the stem in a stand showing mortality due to blister rust. The second source was from trees in the US Forest Service white pine breeding arboretum in Moscow, Idaho (labelled Pw ID).
Table 1. Location, site classification, and elevation of species trials.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Name of site</th>
<th>BEC subzone$^1$</th>
<th>Elevation of site (m)</th>
<th>Geographic location</th>
</tr>
</thead>
<tbody>
<tr>
<td>EP 904</td>
<td>Benny Lake</td>
<td>ICHwk2</td>
<td>1027</td>
<td>N 520 33” W 1210 19”</td>
</tr>
<tr>
<td></td>
<td>Clearbrook Dry</td>
<td>ICHwk2</td>
<td>900</td>
<td>N 520 34” W 1210 05”</td>
</tr>
<tr>
<td></td>
<td>Clearbrook Wet</td>
<td>ICHwk2</td>
<td>1008</td>
<td>N 520 33” W 1210 15”</td>
</tr>
<tr>
<td></td>
<td>McKusky Creek</td>
<td>ICHwk2</td>
<td>940</td>
<td>N 520 25” W 1200 52”</td>
</tr>
<tr>
<td>EP 1153</td>
<td>Hidden Lake</td>
<td>ICH mw2</td>
<td>550</td>
<td>N 510 31” W 1180 28”</td>
</tr>
</tbody>
</table>

$^1$ See Meidinger and Pojar (1991)

Fig 1. Location of species trials in the southern Interior region of British Columbia

Five sites were planted in the ICH wet cool subzone east of Williams Lake. The sites were selected to represent a range of climatic and site conditions from dry to moist (see Table 1) but the driest site was destroyed by the development of a large mine. All sites were broadcast burned the year before planting. Either 100 or 144 seedlings per species were planted at a spacing of 2m in square treatment units using randomized block design.
EP 1153, the Hidden Lake ICH species trial, compares the growth of seven conifer species, including white pine, and two broadleaf species. It is located in the ICH moist warm subzone. The trial uses a randomized block design with 81 seedlings of each species planted at 2.5m spacing in six blocks. The site was clearcut in 1987, slash was piled or windrowed and the area was burned the same year and the seedlings planted the following year.

The species tested in each trial are shown in Table 2 but only data for white pine, and the main plantation species is reported here.

**Table 2. Species and seedlots used in the species trials**

<table>
<thead>
<tr>
<th>Trial</th>
<th>Species</th>
<th>Seedlot Number</th>
<th>Location of seedlot</th>
<th>Elevation of source (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EP 904</td>
<td>PwBC</td>
<td>3876</td>
<td>Adams Lake</td>
<td>800</td>
</tr>
<tr>
<td></td>
<td>PwID</td>
<td>4351</td>
<td>Moscow ID</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fdi</td>
<td>2894</td>
<td>Likely</td>
<td>915</td>
</tr>
<tr>
<td></td>
<td>Pli</td>
<td>3795</td>
<td>5 Mile Lake</td>
<td>1050</td>
</tr>
<tr>
<td></td>
<td>Sx</td>
<td>2643</td>
<td>Cariboo River</td>
<td>946</td>
</tr>
<tr>
<td>EP 1153</td>
<td>Fdi</td>
<td>8147</td>
<td>Larch Hills</td>
<td>800</td>
</tr>
<tr>
<td></td>
<td>Cw</td>
<td>2534</td>
<td>Lee Creek</td>
<td>1100</td>
</tr>
<tr>
<td></td>
<td>Sx</td>
<td>8032</td>
<td>Birch Island</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>Pli</td>
<td>2540</td>
<td>Joe Rich Creek</td>
<td>1100</td>
</tr>
<tr>
<td></td>
<td>Py</td>
<td>3001</td>
<td>OK Falls</td>
<td>600</td>
</tr>
<tr>
<td></td>
<td>Pw</td>
<td>8006</td>
<td>Harbour Lakes</td>
<td>900</td>
</tr>
<tr>
<td></td>
<td>Lw</td>
<td>5235</td>
<td>Creston</td>
<td>1050</td>
</tr>
<tr>
<td></td>
<td>Ep</td>
<td>2756</td>
<td>Larch Hills</td>
<td>800</td>
</tr>
<tr>
<td></td>
<td>Act</td>
<td>hybrid</td>
<td>University of</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Washington</td>
<td></td>
</tr>
</tbody>
</table>

**MEASUREMENTS**

EP 904 was measured at 5 years, 10 years and 26 years after establishment. EP 1153 was measured at five year intervals with the last measurement at 20 years. All top height trees were cored at breast height to determine breast height age.

Analysis was carried out using standard statistical techniques. We excluded the perimeter trees in all analyses. Top height was calculated as the mean height of largest n trees ranked by DBH, where n=6 for the McKusky site in EP 904 and n=4 for all other sites of that trial and for EP 1153, following the methods of Garcia and Botho (2005) and Garcia (1998). Site index estimates were computed using Site Tools software developed by the BC Ministry of Forests and Range (2004).
RESULTS

After 10 years early seedling survival of species was very similar in both trials (Table 3). Douglas-fir survival was lower in EP 904 primarily because of severe frost damage at four of the five sites. Survival of the broadleaved species at EP1153 was poor because of drought. White pine mortality was already high in both trials because of white pine blister rust (*Cronartium ribicola*).

