Insect and Disease Management Series
14.2
WEB 2013

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Topics

Key Points

- WPBR is caused by an introduced fungus with a complex life cycle
- WPBR attacks 5-needled pines of all sizes and ages
- Impacts can be reduced by a combination of treatments
- Periodic monitoring is critical.

White Pine Blister Rust General Ecology and Management

Cronartium ribicola **J.C.Fisch. in Rabh**

Conifer Hosts - All native five-needled pines
Alternate hosts - primarily *Ribes* spp.(currants and gooseberries) possibly *Pedicularis* spp. and *Castilleja* spp.

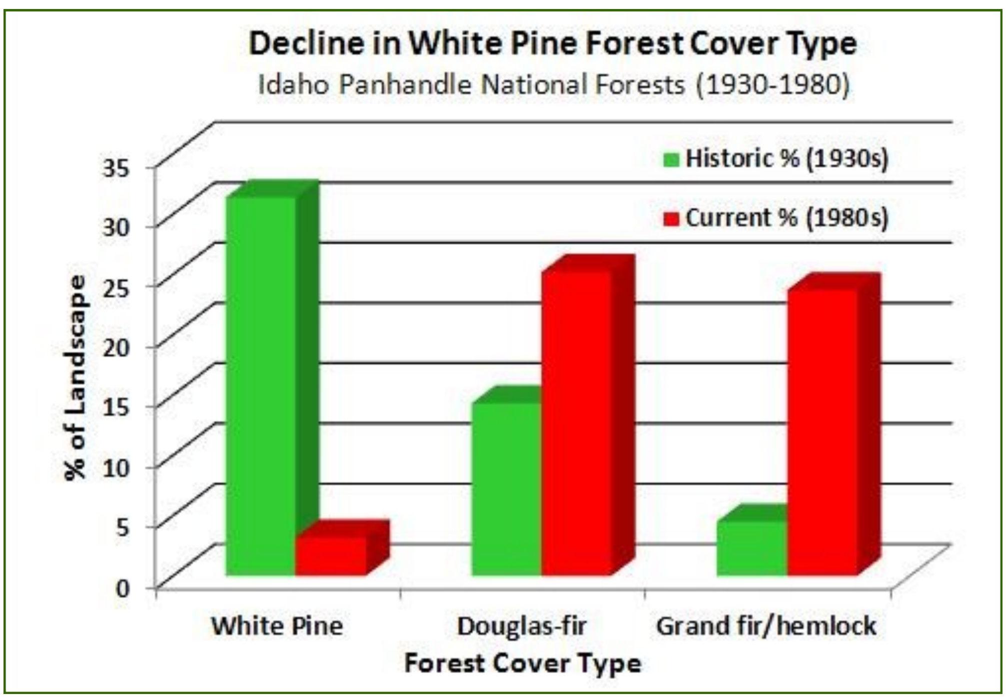
This fungal disease was accidentally introduced from Europe in early 1900s. Since then, it has devastated western white pine forests in the northern and central Rocky Mountains.

Introduction

Management of western white pine (*Pinus monticola*) (WWP) has been confounded by the introduction of white pine blister rust (WPBR), caused by the fungus *Cronartium ribicola*. This disease was introduced into the west coast of North America in the early 1900s on infected eastern white pine seedlings grown in France (Hunt 2009). One documented introduction was at Point Gray near Vancouver, B.C. (Mielke 1943) but it is possible there were other introductions along the West Coast (Hunt 2009). All nine of the five-needled pines native to North America are susceptible (Hoff et al. 1980), but the Great Basin Bristlecone pine (*Pinus longaeva*) is the only pine host that has not yet been infected in its natural range (Nevada and Utah). The disease continues to spread and intensify throughout the range of its hosts and poses a threat to five-needled pines in Mexico.

In the Inland Northwest, WPBR is now distributed throughout nearly all of the ranges of all five-needled pine hosts in Idaho, Montana, and

Figure 1. Decline in western white pine forest type on Idaho Panhandle National Forests in Northern Idaho from 1930 to 1980.



Historic Facts

From 1925 to 1934 the average annual harvest of western white pine from the Inland Northwest was 430 million board feet; enough to build 43,000 homes per year.

Five million acres of the Inland Northwest were once considered white pine cover type.

western Wyoming. This includes whitebark pine (*Pinus albicaulis)* and limber pine (*Pinus flexilis)* as well as western white pine. Western white pine played a critical role in stabilizing ecological processes and was also the most valuable timber species, dominating the timber industry between 1900 and 1965 (Fins et al. 2001). Unfortunately, western white pine proved to be highly susceptible to WPBR with mortality rates of 90 percent or more in what were once vigorous, well-stocked stands. Today, only 5 to 10 percent of the original 5 million acres of western white pine cover type in the Inland Northwest still carries a major component of western white pine (Fins et al. 2001). This loss of western white pine has resulted in a major shift in historic forest succession pathways (Fig. 1) (Samman et al. 2003). Western white pine has largely been replaced by Douglas-fir (*Pseudotsuga menziesii)* and grand fir (*Abies grandis*), which are both much more susceptible to a variety of insects and diseases.

Rust Biology

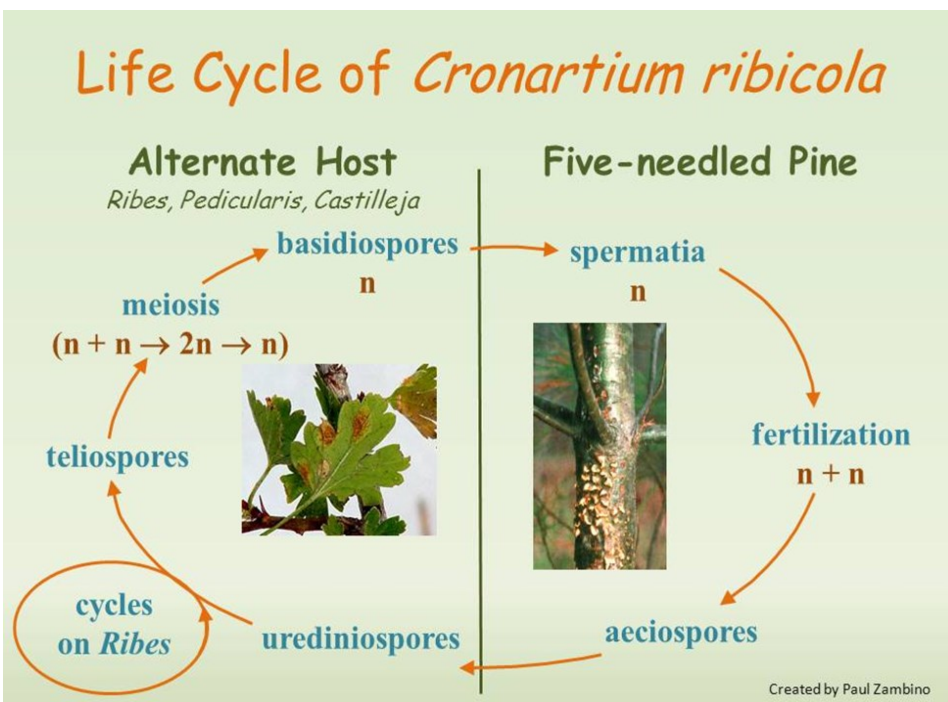
- WPBR requires 2 hosts to complete its life cycle
- WPBR does not go from pine to pine
- WPBR cankers may be active even if:
  - Not sporulating every year
  - The branch has no foliage (and the canker is near the bole)
- Trees with severe stem cankers may still have good growth for many years

Life Cycle

Cronartium ribicola is an obligate parasite, which means it can only survive on living host tissue. It requires two different hosts to complete its complex life cycle (Fig. 2). One host is a five-needled pine and the other is a shrub or herbaceous host referred to as the alternate host. Currants and gooseberries (*Ribes* spp.*)* are the primary alternate hosts. Some species of lousewort (*Pedicularis* spp.*)* and Indian paintbrush (*Castilleja* spp.*)* can also be infected, but their importance in spread and intensification of WPBR has yet to be determined (McDonald et al. 2006).