Table 3. Selected species survival at 10 years by experiment and site

<table>
<thead>
<tr>
<th>EP</th>
<th>Site</th>
<th>Fdi</th>
<th>Pli</th>
<th>Pw ID</th>
<th>Pw BC</th>
<th>Sx</th>
</tr>
</thead>
<tbody>
<tr>
<td>904</td>
<td>Benny Lake</td>
<td>70</td>
<td>89</td>
<td>90</td>
<td>71</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>Clearbrook Dry</td>
<td>41</td>
<td>79</td>
<td>59</td>
<td>68</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>Clearbrook Wet</td>
<td>32</td>
<td>81</td>
<td>49</td>
<td>56</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>Hazeltine</td>
<td>12</td>
<td>53</td>
<td>45</td>
<td>31</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>McKusky</td>
<td>56</td>
<td>97</td>
<td>69</td>
<td>85</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>All site mean</td>
<td>41</td>
<td>79</td>
<td>62</td>
<td>60</td>
<td>72</td>
</tr>
<tr>
<td>1153</td>
<td>mean</td>
<td>85</td>
<td>90</td>
<td>n.a.</td>
<td>67</td>
<td>90</td>
</tr>
</tbody>
</table>

After 26 years, surviving stem density of all species in EP 904 is shown in Table 4. Density of Pw BC was very low as a result of blister rust attacks. Some plots had no living stems. However, survival of Pw ID stock was much higher. *Cronartium* infection continued to be the main mortality agent and a comparison of infection levels by seed source is shown in Table 5. Lodgepole pine mortality was high on one site as a result of recent attacks of mountain pine beetle but attacks on white pine were very low (Table 6). Interior spruce survival was highest in the trial.

In EP 1153, after 20 years, white pine was the poorest performer of the coniferous species because of blister rust attacks. Spruce survival was high as was lodgepole pine with no evidence of mountain pine beetle attacks at the time of measurement.

The general pattern of species height and diameter growth was similar in both trials. Douglas-fir white pine and lodgepole pine grew well in EP 1153 but Douglas-fir growth in EP 904 was affected by the early frost damage.

The site index for all species in both trials was projected to 50 years based on breast height age (Table 4). In EP 904 the highest indices were for white pine and ranged from 28m to almost 40m. The remaining species had indices between 20m and 30m. In the southern trial Douglas-fir and white pine estimates were similar to those in the Cariboo but the estimates for lodgepole pine were surprisingly low.
Table 4. Stand statistics for selected species by experiment. (EP 904 at 26 years and EP1153 at 20 years. SE values in brackets)

<table>
<thead>
<tr>
<th>EP</th>
<th>Fdi</th>
<th>Pli</th>
<th>Pw ID</th>
<th>Pw BC</th>
<th>Sx</th>
</tr>
</thead>
<tbody>
<tr>
<td>904</td>
<td>1121 (174)</td>
<td>1502 (129)</td>
<td>1335 (171)</td>
<td>645 (153)</td>
<td>2010 (105)</td>
</tr>
<tr>
<td></td>
<td>Top height [m]</td>
<td>10.52 (0.62)</td>
<td>14.00 (0.50)</td>
<td>14.07 (0.49)</td>
<td>12.74 (0.64)</td>
</tr>
<tr>
<td></td>
<td>Mean height [m]</td>
<td>8.20 (0.63)</td>
<td>12.07 (0.46)</td>
<td>10.68 (0.61)</td>
<td>9.61 (1.09)</td>
</tr>
<tr>
<td></td>
<td>DBHq [cm]</td>
<td>10.21 (0.80)</td>
<td>12.92 (0.35)</td>
<td>13.92 (0.66)</td>
<td>13.29 (1.45)</td>
</tr>
<tr>
<td></td>
<td>Site index BH @50 yrs [m]</td>
<td>24.8 (1.01)</td>
<td>25.7 (0.56)</td>
<td>32.4 (0.93)</td>
<td>34.23 (0.68)</td>
</tr>
<tr>
<td>1153</td>
<td>1213 (109)</td>
<td>1333 (56)</td>
<td>702 (128)</td>
<td>1387 (53)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Top height [m]</td>
<td>12.29 (0.48)</td>
<td>11.83 (0.31)</td>
<td>11.70 (0.44)</td>
<td>8.50 (0.63)</td>
</tr>
<tr>
<td></td>
<td>Mean height [m]</td>
<td>10.26 (0.37)</td>
<td>10.77 (0.22)</td>
<td>9.71 (0.58)</td>
<td>6.81 (0.71)</td>
</tr>
<tr>
<td></td>
<td>DBHq [cm]</td>
<td>10.88 (0.37)</td>
<td>11.70 (0.16)</td>
<td>11.64 (0.61)</td>
<td>7.70 (0.60)</td>
</tr>
<tr>
<td></td>
<td>Site index BH @50 yrs [m]</td>
<td>30.8 (1.43)</td>
<td>22.7 (1.03)</td>
<td>32.1 (0.43)</td>
<td>25.4 (1.15)</td>
</tr>
</tbody>
</table>

Table 5. Cronartium ribicola effects on white pine EP 904

<table>
<thead>
<tr>
<th>Location</th>
<th>white pine seed source</th>
<th>Pw BC</th>
<th>Pw ID</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>stem infection</td>
<td>branch infection</td>
<td>stem infection</td>
</tr>
<tr>
<td>Benny Lake</td>
<td>100.0</td>
<td>100.0</td>
<td>19.3</td>
</tr>
<tr>
<td>Clearbrook Dry</td>
<td>85.8</td>
<td>82.7</td>
<td>13.2</td>
</tr>
<tr>
<td>Clearbrook Wet</td>
<td>56.0</td>
<td>85.0</td>
<td>7.1</td>
</tr>
<tr>
<td>McKusky</td>
<td>86.9</td>
<td>84.1</td>
<td>13.9</td>
</tr>
</tbody>
</table>

% of live stems 2008
Table 6. Mountain pine beetle mortality in EP 904

<table>
<thead>
<tr>
<th>Location</th>
<th>Lodgepole pine</th>
<th>Species</th>
<th>White pine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dead</td>
<td>green</td>
<td>strip</td>
</tr>
<tr>
<td>Benny Lake</td>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Clearbrook Dry</td>
<td>71</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Clearbrook Wet</td>
<td>6</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>McKusky</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

1 100 tree plots except McKusky which is 144;
2 overall lodgepole pine mortality rate on this site is 27% with attacks concentrated in one of three blocks

WHITE PINE PERFORMANCE

White pine growth and productivity was good to excellent when compared to other conifer species on both sites despite the impact of Cronartium. Survival of the rust resistant stock was high and even the local seed sources showed some resistance (or were in areas with low levels of Cronartium infection). Although the range of inference for the two trials is limited, the comparative performance of the species suggests that further testing of rust resistant selections of the species is warranted. Moving the species into the northern portions of the ICH, and more intensive application on moist sites within the southern ICH warrants further testing. Stratified species mixtures with white pine, Douglas-fir or spruce and western red cedar should also be tested. Further efforts should be made to examine white pine performance in other formal and informal trials throughout the southern ICH in order to test the observations made in EP 904 and 1153 and to extend their range of applicability.

ACKNOWLEDGMENTS

Many people were involved in the establishment, maintenance and measurement of both trials. In particular I wish to thank Warren Mitchell for help with EP 904 and Ed Elmes for help with EP 1153. Forrest Joy carried out the pest assessments on both sites and Ian Cameron assisted with analysis.
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Western White Pine – The Commercial Climate
Past, Present, and Future Perspectives

Stan Hadikin

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Located in the SE interior of British Columbia, Kalesnikoff Lumber is a diversified
forest product manufacturer that relies on the range of diverse tree species found within
the log catchment area of the company. The primary focus of the operation is to
maximize the potential value of all log volume inputs, and as a result, the company has
developed over 250 different lumber and wood products for markets throughout the
world. Although mature white pine stands have been historically decimated by the
introduction of the white pine blister rust, remnant volumes of mature wood continue to
be harvested from stands throughout the range of the Interior Cedar Hemlock
biogeoclimatic zone. For many years, the company has worked hard to value and acquire
harvested log volumes of this tree species to manufacture niche product lines for the
specialty marketplace.

THE ECONOMIC PUZZLE OF WHITE PINE UTILIZATION

Even with aggressive pricing to encourage producers to separate the scarce volumes of
white pine, the company has had limited success in acquiring sufficient log volumes to
sustain a white pine manufacturing program. Situated in the midst of the ecologically
suited landbase for white pine production, the company has only been able to source 5 to
10% of the company production capacity from this tree species in any given year. When
one considers that the allowable annual cut in British Columbia is in the order of
75,000,000 million $^3$, an annual acquisition of 12,000 to 20,000 $^3$ of merchantable
white pine from interior forests would indicate that this species is extremely scarce. The
limited volumes and delicate nature of the tree species has made white pine a nuisance for
logging operations throughout its range. In ecologically suited stand types, white pine
volumes rarely exceed 5% of total stand volumes, and often, a large proportion of the
potential volume is lost due to mortality from blister rust, staining, and poor sorting
whereby contractors blend the species with other white woods such as spruce, lodgepole
pine, and subalpine fir to maintain efficiencies in their operations. To extract the species
for specialty markets regularly requires manufacturers to pay premium sawlog rates for
acquisition of the species compared with other commodity tree species such as Douglas fir, spruce, and lodgepole pine (often in the range of 20-30% above market values).

Current market conditions create some unique challenges for white pine manufacturers. Commodity lumber manufacturers tend to avoid white pine for manufacturing dimension lumber because of the lack of a reliable supply and the rapid staining associated with the species. Mixing the species into whitewood lumber programs present their own unique challenges as white pine characteristics of strength, softness, and drying are sufficiently different from other whitewoods which could affect grades and valuations at the finished product stage. Specialty market manufacturers also must contend with some of the idiosyncrasies of this species. Most importantly, white pine must be manufactured and dried rapidly to avoid discolouration and blue staining of finished products. Discolouration and staining can degrade lumber values by up to 50% relative to higher grades manufactured from freshly felled trees. Niche manufacturers also must factor the additional costs associated with acquiring this elusive species and inherent inefficiencies associated with manufacturing inconsistent supplies. Regardless of the difficulties associated with white pine sourcing, manufacturing, and marketing, this species continues to be sought after by the marketplace and finished products tend to be valued higher than equivalent product lines from similar species.

HISTORIC AND CURRENT USES OF WHITE PINE

Historically, white pine was extensively utilized for a wide range of products including ship masts, paneling, flooring, furniture, and framing materials. White pine was also used by aboriginals and settlers alike for food stocks, medicines, salves, and animal feed. Traditionally, white pine accounted for over half of the U.S. supply of lumber for over 200 years, but gradually fell out of favour as forests were depleted and stocks were ravaged by blister rust.

Presently, white pine continues to be valued for its favourable woodworking properties. White pine is often the species of choice for woodworkers who value its ease of handling, sanding, repair, and finishing. White pine products tend to be very stable and exhibit limited twisting or cupping. White pine has a very attractive knot structure relative to its other pine counterparts (i.e. ponderosa pine, lodgepole pine). The wood fibre is also much whiter and brighter. These characteristics allow white pine to command a higher sale value than equivalent products from species such as lodgepole pine, spruce, and balsam. Part of the mystique of this species is likely a result of its present day scarcity in the marketplace. This scarcity fuels the appetite of discerning consumers who are willing to pay more for its products.