On white pine hosts, infections must occur through the needles by spores that come from an alternate host usually late in the fall during

Figure 2. Life cycle of white pine blister rust



periods of high relative humidity. Over 50% of the infections occur on one-year old foliage, 25-30% on 2-year old foliage, 10-15% on current year foliage and 5-10% on 3-year old foliage (Lachmund 1933). The following spring, small yellow needle spots form. The rust fungus grows through the branches about 2-inches per year toward the bole, killing tissue as it advances (Schwandt et al. 2013). Once it reaches the main stem, the fungus creates stem cankers that eventually girdle the stem and cause top kill (Fig. 3) or mortality. All sizes of trees are attacked and small regeneration can be killed rapidly. Generally, the larger the tree is at the time it becomes infected, the longer it survives after infection.

Figure 3. Top kill by multiple WPBR cankers.

During the late summer, spermatia (pycniospores) are produced on the pine hosts near canker margins in watery droplets (Fig. 4) which insects then carry from canker to canker resulting in fertilization of the rust fungus. The following spring, cankers on white pine may produce characteristic yellow-orange blister-like aecia that erupt through the bark (Fig. 5). Aeciospores from these blisters can travel many miles to infect leaves of the alternate hosts (Buchanan and Kimmey 1938).

Figure 5. Characteristic blisters of aecia erupting through the bark of a WPBR canker.

The fungus builds up on the alternate host during the summer by producing urediniospores, which re-infect the same or adjacent alternate hosts. Usually in late summer the fungus produces teliospores on small hair-like projections on the underside of leaves of the alternate hosts (Fig. 6). During periods of high relative humidity, teliospores produce thin-walled, delicate basidiospores, which usually travel very short distances (a few hundred yards) to infect needles of white pines (Zambino 2010). On the alternate hosts, damage from WPBR is usually confined to small leaf spots (Fig. 7), but premature defoliation may occur if they are severely infected. About once every ten years conditions are highly favorable and a "wave year" of infections occurs. It is unknown if this is due to: an early moist spring that would favor early aecia production; and/or a cool moist summer that would favor spread and intensification on the alternate hosts; and/or a prolonged warm, moist fall that would favor basidiospore production and spread before frost causes *Ribes* to shed their leaves.

Figure 4. Watery droplets of spermatia on WPBR canker.

Figure 6. Hair-like telia on the underside of the alternate host.

Figure 7. Small leaf spots on Ribes caused by WPBR infections.

Symptoms

- Dead branch "flags"
- Swollen or discolored areas
- Prolific pitching
- Rodent chewing
- Roughened, cracked bark
- Insect boring activity

Figure 9. Typical diamond shaped bole canker after light scrubbing with water.

Figure 10. WPBR stem canker before (left) and after moistening with water (right).

Identification

There are several signs and symptoms associated with WPBR cankers that can help in making an accurate diagnosis. The most obvious sign is the presence of aecial blisters erupting through the bark near the canker margin (Fig. 5). These blisters and their papery remnants that may remain most of the summer are a positive diagnosis that a tree is infected with WPBR. Unfortunately, aecia are not produced until at least 3-5 years after foliage infection, and may not be produced every year. A study that monitored nearly 200 individual cankers annually for 10 years, found individual cankers only sporulated an average of 1.2 times even though cankers were continuing to expand every year (Schwandt et al. 2013). During this period the total number of sporulating cankers per year varied from less than 10 to over 700 on 48 monitored trees.

Another positive sign is the presence of the watery spermatial droplets that may form during the summer near the canker margin (Fig. 4). These are much less obvious than aecia, but if present are indicative of WPBR infection. Production of spermatia is also sporadic, which may help explain the inconsistent production of aecia since it is thought that aecia are only produced on cankers that produce spermatia the prior year (Baxter 1952).

Several other symptoms can also be used to diagnose WPBR infections, and the level of confidence increases with the number of these that are present. It is important to look throughout a tree for these symptoms, as trees frequently have many infections, and some may be easier to recognize than others. It is also important to look at many trees in a stand, since it is highly unlikely to find only a single infected tree in a stand.

Once the fungus girdles the branch or stem, it effectively kills the tissues beyond the canker resulting in distinctive "flags" (Fig. 8) or top-kill (Fig. 3). Most bole cankers are diamond shaped with a distinct yellow/orange margin that is best seen when moistened or lightly scrubbed with water (Figs. 9 and 10). Large stem cankers often produce copious amounts of pitch (Fig. 11) that tend to "glue" bark to older dead trees that have sloughed off much of their bark. Western white pines with cankers girdling more than 90% of the stem often continue to grow and can have healthy appearing crowns many years (Schwandt et al. 2013). Eventually, trees may have stunted growth and chlorotic foliage the year or two before they die (Hoff and McDonald 1977).

Figure 8. Distinctive branch flag caused by WPBR.

Other symptoms of WPBR infections may require closer inspection. Needle spots may be the first symptom of infection on pines, but are usually so inconspicuous and easily confused with other needle spots that they are of little diagnostic value in the field. However, the pathogen creates a distinctive orange-yellow spot at the base of an infected needle fascicle that enlarges as the fungus invades a branch (Fig. 12). Young

Figure 12. Small spot canker caused by WPBR branch infection.

branch cankers are often swollen (Fig. 13), while older cankers (especially on dead branches or trees) may have cracked bark (Fig. 14).

Figure 13. Branch cankers may be swollen.

Cankers are also attractive to other organisms. Rodent chewing of cankers on western white pine (Fig. 15) is almost always an indicator of WPBR infection since rodents are attracted to high sugar concentra-

Figure 14. Cracked bark on older WPBR canker.

tions in canker tissues. Evidence of rodent chewing on dead trees may help diagnose old WPBR infections. During periods of high moisture, cankers may be partially covered with a pink-purple, weakly-parasitic

Figure 16. In moist periods, Tuberculina sp. may be found on WPBR cankers.

fungus (*Tuberculina* sp.) (Fig. 16). This fungus has minimal effects on the rust but may help to identify WPBR cankers. A small insect, *Dioryctria* spp., also finds the margins of active cankers attractive (Furniss and Carolin 1977), and its frass (Fig. 17) may help diagnose WPBR cankers.

Some trees have bole cankers that appear "abnormal" with irregular margins and areas of sunken, dark brown or necrotic bark without a distinct yellow margin (Fig. 18). This is frequently referred to as "bark reaction" and is thought to slow pathogen growth. These abnormal cankers are relatively rare

Figure 11. Profuse bole pitching.

Figure 15. Rodent chewing on WPBR cankers is common.

Figure 17. Small insects can often be found boring in WPBR cankers.