White pine is found in a number of modern day products including furniture, fascia, moulding, trim, flooring, and paneling. Lower grade white pine uses include crates, pallets, building stock, framing, and fencing. The marketplace struggles to source enough building log and timber frame quality materials for log and timber frame construction. White pine is a species of choice for timber frame construction as the
timbers are very stable in that they express limited movement, twisting, and checking when drying as compared to other tree species used for these purposes. White pine is popular with panel board producers who utilize thinly sliced veneers for decorative finishes for their products. Prime white pine sawlogs are best derived from 60 to 100 year old stands which are tightly grown to encourage self-pruning and small knot sizes. Traditional old-growth white pine (>100 years of age) is not as highly valued in specialty markets due to discolouration of heartwood, defects, and black knots associated with its finished products.

FUTURE OPPORTUNITIES

Given current consumer tastes and trends, it is highly probable that the marketplace could easily absorb a doubling or tripling of available merchantable white pine inventory without an offsetting reduction in market values for finished specialty products. Any significant increases to white pine inventory in the long term (>5%) would likely see the emergence of producers with an eye to commoditizing and mass producing the species to compete with current whitewood commodity lumber products. Any available increase in building log grade and timber grade volumes would see a rapid uptake in the marketplace as current demand far outweighs available supply of suitable logs for these purposes. Managed stands of white pine from blister rust resistant stock could help fill the market void through the production of straight, tall, and cylindrical building logs that would have limited twisting and shrinkage.

WHITE PINE - GROW IT AND THEY WILL COME

Kalesnikoff Lumber’s reliance on white pine products has inspired company foresters to pursue reforestation on company operations with blister rust resistant white pine stock where ecologically suited. Stocking standards within both the Arrow and Kootenay Lake Timber Supply Areas have been adjusted in recent year to encourage use of blister rust resistant stock within the Interior Cedar Hemlock Biogeoclimatic zone. Generally, the company avoids planting greater than 25% white pine seedlings on any given site and white pine is always planted in a species mix to provide insurance against long term losses to white pine blister rust. Blister rust resistant stock has been utilized on company operations for over a decade, and from all indications, regenerating stands are showing a high degree of survival and productivity relative to other regularly planted tree species. The continued success of returning white pine to the landbase is encouraging and as a result, the company will continue its reforestation efforts with this species.

Forecasting consumer habits 60 to 100 years in the future is purely speculative. Nevertheless, given white pine’s productivity and wide ranging physical, chemical, and aesthetic properties, it is highly probable that it will maintain its consumer appeal well into the future. Moving the landbase inventory of white pine closer to pre-blister rust inventory levels is biologically and ecologically correct and should be the primary focus for land managers as they embark on greater utilization of blister rust resistant stock.
There should not be any fear about market acceptance of this species. Increasing populations, scarcity, and growing forest product demand will ensure its continued utilization. If history is any indication, the marketplace will continue to evolve and will inevitably find an appropriate socio-economic use for a growing inventory of merchantable white pine.
Production of Blister Rust Resistant White Pine Seed and Realized Genetic Gain Trials in the British Columbia Interior

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ABSTRACT

Since its North American introduction in the early 1900s, white pine blister rust (Cronartium ribicola) has killed millions of white pine trees throughout the species natural range. Selective breeding for resistance to this pathogen began in the mid 1950s in the U.S. Pacific northwest. After a parallel breeding effort began in the 1980s in British Columbia (B.C.) and with the establishment of a seed orchard for producing disease resistant/tolerant seed in 1995, B.C. field foresters have been given a chance to reintroduce white pine into their silvicultural prescriptions. Today, our interior white pine seed orchard annually produces enough disease resistant/tolerant seed for the growing of 800,000 seedlings. Two field trial series (10 and 25 years from planting) demonstrate the disease resistance/tolerance expected of seed from this orchard relative to wild collected seed. The estimated resistance/tolerance of this seed is 65%, meaning that we expect 65% of trees planted today to be merchantable (harvestable) at rotation age less other forest health factors. The high level of certainty of survival coupled with its wide geographical transferability, excellent growth rate and commercial wood characteristics make white pine a natural choice for reforestation of low to mid elevation productive sites in the southern interior. The availability of seedlots resistant to blister rust should precipitate a change in current species choice guidelines to consider white pine a ‘preferred species’ in certain biogeoclimatic zones/subzones where it is currently either an ‘acceptable’ species or not considered at all.
INTRODUCTION

White pine blister rust is not native to North America but was introduced early in the twentieth century via eastern white pine (Pinus strobus) seedlings grown in Europe and imported into Vancouver, B.C. The disease spread rapidly across the range of western white pine (Pinus monticola) as well as other indigenous North American 5-needle soft pine species. By the 1950s, millions of mature white pine had been killed by the disease throughout its range which threatened its future role in commercial forestry (Hunt, 2004). In the mid 1950s, the U.S. Forest Service (U.S.F.S.) began an ambitious selective breeding program in an attempt to develop production seed orchard populations of blister rust resistant trees. This program was headed by Richard Bingham and was based in northern Idaho. The program involved the field selection of putatively resistant parent trees followed by artificial inoculations of their offspring and nursery bed evaluations of rust presence/absence and disease behaviour (Bingham 1972). A number of resistance ‘mechanisms’ were described (Hoff and McDonald 1980) and used to characterize seedling family resistance levels. The seedling resistance mechanisms identified included: 1) few infection spots, 2) needle shed, 3) fungicidal short shoot, 4) bark reaction(s), 5) difficult to infect or ‘no spots’, and 6) slow canker growth. For a discussion of the current understanding and utility of these mechanisms in our screening and breeding activities see a review Hunt (2004).

Selective breeding for rust resistance in B.C. began in 1985 (Meagher and Hunt, 1985) with a total of 358 coastal and 259 interior parent trees selected and their seedling offspring subjected to inoculation and screening protocols similar to those used by the U.S.F.S. researchers (Hunt 2004, Hoff and McDonald 1980). After two decades of inoculations and subsequent multiple year nursery bed observations, B.C. researchers have concluded that the ‘difficult-to-infect’ (few or ‘no spots’) and ‘slow canker growth’ mechanisms are the most reliable for identifying rust resistant parents from interior native white pine populations.

A B.C. rust resistance seed orchard for interior white pine was established in 1995 near Vernon and today supplies all reforestation white pine seed used in the B.C. interior. In addition, realized genetic gain trial plantations have been established to verify and estimate levels of rust resistance expected from using seed orchard seedlots.

A RUST RESISTANCE SEED ORCHARD FOR THE B.C. INTERIOR

By 1995, the B.C. white pine rust resistance selective breeding program identified several resistant parents after years of seedling screening at the Cowichan Lake Research Station. A decision was made to combine advanced generation selected trees from the U.S.F.S. program with selections from the B.C. breeding program to establish a seed orchard near Vernon. In the winter of 1995/96, B.C. researchers traveled to the U.S.F.S. Priest River experiment station in northern Idaho and with the help of U.S.F.S. researchers, selected 50 disease-free parents from a 17 year-old full-sib family screening trial. These families originated from the inter-crossing of tested and selected first generation parents. While
these trees had not yet been offspring tested themselves, their average level of rust resistance should have been equal to that of their parental generation plus some additional measure of resistance gain due to their individual tree rust resistance/tolerance at age 17 in a high rust hazard environment. Scion collected from those trees were grafted at the B.C.F.S. Skimikin seed orchard site in 1996 and out-planted at the Vernon Bailey Rd. site the same year. In addition to the U.S. selections, approximately 600 B.C. selections were planted. The original proportion of U.S. and B.C. seed orchard trees was approximately 80/20. Over the next ten years, additional B.C. selected trees were added to the orchard. Today, 2,400 orchard ramets are of approximately 60/40 U.S./B.C. origin. Rust resistance screening of control-crossed full-sib seedling families from the 50 U.S. parents continues still today at the Skimikin site. After several years of post-inoculation nursery bed observations, canker-free trees from ‘difficult to infect’ families and those exhibiting ‘slow canker growth’ will be grafted for seed orchard use. Total seed production and average numbers of seed per cone for the Bailey Rd. orchard are shown in Figure 1.

![Bailey Rd White Pine Seed Orchard #335](image)

Fig.1 Total seed production and mean seed per cone obtained from Bailey seed orchard (1998-2007).

Seed production for the last three years has averaged approximately 1 million seed annually. Our estimate of rust resistance for seedlots from this orchard is 65%. We define rust resistance as the percentage of trees planted today that will be merchantable (harvestable) at a rotation age of 45-50 years. When the Bailey Rd. white pine orchard reaches full production, it will produce enough seed for approximately 2 million seedlings. Current demand for interior rust resistant seedlings ranges from 500,000 to 1 million annually (average of 800,000) and all interior seedlings planted between 2007 and 2009 came from Bailey Rd. seed orchard seedlots.
REALIZED GENETIC GAIN TRIALS FOR THE B.C. INTERIOR

In selective breeding programs the quantitative and qualitative changes in a trait (stem growth rates, wood relative density, disease resistance, etc.) from one generation of testing and selection to the next is termed ‘genetic gain’. Typically, a breeder relies on quantitative genetics theory and the estimation of trait means and variance components generated from progeny test data to estimate expected genetic gain from one generation of selection for a particular trait. While these indirect estimates usually serve the needs of breeders for fine tuning breeding strategies, and of forest managers for justifying investments in breeding programs, the ultimate measure of gains achieved in operational plantations comes from ‘realized genetic gain’ trials in which production seed orchard seedlots are planted side-by-side with wild seedlot controls and their performances compared over a significant portion of a rotation. With the 1995 establishment of the Bailey Rd. seed orchard it was known that it would be several years until seedlots representative of the mature seed orchard would be available for testing. In 1997 the decision was made to take seed as representative as possible of future seedlots from the orchard and field-collected wild control seedlots and establish a series of realized gain test sites in blister rust prone forest environments. Open pollinated seed from 34 of the 50 U.S.F.S. selected parents was available from the U.S.F.S. research program and 4 field-collected white pine seedlots were sampled to serve as a wild control. A seedlot from the U.S. Moscow Arboretum/Seed Orchard in Idaho was obtained (the first U.S. rust resistance seed orchard) and a seedlot from a white pine seed stand (of Moscow seed orchard origin circa mid 1970’s) at the Skimikin seed orchard site was also available.