WPBR Management Key Points

- Plant stock with improved resistance
- Prune as needed to minimize rust impacts
- Thin stands sparingly to avoid enhancing infection and mortality
- Leave some uninfected white pine in mature stands

but are most common on trees with some level of WPBR resistance. Some cankers also appear to be

Figure 18. Abnormal WPBR canker with irregular brown bark reaction.

slow growing with swollen callus ridges, sunken centers, and little (if any) pitch (Fig. 19). Small trees may be bent by snow creating basal wounds that may be hard to distin-

Figure 19. A slow growing abnormal WPBR canker with a sunken center.

guish from basal WPBR cankers or root disease which can create basal pitching. However, basal damage from root disease or mechanical injuries usually has an irregular margin without any yellow discoloration and copious resin that increases below ground line.

Management

More than $100 million dollars were spent attempting to control WPBR in the western United States (Benedict 1981). Many different treatments were tried including quarantines, antibiotics and wide-scale *Ribes* eradication. Quarantines were attempted, but were unable to keep up with the aggressive spread of *C. ribicola*. Antibiotics (e.g. Actidione and Phytoactin) were sprayed from the ground and from the air, but also proved ineffective (Ketcham et al. 1968). *Ribes* eradication was carried out for nearly 40 years, and at the peak, 6,200 men in 42 camps were doing WPBR control work every year in the Inland Empire (Benedict 1981). The *Ribes* control program was discontinued in 1965, when it was determined that an acceptable level of control could not be achieved because it was impossible to remove all the plants, roots, and especially seed that might lie dormant in the duff for many years (Moss and Wellner 1953).

The control strategy that has the prospects for success is tree improvement. Early in the epidemic, an occasional uninfected tree would be found in an otherwise severely diseased stand. Nursery testing showed that some of these were resistant to WPBR and produced resistant progeny. This early work led to the development of a comprehensive tree improvement program aimed at developing an acceptable level of rust resistance for operational use. See Appendix A for more details on the tree improvement program.

Ribes Eradication Program 1923-50

- Hired a total of over 250,000 workers (8-12,000/yr)
- Over 4,000,000 *Ribes* plants were pulled 93% were *R.viscosissimum* or *R. lacustre*

Management of Natural Western White Pine in Mixed Forests

Early control efforts were an attempt to save the valuable native western white pine forests. Today these forests are largely gone, but scattered mature trees still occur in mixed-species forests and natural regeneration continues to occur where conditions allow and a seed source is available. It is reasonable to believe that the level of rust resistance in natural regeneration may have increased due to many decades of natural selection, but this has not been well quantified.

The long-term natural selection that is occurring in these trees is a strong justification for retaining white pine during routine management of natural stands with a western white pine component. Fins et al. (2001) and Neuenschwander et al. (1999) both call for conservation of genetic diversity by retaining western white pines that still remain in natural stands. Guidelines for leaving up to 10 of the most vigorous trees with no WPBR (Fig. 20) per acre in operational timber sales are provided in Schwandt and Zack (1996). The Inland Empire Tree Improvement Cooperative encourages foresters to look for and document possible WPBR-free "plus" trees since they may contain resistance genes that are not currently in the breeding program.

Figure 20. Healthy mature western white pine leave tree.

Management of Young Western White Pine

Three silvicultural treatments are currently being used operationally for the management of western white pine: (1) planting rust resistant stock, (2) pruning young plantations when needed, and (3) thinning to release young western white pine. Canker excision is an additional tool that may be considered for use in special situations (Schnepf and Schwandt 2006), and *Ribes* management and WPBR hazard rating are potential tools that need more development and testing. The best management strategy uses a combination of silvicultural techniques applied at appropriate times to rminimize WPBR impacts. Management of western white pine in the face of WPBR requires regular monitoring to determine the need for intermediate treatments and to evaluate treatment success.

Planting

The planting of rust resistant western white pine has become the dominant approach for western white pine restoration (Fins et al. 2001, Nuenschwander et al. 1999). Although western white pine often occurred in pure stands historically, Bingham et al. (1973) recommended that rust resistant western white pine (F_2) be planted with other tree species. The presence of other site-suited native species provides some insurance against understocking should a new, virulent strain of the pathogen arise. Although there is no evidence that a new race is present in the Inland Northwest, mixed-species planting provides options where mortality of western white pine may become excessive on high hazard sites.

Since improved stock became available in the 1970s rust resistant seed-

The term "rust resistant" stock refers to F_2 stock with improved rust resistance produced by the breeding program. It does not infer that the stock is immune to WPBR.

Pruning

- Pruning improves tree survival
- Never prune more than 50% of the total tree height
- No need to disinfect tools between cuts
- Pruning wounds are not a risk for WPBR infection or decay fungi
- Pruning doesn't change the genetics of a tree
- If a stand with > 10% rust is thinned, it should probably be pruned

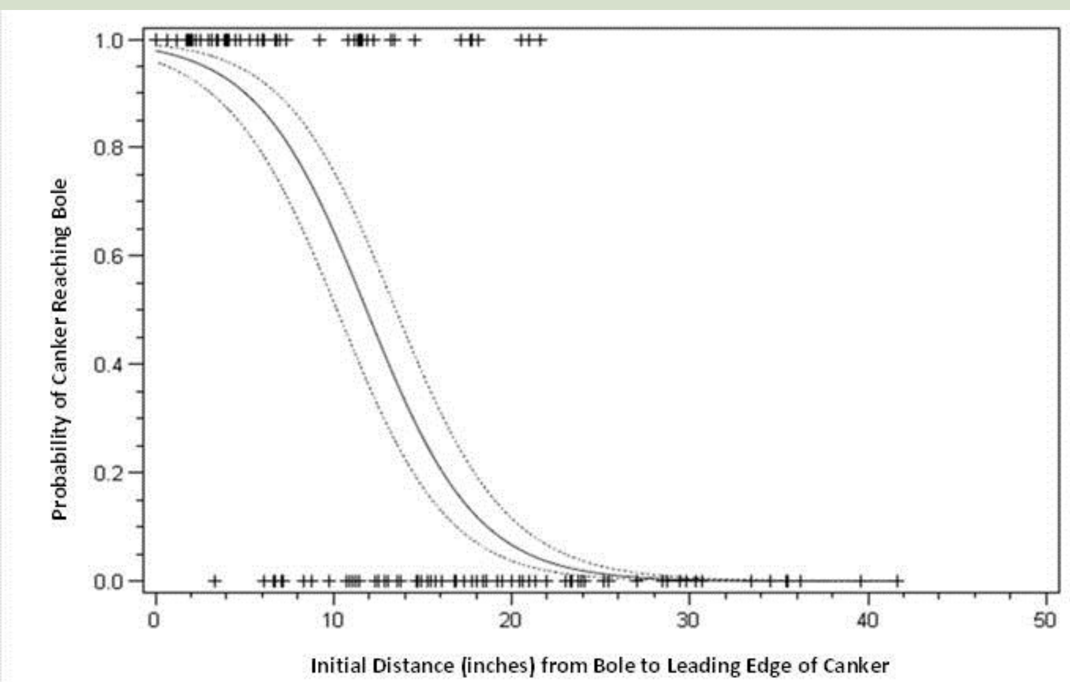
lings have been planted on over 170,000 acres of federal lands (Mahalovich 2010) and over 125,000 acres on state and private lands (Marc Rust, Inland Empire Tree Improvement Coop, pers. comm.) in the Inland Northwest. Nearly all of the plantings have been mixed with other desirable species.