The 34 seedlots from selected Idaho parents were subdivided into 4 groupings representing the four selection mechanisms used to classify the parent trees: 1) no spots, 2) needle shed, 3) slow rust, and 4) canker dead. Altogether, seven genetic entries were planted in replicated 100 tree square plots across four sites in the southern interior in 1998: Baird Lake, Cranberry-Polson, Burton, and Duncan Lake. Rust incidence was surveyed after 5 and 10 field seasons. Three of the sites had less than 10% of trees infected with blister rust at age 5 and less than 15% averaged at age 10. The Baird Lake site near Enderby had 16% and 37% of trees infected at ages 5 and 10, respectively. The level of infection at the Baird Lake site provides reasonable confidence in comparisons among genetic entries. Results of these surveys are shown in Figure 2. The four selection mechanism categories (no spot, needle shed, slow rust, and canker dead) are lumped into the ‘selected’ category and entry rankings at ages 5 and 10 years are similar. By age 10, the ‘wild’ seedlot had 69% of its trees infected or dead, while the ‘selected’ entry had only 31%. The two ‘Moscow’ seedlots (recall the ‘Skimikin’ entry is from the Moscow collection) have identical scores of 22% trees infected. The fact that the ‘selected’ seedlot is somewhat less resistant than the Moscow seedlot(s) can be explained by the fact that half the parentage (pollen parents) of the open-pollinated seedlots representing the 34 parents is from the Idaho test plantation trees and from surrounding wild white pine trees while the Moscow seedlots are comprised of seedlings with two tested and selected rust resistant parents. While this test is relatively young (10 field seasons), most pathologists believe that the majority of rust infection risk occurs in the first 10 to 15 years after planting and drops off rapidly after that.
Between 1970s and 1990s, very little white pine was planted in the B.C. interior because field foresters were well aware of the rust infection risks in young plantations, and even rust-free white pine plantation trees were not considered in free-to-grow applications. In 1984, Dave Wallinger with the B.C. Forest Service silviculture branch decided to compare resistance levels between rust-resistant white pine from the U.S.F.S. seed orchard at Moscow, Idaho and wild B.C. seed sources. At that time, the only rust resistant seed available was the Moscow, Idaho source. While Wallinger’s main objective was to test for rust resistance in the Moscow seed source, he was also interested in comparing growth characteristics of white pine and Douglas-fir when grown together. In 1984, three southern interior sites (Vlem Creek, Breaberry, and Creston) were planted with Moscow seed orchard origin white pine, a local B.C. white pine seed source and a local B.C. Douglas-fir seed source. The planting design at each site consisted of three blocks planted with a checkerboard design of the three seedlots, and three blocks planted with solid sub-blocks of the three seedlots (Figure 3).

The last assessment of the Vlem Creek site occurred in 2003 after 20 field seasons (R. Hunt, pers. comm.). Results showed 97% of the white pine wild seedlot trees and 30% of the Moscow seed orchard seedlot trees had been killed by blister rust infection (in Figure 3 this is shown as dead trees colored red and living trees colored green). Five percent of the living Moscow trees had stem infections, none of which were judged to be a serious threat to the trees future survival. Because of the high (and likely early) wild seedlot mortality in the trial, western larch ingress from the surrounding stand has been substantial. This provided the opportunity to estimate height growth rates and site indices.
(SIs) of all three species knowing that the larch has a 2-4 year disadvantage in terms of establishment. Samples of dominant individuals of all three species were height measured and site indices estimated from height over age curves for each species. Averages for the three species were: 26.5m, 28.7m and 31.5m for interior Douglas-fir, western larch and white pine, respectively. Even when a 2-4 year establishment lag for western larch is considered, the growth potential for white pine on this site is exceptional. These three species in combination on this moist Interior-Cedar-Hemlock BEC site seems a perfect silvicultural prescription!

Fig. 3. Vlem Creek White Pine Blister Rust Tolerance Demonstration (Planted 1984 by Dave Wallinger)

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<tr>
<td>10</td>
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<td>Pw</td>
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</table>

- Dead
- Healthy
- Selected
- Douglas-fir (Fd)
- Missing

Baird Lake Site Map – 6 Blocks

Fig 3.

**Fig. 3.** Planting design of Wallinger trial testing rust resistance of Idaho white pine against a wild BC seedlot and comparative growth performance of white pine with interior Douglas-fir.
CONCLUSIONS

Until relatively recently, the planting of western white pine has not played a significant role in plantation forestry in the southern interior of British Columbia. The introduced pathogen has consistently infected and killed much of the natural white pine regeneration throughout the species range, often within 10-15 years after establishment. Within the last two decades however, we have combined tested and selected genotypes from the U.S. and B.C. rust resistance selective breeding programs and established a seed orchard that is producing approximately 800,000 rust tolerant seedlings annually for southern interior reforestation. Realized genetic gain trial results suggest that our orchard seedlots will produce trees that have at least a 65% chance of surviving blister rust infection, less other forest health factors. In addition, white pine is considered an ecological generalist capable of good survival and growth across a broad range of site conditions at low to mid elevations in most subzones of the Interior-Douglas-fir, Interior Cedar Hemlock and Montane Spruce biogeoclimatic zones.

Given the availability of blister rust resistant seed, the considerable ecological amplitude of white pine, its wide transferability compared to other species, and its excellent growth rates and product value, white pine should become a ‘preferred’ species in much of the future reforestation work on productive low to mid elevation sites in the B.C. southern interior.

LITERATURE CITED


Pruning of Western White Pine in British Columbia

Stefan Zeglen

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Rounding out the day was our final stop on the field tour, a pruned white pine stand on Toledo Road. Previous stops have discussed the genetic approach to combating WPBR using tree breeding to reinforce putatively resistant traits in offspring. But what about doing things the old-fashioned way, by manipulating the trees or stand environment to remove, hinder or discourage the presence of WPBR in a managed stand?

From the handout you can see that various cultural practices have been tried over the decades to combat or prevent WPBR infection and subsequent mortality. Some practices have a better track record of success than others. For example, trying to break the life cycle of WPBR by eliminating Ribes spp has been tried using various techniques. Winter harvesting to limit soil disturbance and subsequent seed germination can work but does not create the preferred substrate that pioneer white pine seedlings desire. Similarly, trying to reduce the Ribes seed bank by burning prior to planting has had mixed success. Of course, everyone is familiar with the story of the massive eradication program in the western United States that tried to eliminate Ribes from the landscape. Ultimately unsuccessful, it did provide some local relief and may have delayed the spread of the fungus in some areas.

Other silvicultural interventions have also been tried with varying results. Various cultural, chemical and biological weapons of fungal destruction have been unleashed but almost none have provided reliable, repeatable or durable relief from WPBR mortality. Perhaps the oldest treatment has been branch pruning, advocated for use in North America since the 1920’s. Relying on the fact that the vast majority of cankers occur on the lowest portion of the tree’s bole, removal of these lower branches provides a prophylactic effect that can see pines through the highest risk period for rust infection. This stand we’re in provides a graphic example of that theory put into practice. Pruned to 50% live crown at about age 12, the treatment has reduced, but not eliminated the incidence of rust cankerings and lowered the amount of mortality that would have been experienced in an untreated stand.

Unfortunately, like many aspects of WPBR, nothing is quite as simple as it seems. There is a great deal of variability in advice regarding the timing (age) best for pruning, the
correct amount of crown to remove, whether or not it should be done in conjunction with stand thinning, whether the same rules apply to white pine growing on the Coast as opposed to the Interior and, not least, the economic benefit of doing the treatment at all.

For those that want a more detailed discussion of not only the silvicultural management of WPBR but also many of the other topics we’ve discussed during this workshop, there will be a comprehensive series of papers covering WPBR published in the journal *Forest Pathology*. Look for this issue sometime in late 2009 or 2010.
Suitability of Western White Pine in Juvenile Plantations and Other Forest Health Issues

Michelle Cleary

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There is a misconception amongst practicing foresters regarding the suitability and long-term performance of western white pine relative to other common conifers in juvenile plantations located in the Interior Cedar-Hemlock (ICH) biogeoclimatic zone. In a recent survey of post-free growing stands in the Okanagan Timber Supply Area (TSA), 56% of white pine trees showed attack by Cronartium ribicola (Woods and Bergerud unpublished). However, other common conifers including lodgepole pine and Douglas-fir are also susceptible to a number of diseases which affect their ability to survive in the long-term.

Armillaria root disease, caused by the fungus Armillaria ostoyae, is almost universally present throughout most subzones in the ICH. In general, all conifers are highly susceptible to killing by Armillaria up to about the age of 15 years or so (with the possible exception of cedar), and after which some conifers become more ‘tolerant’ of the disease. Results from the species trial discussed by Alan Vyse yesterday, located just down the road from where we are situated, showed that Armillaria-caused mortality in western white pine after 20 years was drastically lower than in western larch, Douglas-fir, Ponderosa pine, Englemann spruce and lodgepole pine.

Similarly, a study of symptom development and mortality rates among species in juvenile mixed conifer plantations throughout the southern ICH, revealed that white pine fared moderate in terms of its susceptibility to killing by Armillaria. Cumulative mortality in Douglas-fir was approximately 25% by about the age 25-30 years. Other long-term studies tracking the disease in Douglas-fir plantations (D. Morrison, unpublished) show that mortality will continue throughout a rotation and that growth of trees will be significantly reduced as a result of non-lethal infections on their root systems. Now, if the expected survival for white pine is about 65% as indicated from the realized genetic gain trials for interior populations of western white pine, and the anticipated losses of more favourable and ‘preferred’ species like Douglas-fir (post-free growing) will surpass our expectation of loss in white pine, then why isn’t white pine also considered a ‘preferred’ species? The notion that these young plantations will continue to meet our timber productivity expectations in the long-term has recently been put to test with the Effectiveness Evaluation study of post-free growing stands led by Alex Woods. Results from the Okanagan TSA indicate a significant drop in
the stocking of free-growing stems since they were first declared as a result of insects and disease. These results have important implications for improving best management practices when it comes to species selection and also managing for stand- and landscape-level species diversity in order to reduce the risk of losses to forest health agents.

With regards to other forest health agents, the strong tendency of western white pine to be more tolerant of Armillaria root disease can also be echoed for Phellinus root disease on the coast; white pine considered a good species choice for root-disease infested sites. Recent discovery of *Dothistroma* needle blight damage on Idaho resistant white pine in a select number of stands is concerning for its ability to achieve and maintain free-growing status. Further monitoring of these stands is required.
Various cultural practices have long been advocated for use in controlling WPBR
Some of these practices, and their relative utility, are described below:
- Winter harvesting to limit disturbance – regen prefers disturbance;
- Broadcast burning to reduce seed bank – mixed results;
- Ribes eradication – difficult and costly;
- Seedling protectors – does it limit spore exposure? Still testing, stay tuned;
- Stand thinning – ineffective by itself;
- Canker excision – effective but impractical on a large scale;
- Biological controls – potential but no practical application developed yet;
- Fungicides – mixed results and difficult to apply effectively on a large scale; some success when used with planted seedlings.

Branch pruning
- Has been advocated as a treatment since 1921 (US) and 1929 (Canada)
- Also used for Cronartium rusts on lodgepole, southern and Scots pine.
- 85% of cankers occur within 1.5 m of the ground, so removing lower branches early should reduce risk
- Complicating factors: Coast vs Interior, rust incidence, Ribes presence, slope
  - Early studies in Idaho (e.g., Hungerford et al. 1981) thinned and pruned diseased stands that were already 10-20 years old
  - Found thinning alone increased infections but pruning counteracted effect
  - Led to recommendations to wait until mortality peak had passed and then clean up the survivors (25-30 years)
  - Follow-up study (Scwhandt et al. 1994) found thinned and pruned sites had twice the number of live white pine, 60% more merch volume than controls
  - Hagle and Grasham (1982) found 2/3rds of treatable trees could have lethal infections removed by pruning alone (18 year old stand)
  - This was problematic for coastal BC since trees didn’t live that long
  - Also, presence of Ribes tended to counteract positive effect of treatment (i.e., the more Ribes, the less effective the treatment)
  - Slope complicates treatment as increasing slope leads to more upper crown infections (top kill)