Pruning

Infections in young trees usually occur on branches near the ground and eventually grow into and girdle the stem, killing the tree. A recent study of nearly 200 WPBR cankers on 48 rust resistant (F_2) western white pine found that branch cankers expand ("grow") an average of 2.0 inches per year toward the bole (Schwandt et al. 2013). Cankers closer than six inches to the bole are considered "lethal" since they have greater than 90% probability of reaching the bole. Cankers more than 24 inches from the bole are considered "safe" since they never reached the bole (Fig. 21). Cankers near the bole may continue to grow toward the stem for several years, even in branches that have no live foliage remaining. Therefore, pruning of infected lower branches prevents cankers from spreading into the bole. In addition, pruning of all lower branches regardless of infection removes susceptible foliage from the lower crown where the microenvironment is generally much more conducive for WPBR infection. This can prolong survival by reducing future infections and mortality.

A western white pine pruning and thinning study was established in four northern Idaho plantations of 15 year old unimproved western white pine in 1969 (Hungerford et al. 1982) and was monitored periodically until 2009. This study

Figure 21. Probability of branch cankers reaching the bole or branch collar by initial distance out (2001-2009), with 95% confidence nterval[1]



Hash marks indicate initial distance out for cankers the reached the bole (at top) or failed to reach the bole (at bottom) of graph found that pruning of lower branches from young unimproved western white pine greatly reduced infection and mortality over the next forty years (Schwandt et al. 1994, Schwandt and Marsden 2002, Ferguson et al. in prep). Forty years after establishing three replications of four treatments in each plantation, survival of western white pine that were pruned and thinned was nearly double that of control or thinned only trees (Fig. 22). Although these treatment differences are encouraging, the survival of unimproved western white pine 40 years after pruning and thinning was only about 24% compared to an average of about 12% for the untreated trees.

There is no long-term pruning efficacy data available for F_2 stock, but since F_2 has always out-performed naturals, pruning is expected to be at least as effective in F_2 as in naturals. Forest Health Protection recently established plots in 14 F_2 plantations to monitor effects of pruning and/or thinning over the next 10-20 years.

Periodic monitoring of stand stocking and infection levels is recommended in order to apply pruning at the most beneficial time to maintain desired stocking of western white pine. It is preferable to allow the rust time to infect the most susceptible trees, but to prune a stand while enough trees are still "prunable" or uninfected in order to maintain acceptable stocking levels. Stands at least 10 years of age but less than 35 feet in height offer the greatest opportunity for pruning to reduce WPBR infection and mortality (Schnepf and Schwandt 2006).

Decisions to prune should always be preceded by a rust status survey to quantify current levels of WPBR infection in a stand. A rust status survey should include at least 100 western white pines randomly selected throughout the stand. Fixed area plots are needed to calculate trees and *Ribes* per acre. Additional tallies of other tree species may be beneficial to determine total stand density of all species especially if the stand is being considered for thinning.

Each western white pine is rated by

Canker Types

- Branch cankers that are 6-24" from the bole and <8 feet from the ground are considered "Prunable."
- Cankers within 6" of the bole are considered "Lethal" (too late to prune).
- Cankers more than 24" from the bole are "Safe" and can be ignored.

Figure 22. Average survival of pruned and thinned western white pine across four study sites monitored for 40 years.

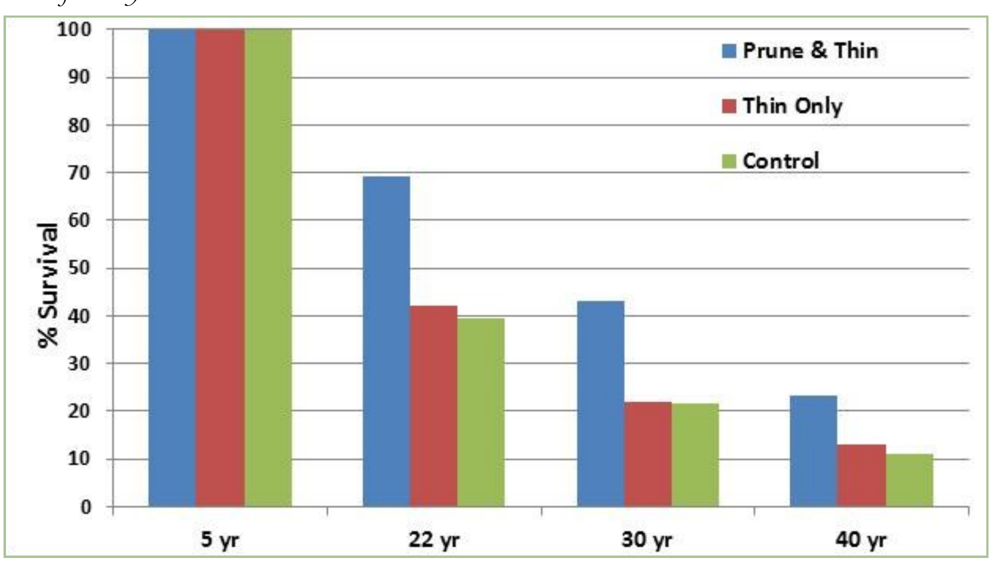


Figure 23. In recently thinned or pruned stands, western white pine may be damaged to various degrees by sunscald.

the most lethal canker observed (clean, safe, lethal or prunable). If the margin of the most lethal canker is on a branch between six and 24 inches from the bole and within easy reach from the ground (usually eight feet), trees are considered "prunable." A sample rust status survey form can be found in Appendix B.

Since the fungus grows about two inches per year toward the bole (Schwandt et al. 2013), pruning contracts that will be implemented within a year could be written with a four inch minimum distance from bole to leading edge of canker. However if pruning will be not be conducted for at least a year, pretreatment surveys should consider cankers within six inches of the bole to be lethal. Moistening the canker with water will usually make the margins of the canker much more visible (Fig. 12). The total number of prunable trees includes "clean" and "safe" trees as well as trees with "prunable" cankers.

Figure 24. Young pruned and thinned F_2 western white pine plantation.

Even if a stand has some WPBR infection, it may not need to be pruned. The rust status survey will indicate how many trees per acre are uninfected as well as number of trees with prunable and lethal cankers so an informed decision about pruning can be made. In a dense stand, there may be many infected trees, but the number of clean trees may still be high enough to satisfy management objectives, so pruning may be unnecessary (or delayed). Pruning in lightly stocked stands (< 50 TPA) may not be worth the effort unless every white pine is needed to accomplish management objectives.

In stands selected for pruning, only prune the desired number of white pine crop trees per acre evenly spaced throughout the stand. Preference should be given to pruning uninfected western white pines as these may possess some level of resistance and are therefore more likely to persist through the rotation. Additional white pine and other species should not be pruned as their shade will help prevent sunscald (Fig. 23), reduce *Ribes*, and impede movement of WPBR spores.

A single pruning to a height of eight feet or the lower 50 percent of the tree height (whichever is less) is recommended (Fig. 24). Individual infected branches above this height should also be pruned ("pathological pruning"). Pruning above eight feet in trees greater than 16 feet tall has not been shown to be justified for control of WPBR, but may be considered if pruning for clear wood. Both dead and live branches should be cut since infections on apparently dead branches may continue to grow toward the bole for several years (Schwandt et al. 2013). Live branches near the base are often partially buried in duff or brush so check carefully for hidden branches as well as basal cankers. Cuts should be flush with the outer edge of branch collar to promote healing. Pruning wounds have never been demonstrated as a risk for rust infection or decay fungi. Pruning can be accomplished using hand pruners, loppers with two-foot handles, or pruning saws. Pruning tools have never been reported to transfer the WPBR fungus and are not required to be cleaned between pruning cuts.

It is not necessary to dispose of pruned branches since WPBR is an obligate parasite and therefore does not survive on dead material. However, red turpentine beetle (*Dendroctonus valens*) may be attracted to the pruning wounds and attack the base of a few pruned trees. Since these insects mine under the bark of pines, they may succeed in girdling a few trees, but damage is usually minor (Kegley and Schwandt 1994).

Pruned trees may also be the subject of "buck rub" or bear damage (Fig. 25 & Fig. 26). In areas where this is a chronic problem it may be wise to prune fewer trees. Leaving long branch stubs with no foliage or cankers might help deter animal damage, but it has yet to be proven.

It is important to remember that pruning does not change the susceptibility of white pines to WPBR, so a tree with a branch canker is still susceptible to future infections. Therefore, pruning a "clean" tree is preferable to pruning an infected tree, but pruning an infected tree may greatly increase its chance of survival. Additional information regarding pruning is available in Schnepf and Schwandt (2006).

Thinning

Pre-commercial thinning is often used in the white pine type to release desired crop trees. However, research has found that while western white pine responds to thinning, it does not need release if it is not over-topped by other species (Jain et al. 2004). Thinning can greatly alter the micro-environment by increasing air movement which will lower the relative humidity and raise the temperature, thus reducing the opportunities for WPBR infection. But opening the stand will also enhance the environment for *Ribes* growth and the retention of lower branches if trees are not pruned. Survival of unimproved western white pine in plots that were thinned only had no better survival than in untreated plots after 40 years (Fig. 22).

Western white pine is also very susceptible to sunscald damage (Fig. 23) when stands are opened by thinning. Therefore, unless western white pine is very dense, we recommend leaving all western white pines regardless of infection or spacing (often referred to as "ghosting") and allowing WPBR to thin them. Even trees severely infected by WPBR can be left as they may provide some temporary protection from sunscald and will not contribute significantly to WPBR spread.

Biologically it may be best to prune 1-3 years before thinning to reduce sunscald and allow any missed cankers to grow and identify pruning mistakes. However, local objectives and conditions may dictate whether

Figure 25. "Buck rub" damage from deer and elk can be severe on pruned trees.

Figure 26. Pruned trees can be attractive targets for bears in the spring.

We generally recommend "ghosting" all western white pine regardless of infection or spacing to allow WPBR to thin the white pine. The additional density and shade may also reduce sunscald, *Ribes* densities, and bear damage in thinned stands.

Pruning Priorities

- Desire to maintain WWP
- Stand age and height
- Rust infection levels
- TPA of WWP
- TPA of other species
- Stand access
- Thinning plans

or not to combine treatments. The desired species mix will depend greatly on species composition and density and the levels of WPBR, root disease, and other damaging agents in the stand. Thinning may lead to an under-stocked stand if there is high mortality in the residual western white pine crop trees from WPBR.

Prioritizing Stands for Treatment

Pruning and/or thinning may not be necessary in all plantations with western white pine and decisions on priorities should be based on maximizing benefits. If several stands are being considered for pruning it may be necessary to prioritize them to ensure that limited resources are applied to the stands that will benefit the most. Priority for pruning will depend on many factors including management objectives, access, thinning plans, and other species present, as well as average age, height, and rust infection levels of western white pine. (See Appendix C "White Pine Pruning Priorities" for more details.)

Prescriptions involving stocking reduction in young mixed stands should be based primarily on the level of WPBR infection and stocking density of all species. Grand fir, western hemlock, and western redcedar more effectively suppress *Ribes* than do Douglas-fir, western larch, and pines (Moss and Wellner 1953). Therefore, *Ribes* populations will decline most rapidly in heavily stocked stands with high proportions of grand fir, western hemlock, and western red cedar. However, stands with large amounts of grand fir and Douglas-fir may suffer increasing mortality from root disease so retention of the less susceptible western white pine may be increasingly important.

Other Methods to Minimize White Pine Blister Rust Impacts

Figure 27. Cankers on valuable trees may excised to increase survival.

Excising cankers

Small stem cankers (or branch cankers within six inches of the stem) can be excised to eliminate individual cankers. Excision consists of cutting a channel completely through the bark and cambium at least two inches beyond the visible margin of the canker (Fig. 27). This essentially creates an island of tissue that dies along with the rust fungus. Excision is very time consuming (expensive) and far more difficult than pruning; so it is generally not recommended for operational use in forest stands. However, it may be justified for use on high value trees in urban areas or other intensively managed sites.

Excising is best accomplished between mid-April and early June when bark is soft and canker margins are most obvious. Extra care to determine the actual margins of the canker is necessary to ensure the fungus is confined within the excised area. Failure to completely isolate the fungus within the excised area results in continued canker expansion. To be considered for excising, the treated area should girdle no more than 50 percent of the tree circumference, have its upper edge no more than six feet from the ground, and lower edge no less than six inches from the ground. Cankers that don't meet these criteria are very difficult to excise with success. Branch cankers that are within four inches of the bole should be treated as bole cankers by pruning the branch and then excising the bole around the branch collar.

Ribes Management

Although spores produced on white pines can travel many miles to find an alternate host (primarily *Ribes* plants), the spores produced on alternate hosts that infect white pines are very thin-walled and desiccate easily so usually do not survive very long (Zambino 2010). This was the biological basis for the massive *Ribes* eradication program. In theory, pine infection should come mainly from local *Ribes* populations, so reducing numbers of the alternate host prior to planting should reduce subsequent WPBR infections. However, recent surveys have not found a high correlation between local *Ribes* populations and infection levels, although high populations of *Ribes* could still be a factor in local inoculum levels (Muller 2002).

Most *Ribes* species are shade intolerant (Fig. 28), so any management activity that increases shade will help reduce *Ribes* abundance, while any activity that increases sunlight will encourage *Ribes* populations (Moss and Wellner 1953). Since *Ribes* seed can remain dormant if undisturbed in the forest floor for many decades, activities that disturb the duff layer can activate dormant seed. Light, partial cutting may activate the dormant seed, but the stands may close and shade out the plants. Site preparation can also be a factor; burning generally increases *Ribes* production (except for hot burns), compared to unburned sites (Muller 2002).

Ribes can also be directly controlled by the use of herbicides. The application of certain soil-active herbicides has been shown to significantly reduce *Ribes* populations if applied prior to seed germination. However, populations of *Ribes* on nearby road banks or other openings may contribute enough inoculum that on-site *Ribes* eradication may not be worth the investment. Further testing and monitoring is needed to determine if results justify the costs.

WPBR Hazard

Determining the favorability of a site for the development of WPBR, known as hazard rating, prior to planting is critical. Site hazard appears to be very complex and depends on many interacting environmental and biological factors. These include *Ribes* species and abundance, environmental conditions that favor infection, and possibly other factors such as wind patterns. In a British Columbia study where hazard is generally low compared to northern Idaho, Hunt (1983) found that trees growing on slopes had a higher risk for infection than those on level sites. He also suggested cankers near the ground may be from local inoculum while infections high in the canopy may be from a distant source. These differences are due to both topography and air flow.

Several site and stand factors were implicated by a University of Idaho study of 41 plantations of improved western white pine stock (Muller 2002). Muller found infection levels increased with: elevation above 3500 feet, slopes greater than 15 percent, more than 100 *Ribes* bushes/acre, stand age, presence of

Figure 28. Most important local *Ribes* species

Ribes viscosissimum (top) and Ribes lacustre (bottom) are the most common and important alternate hosts for WPBR in the Inland Northwest.