Current MFR pruning guidelines
- From Appendix 3, Pine Stem Rust Management Guidebook (1996)
  - Prune trees as early as possible in order to maximize survival.
  - Prune in multiple lifts, if possible. The first lift is the most critical.
  - Lift 1: when mean tree height is 1.0 to 2.5 m for plantations
    - Prune up to 50% of tree height (Interior) or 65% (Coast)
    - Selectively prune infected branches above target pruning height
  - Lift 2: when mean height is 5 m or greater
    - Prune to 3 m or 50% of live crown
    - Prune any smaller white pine to 50% live crown
  - Lift 3: to about 5.5 m for wood quality purposes only

Toledo Road site info
- Opening 82L056-039
- Harvested 1979, windrowed and burned 1980
- Planted April 1981 (9000 Pw from two provenances:
  - Kwiok Creek, west of Lytton, 1400 m, natural stand collection
  - Whatsan Lake, east of Vernon, 1300 m, natural stand collection
- Brushed and part of block pruned in early 1990’s by job training crew
- Prescription: prune all Pw leaving at least 50% live crown if no obvious stem canker and no sign of stem swelling/canker symptoms at stem junction. Trees need to be minimum 2 m in height to be pruned

Western White Pine Management Workshop
Vernon, BC
June 17-18, 2008
White Pine Field Tour – Stop #3 Toledo Road

Western white pine silvicultural management
Stefan Zeglen and Michelle Cleary, BC Ministry of Forests and Range

Relative susceptibility of Pw to Armillaria root disease: results from surveys of juvenile mixed conifer stands in the ICH

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<th>Cw</th>
<th>Lw</th>
<th>Pl</th>
<th>Se</th>
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<td>Healthy</td>
<td>68.5%</td>
<td>78.0%</td>
<td>94.5%</td>
<td>72.2%</td>
<td>72.7%</td>
<td>86.3%</td>
<td>64.0%</td>
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<td>0.0%</td>
<td>5.8%</td>
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<td>Dead (A. ostoyae)</td>
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<td>10.7%</td>
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<td>23.3%</td>
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<tr>
<td>Dead (other)</td>
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<td>0.1%</td>
<td>2.2%</td>
<td>9.1%</td>
<td>0.0%</td>
<td>19.0%</td>
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Results from root disease surveys suggest Pw fairs better as far as tolerance to Armillaria relative to other conifers. Pw is resistant to Phellinus root disease.

Surveys of post-free growing stands in Okanagan TSA show 56% of Pw trees attacked by *C. ribicola* (Woods & Bergerud, unpublished)

Other forest health issues on White Pine: Red band needle blight (*Dothistroma septosporum*)

Opening 82M075-1059, Sunset Mammoth, N.Adams Lk., ICHwk1
- Planted with ID-Pw (Seedlot 60254), Se, Cw
- Pw changed to preferred species (from acceptable)
- No intent to prune for PWRR control

White Pine Realized Genetic Gain Trial
Opening 82K036-040, Duncan Lake, ICHmw
- low rust incidence (environment? presence of *Dothistroma*? Both?)
## Registered Participants

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<th>Location</th>
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<tr>
<td>Babita Bains</td>
<td>UBC MFR</td>
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<td>Wolfgang Beck</td>
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<td>Vicky Berger</td>
<td>Kalamalka RB</td>
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<td>Marino Bordin</td>
<td>Interfor, Chase BC</td>
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<td>Zoric Boskovic</td>
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Pat Hughes
DOS MFR
Vernon BC

Rich Hunt
CFS
Victoria BC

Tom Johnston
DAB MFR
Castlegar BC

Bernie Kaplun
DBA MFR,
Castlegar BC

Stephen Joyce
NS BCTS
Vernon BC

Les Josza
Vancouver BC

John King
RB MFR, Victoria BC

Dave Kolotelo
TSC MFR
Surrey BC

Harry Kope
FPB MFR
Victoria BC

Jodie Krakowski
CLRS RB
Mesachie Lake BC

Kevin Lavelle
DCO MFR
Revelstoke BC

Jun-Jun Liu
CFS, Victoria BC

Dennis Lloyd
RSI MFR
Kamloops BC

Carolyn Lohr
Saanich SO
Saanichon BC

Neil MacEachern
RSI MFR
Kamloops BC

Heather
MacLennan
DHW MFR
Clearwater BC

Ted McRae
DOS MFR,
Vernon BC

Mary Frances
Mahalovich
USDA RMRS
Moscow ID

Penny Major
Kalamalka SO
Vernon BC

Dana Manhard
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Kennon
McClintock
FCP LLC
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Lisa Meyer
Saanich SO
Saanichon BC

Larry Michaelsen
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Kamloops BC

Diane Millar
DCO MFR
Revelstoke BC

Kerry Milner-Cairns
DHW MFR
Clearwater BC

Keith Monroe
DKA MFR
Kamloops BC
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Det Vogler
USDA FS
Placerville CA

Alan Vyse
TRU, Kamloops BC

Bill Walker
TCC BCTS
Quesnel BC

Caroline
Whitehouse
UA MFR
Vernon BC

Jack Woods
SelectSeed FGC
Duncan BC

Don Wylie
Tolko, Lumby BC

Yu Xiang
Agric Can
Summerland BC

Alvin Yanchuk
RB MFR
Victoria BC

Stefan Zeglen
RCO MFR
Nanaimo BC