Ribes Ecology

- *R. viscosissisum* can tolerate fairly hot, dry sites but dies out with >40% shade.
- *R. lacustre* prefers moist sites and can tolerate up to 75% shade.
- *Ribes* produce abundant seed that can lay dormant for many decades in undisturbed duff.
- *Ribes* seed are stimulated by any site disturbance that increases sunlight, especially low severity fires or broadcast burns.

Survey of 66 young F_2 plantations in Northern Idaho found:

- Infection levels varied from 0 to 96%
- Nearly 50% had infection levels > 33%
- 23% had infection levels > 50%

"Wave year"

Some WPBR infections may occur every year, but a "wave year" has extremely favorable environmental conditions that result in very high levels of infection.

tall brush (>4.5 feet), cedar-wild ginger habitat types, and sites treated with broadcast burning. None of these relationships were statistically strong and additional testing is needed. In the meantime, local data on WPBR infection levels from nearby existing plantations on similar sites to those planned for planting may be the best predictor of future infection (Hagel et al. 1989).

Monitoring of WPBR

The importance of monitoring stands for WPBR impacts cannot be emphasized enough. Young stands that currently appear to be relatively unaffected by WPBR may not be highly resistant, but may have simply escaped infection so far because they have not yet experienced a wave year of infection. Therefore, young stands need periodic monitoring to determine if and when silvicultural treatments are needed. Even after silvicultural treatments, stands should be monitored to evaluate treatment effectiveness.

Although results of artificial inoculations of F_2 stock were promising (Hoff et al. 1973), several surveys of field performance have found widely varying infection and mortality levels in F_2 plantations (Table 1). For example, mortality from WPBR in unpruned and unthinned F_2 stands varied widely from 0% to as much as 66% of the trees by age 26 in the studies reviewed by Fins et al. (2001). Miller et al. (in prep) found that WPBR caused tree mortality in 20 F_2 plantations in northern Idaho was 26% but was highly variable (ranged from 0 to 63%).

Repeated monitoring of stands found that WPBR infection and mortality levels can increase dramatically in a few years (Fig. 29). Miller et al. (in prep) and Kearns et al. (2012) provide the most complete analyses of performance to date. Eighteen F_2 plantations in northern Idaho were measured four times, at 5–6 year intervals from 1995 to 2011. During this 17 year

Table 1. Results of WPBR impact surveys in F_2 western white pine plantations in northern Idaho

Source (Survey Year)	N	Age	Mean % Infection	Range of Infection	Mean % Mortality	Range of Mortality
Fins et al. 2001 (1992-96)	8	11–15	31	2-64	7	0-16
Fins et al. 2001 (1996)	4	14–26	60	20–93	25	10-66
Schwandt and Ferguson 2003[1] (1997)	9	8-13	30	2-64	1.5	0-6
Schwandt and Ferguson 2003[1] (2002)	9	13-18	47	5-95	5.0	0-18
Muller 2002 (2000-2001)	41	15–20	35	2–95	5.4	0-41
Kearns et al. 2012 (2006)	18	12–22	39	0–84	22.4	0-55
Miller et al. in prep[2] (2011)	20	17–27	52	6–87	26.3	0-63

[1] This paper reports WPBR impacts on 9 plantations measured in 1997 and 2002
[2] This paper reports a five year remeasurement of the plantations reported on in Kearns et al. 2012

period, the average percent infection across all 18 F_2 plantations increased from 13.7 to 51.9 while the average percent mortality increased from 7.9 to 26.3. Natural regeneration monitored within these plantations had an average percent infection level that increased from 12.3 to 71.5 while the mortality in natural regeneration increased from 7.2 to 46% (Fig. 30).

Once WPBR infection reaches the bole, it usually leads to death (or top kill) in all stock types (Kearns et al. 2012). However, the rate at which infected trees die is highly variable, depending on age at infection, number of infections, and other factors. Stems that are small when infected are killed within a few years, while those that are large may live for several decades. Lupo (2004) found that the survival in two F_2 performance tests averaged 20% after 31 and 32 years rather than the 66% predicted from the nursery tests. In a canker monitoring study of F_2 western white pine with WPBR infections, Schwandt et al. (2013) found that 21 of 48 trees (44%) died during a 10-year monitoring period and the remainder all had bole infections; most of these (63%) were over 80% girdled. In the study of 18 F_2 plantations by Miller et al. (in prep), over half of the young F_2 trees that were diagnosed with WPBR at the first exam were dead five years later, and 92% were dead 17 years later.

Infection and mortality levels can be expected to increase in these young stands but the rate at which it will increase is unknown. However, Kearns et al. (2012) noted that if infection remained constant at an annual rate of 2.4%, the average rate at the last measurement interval, it would take just over 40 years for all trees to become infected. Fortunately, there is a wide variation of stand trajectories, and some stands continue to have low infection levels after 17 years (Fig. 29).

Most branch cankers die, but cankers that reach the bole usually girdle the stem; resulting in top kill or death.

Figure 29. White pine blister rust caused mortality in nine F_2 plantations.

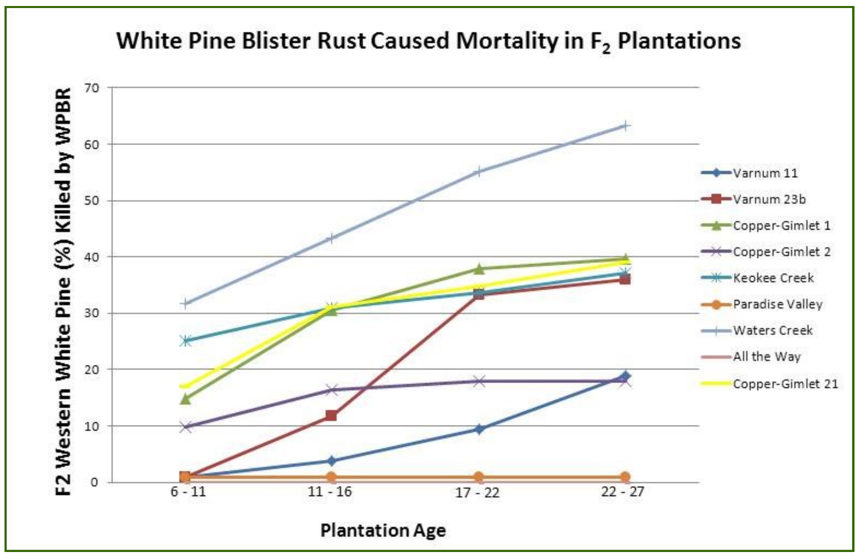
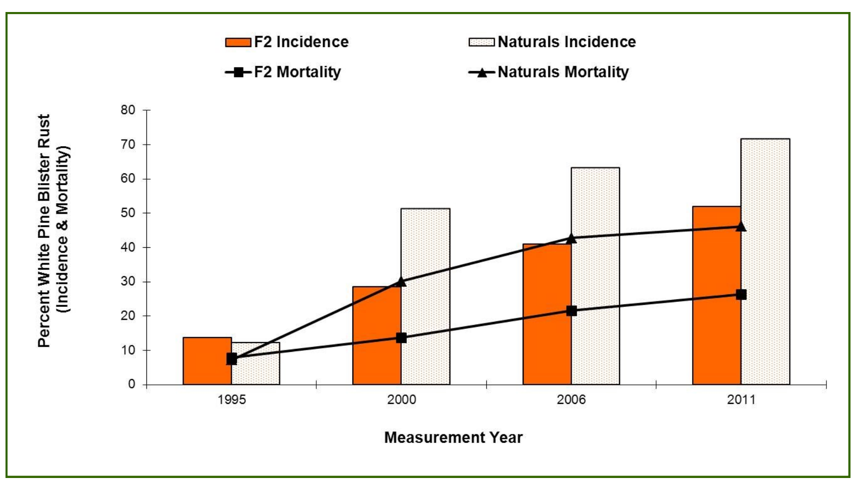


Figure 30. Average WPBR incidence and mortality of F_2 and natural regeneration in 18 stands over 17 years.



The Future

It has been more than a century since the introduction of *C. ribicola* into western North America. Impacts from WPBR have been devastating and have contributed to major changes in forest succession across millions of acres. However, there is reason for guarded optimism for the future of western white pine. The breeding program to develop rust resistant western white pine is now producing stock with resistance levels well above that of natural stock. However, further improvements in rust resistance are needed and long-term support for these efforts is essential to assure the future of white pines (Mahalovich 2010).

Tree improvement needs to be coupled with a major effort to create planting opportunities for improved western white pine stock. In the past 15-20 years there has been a drop of over 70% in both volume harvested and acres of western white pine planted in Region 1. The annual planting levels of 8,000-10,000 acres from 1985 to 1995 have dropped to only 2,000-4,000 acres, and at this rate it will take over 300 years to reforest just 20 percent of the 5 million acres of prime western white pine habitat in the inland Northwest. As a result of this reduction in acres planted, there is now an 8-10 year supply of improved seed available to be planted.

Current results from operational plantations underscore the importance of active forest management to the restoration of western white pine. Variability in performance of rust-resistant stock heightens the need to monitor operational plantings and to use information on stocking and rust incidence to design thinning and/or pruning treatments to minimize WPBR impacts for individual stands. Long-term monitoring is vital to evaluate the performance of current and future genotypes in the field and determine the effectiveness of pruning and other intermediate stand treatments in plantations of improved stock over time.

Critical information gaps still remain in understanding WPBR and its management. For example, we need a better understanding of the genetics of resistance, including resistance mechanisms, and the role of other alternate hosts. We also need better documentation of wave year conditions and how pruning and thinning treatments impact the microenvironment. The most critical need for managers is the development of a viable site hazard rating technique that will give managers more confidence about the prognosis of improved stock and explain the reasons for variability of performance of the same genotypes on different sites.

Current results show that at least some plantations with improved stock can be successfully managed to meet timber management objectives (Fig. 31). Even plantations with high losses to WPBR can be expected to help keep this critical species on the landscape. This may become especially important in mixed species stands impacted by other agents such as bark beetles and root diseases. However, a site hazard rating technique to guide an aggressive planting program plus a continued tree improvement program will be needed to begin to restore western white pine to its vital role in ecosystems in the Inland Northwest.

Figure 31. Young F_2 western white pine plantation.

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Photo citation

Unless noted otherwise, photos provided by John Schwandt, USDA Forest Service.

Forest Health Protection and State Forestry Organizations

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Ogden (801) 476-9720
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Appendix A: White Pine Tree Improvement Efforts

A cooperative western white pine tree improvement program to capture and concentrate naturally occurring resistance mechanisms was started in 1946 (McDonald et al. 2004). The early crosses proved resistance traits could be successfully passed on through breeding; and nearly 15 years later seed became operationally available from this first generation (F_1) of selectively bred trees (Sandpoint, Idaho seed orchard). The best candidates from the first breeding were crossed to create a second generation (F_2) to further improve resistance. F_2 seed orchards were established at Moscow, Lone Mountain, and Coeur d'Alene, Idaho. Most of the white pine planted since the mid-1980s have been (F_2) stock from these three seed orchards.

The genetics program to enhance rust resistance is on-going (Mahalovich 2010) (Fig. 32). Phase I (1946-1971) of the program was based on only 400 parent trees. Phase II (1971-1995) includes 3,098 parent trees exhibiting resistance that have been selected and tested. Phase III (1996-) involves parents from additional areas not previously sampled (350 so far). The testing is conducted at the Coeur d'Alene nursery where seedlings from phenotypically resistant trees are subjected to an intense spore load under favorable infection conditions. All phases are based on screening for seven rust resistant host responses: reduced needle spot frequency, bark reactions, reduced early stem symptoms, canker tolerance, no spots, needle shed, and short shoot. Trees are checked for survival, resistance and good growth characteristics over four inspections during three years. Phase II and III best performers (forward selections) are being planted at Lone Mountain, a new seed orchard established in 1986 at Grouse Creek, Idaho, and the Inland Empire Tree Improvement Cooperative (IETIC) R. T. Bingham Orchard (formerly known as the Moscow Arboretum). Because Phase II and III orchards will have a higher effective population size than phase I, they are expected to have about the same level of rust resistance (60%) but a much broader genetic base to better respond to changing climates and any change in the frequency of virulence in the rust population (Mahalovich 2010).

The goal was not to develop stock that is immune to the rust, meaning none of the trees become infected ("vertical resistance"). Even if it were possible, that may not be desirable because immunity may put too much selection pressure on the rust. Strains of *C. ribicola* have overcome vertical (major gene resistance or MGR) resistance in white pines in Oregon and California and the potential also exists here in the Inland Northwest. Vertical resistance is usually a single gene providing resistance while horizontal resistance may allow higher infection to occur in the short term but is considered more stable over the long-term. This means it is less likely to be susceptible to a new strain of the rust (McDonald and Dekker-Robertson 1998). Because of the concerns about vertical resistance, there have been no attempts to incorporate MGR into the Inland Northwest breeding program. European pines have a much higher level of blister rust resistance, but this has been linked to undesirable growth characteristics and western white pine appears to have sufficient genetic variation that interbreeding or

Breeding

- Primary goal is to produce rust resistance levels that will provide good survival while minimizing selection pressure on the rust.
- Provide seedlings that have good silvical characteristics as well as improved resistance.
- Rust "resistant" trees are not immune to rust.
- Selecting and testing additional parent trees exhibiting resistance is ongoing

Figure 32. Controlled pollination to improve WPBR resistance at the Coeur d'Alene Nursery.

hybridizing with other pines has not been deemed necessary.

Early in the blister rust resistance breeding program, it was decided that a level of 50% resistance in the population would be adequate for operational use, and that level might be an achievable goal (Bingham 1983). Seedlings were tested using a one-time heavy dose of spores under artificially favorable conditions using the detached leaf method. The expectation was that this test might be at least as severe as would be experienced over many years of lower exposure in the field. Results of the artificial inoculations of F_2 parentage were especially promising. After 2 ½ years, nearly 66% were canker free (Hoff et al.1973). Thirty-three percent of the F_1, and only 19% of the controls were canker free. The 66% figure became the expected level of performance for F_2 stock in the field. And early results from field tests seemed to confirm this (Bingham et al.1973). However, the actual "realized gain" under operational conditions is just now being investigated and is anticipated to be closer to 20% (Lupo 2004).

Gene conservation is an important part of the white pine genetics program (Mahalovich 2010). Fins et al. (2001) and Neuenschwander et al. (1999) both call for conservation of genetic diversity by retaining white pines that still remain in wild stands. *In situ* conservation includes long-term performance tests, realized gains trials, and a network of plus trees across the landscape. *Ex situ* conservation includes a seed and pollen inventory at Coeur d'Alene Nursery.

Stem infection usually leads to death in all stock types. However, a low level of genetic resistance to normal canker growth and tree killing ability also seems to be present in white pine. Hoff (1984) found that about 1.5 percent of the inoculated and cankered unimproved seedlings were still alive after nearly thirty years. "Canker alive," or cankers that have not killed the trees after 4 years, is listed as a type of resistance (Fins et al. 2001). Eckert (2007) found a few slower growing cankers in F_2 plantations, and cankers in the least aggressive classes grew more slowly than normal appearing cankers.

Other stem infections can be curtailed by the development of callus tissue around an active canker, thereby preventing the growth and subsequent girdling of the tree. This resistance mechanism is referred to as a bark reaction (Hoff 1986) and is presumed to be under polygenic inheritance. The frequency of bark reactions in 16 cycles of rust screening (Cycles 7 through 22) is also in low frequency and averages 6.4% (± 2.8) (Mahalovich unpublished data).

Results so far find the relative level of resistance is much better in the improved stock compared to the unimproved, but the level of resistance is highly variable and less than expected in some plantations. The nature of resistance seems different than expected as well. One early expectation was that the improved population would include some susceptible individuals that would become infected and die early, but that most of the population would remain uninfected, presumably over the long-term (unless there was a change in the rust). This theory assumed all spore populations were highly virulent at the time of the artificial inoculation. Another explanation for the differential response is the frequency of each resistance trait may vary geographically across the Inland Northwest (Mahalovich in prep). Another possibility is that resistance may reduce the *rate* of infection compared with unimproved genotypes, rather than limiting the percent of the population that becomes infected. Goddard et al.(1985) found that resistance decreased both the infection rate and early mortality.

The variability in incidence of infection on different sites may be a result of differences in site hazard or level of virulence in the rust population (McDonald and Dekker-Robertson 1998). Although there is genetic variability within the rust fungus (Vogler and Delfino-Mix 2008), on-going tests do not indicate any change in blister rust virulence especially near Merry Creek where a rapid change in infection levels was detected (Mahalovich 2010).

It is clear that long-term exposure in the field will at times result in greater infection than the mass artificial inoculation in the nursery. Mahalovich (2010) notes that percent resistance in artificial tests is variable, and depends on spore loads, nursery practice, and stock types. The twenty percent long-term survival that Lupo found (2004) is very successful compared to the 1% survival of unimproved controls, and is well within the range of first generation gains with other host-parasite combinations (Fig. 33). These results confirm the wisdom of continuing efforts to further improve resistance. But these results may mean that managers need to adjust their management plans, restoration strategies and site-specific prescriptions, e.g., the number of trees planted per acre given a desired future objective for stand density. Seven year measurements of realized gains trials are finding 67% survival in Phase I stock and over 80% survival of Phase II stock, but continued monitoring is needed to better understand long-term performance of this stock in the field. This long-term monitoring of Phase II and III plantings will provide information that will help guide future breeding and management.

In addition, the current tree improvement program is focusing on creating a new testing population of 360 "elite" trees for a second generation of improvement. It will be structured in a way to minimize inbreeding and also provide an *ex situ* gene conservation clone bank made up of 10% of the original selections. 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 (replicate breeding populations) based on their geographic origin. The role of sublines is to structure the breeding groups within a population to tolerate inbreeding within sublines, but with the long-term goal of having unrelated entries in a second-generation seed orchard (Bridgewater et al. 1993).

A circular half-sib mating is employed within each subline rather than single-pair matings or a complementary testing scheme. Crosses are assigned by an index rank to promote additional rust resistance gains. 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.

Figure 33. F_2 western white pine seedlings growing at the USFS Coeur d'Alene Nursery.

Appendix B: Data form for field surveys to determine the status of stands with respect to white pine blister rust infection

WHITE PINE RUST STATUS

Area Name:____________________ Forest ______________ Seed Lot _________ Date _______
Stand No: ______________________ Acres ___________ Plant Date __________ TPA___________
Location: T____ R. _____ Sec____ Plot size: __________ Crew: _____________________________

Plot#	Clean	Safe	Prun	Lethal	Dead Rust	RR	Unk	Ribes
Total	Clean	Safe	Prun	Lethal	Rust	RR	Unk	Ribes

Summary

______ % Clean _____ TPA*
______ % Prunable _____ TPA*
______ % Lethal _____ TPA*
______ **Total % Live** _____ **Total Live WP**
______ % Dead _____ TPA*

Other Sp. TPA: Larch ______ TPA*
DF/GF ______ TPA*
Other ______ TPA*

****TPA =*** ***#trees X inverse of plot size*** / ***# plots***

Average Crop Tree Height.: ___________

Plot Size: 1/10 ac. = 37.2' radius
1/20 ac. = 26.3'
1/50 ac. = 16.7'
1/100 ac. = 11.78'
1/250 ac. = 7.5'
1/300 ac. = 6.8'

Definitions/Codes:

Clean: No visible cankers
Safe: All cankers > 24" from bole
Prun(able): Branch cankers 6-24" from bole**
Lethal: Stem canker < 6" from bole**
Dead rust: Dead with rust cankers
Dead RR: Dead with evidence of root disease
Dead Unk: Unable to determine cause of death

*****If pruning the same year as survey use 4" from bole instead of 6"***

Comments and recommendations:

9/8/13

Appendix C: Guidelines for setting white pine pruning priorities

The goal of pruning is to remove infections and the most susceptible branches (usually 4-8 feet from the ground where the brush layer creates a shady, moist microenvironment favorable for infections). A rust status survey that shows TPA and white pine blister rust levels is critical to this process. Stands should be at least 10 years old and average height of white pine should be at least 15 feet. **Prune no more than 50% of the total tree height**. Assign points based on the following criteria; use total points to determine relative priorities between stands. (Suggested points may be "tweaked" to better reflect other local issues or priorities.)

Criteria/Comments	**Points**

1. Target Stand/Management objectives:

Relative importance of maintaining white pine to management objectives

Very high = **6**; high = **4**; moderate = **2**; low = **1**

2. Infection Levels and # Prunable WP TPA: (including clean & safe trees)

	Points for total # Prunable WP per Acre						
%Infection	**0 -**	**50 -**	**100 -**	**150 -**	**200 -**	**250 -**	**300 - +**
0-10%	**0***	**1**	**2**	**1**	**1**	**0**	**0**
10-25%	**0***	**1**	**4**	**3**	**2**	**1**	**1**
25-50%	**0***	**1**	**3**	**4**	**4**	**3**	**2**
>50%	**0***	**0***	**3**	**3**	**4**	**3**	**2**

*If <50 prunable trees – it may not be worth finding them especially if >50% infected

3. Other Desirable Species Present (crop trees/ac) WL, PP, etc.:

The presence of root disease or other problems observed in other species might elevate the importance of maintaining the white pine component of the stand.

- **0** = >400
- **2** = 200-400
- **3** = 100-200
- **5** = <100

4. Ave Height of WP: (assuming equal TPA and % infection)

- **0 = < 8'– monitor only; do not prune unless absolutely necessary OR if you have the opportunity to have additional "lifts"**
- **1** = 8'-12'consider delaying if possible a year or two
- **3** = 13'-18' the best size
- **4** = 19'-35' these will be too tall if not done soon
- **0** = >35' should already be self-pruned; unless pruning >8 feet

5. Access to stand for treatment:

- **4** = Access may be lost in near future due to road closures
- **3** = Drivable to stand
- **2** = < ½ mile walk into stand
- **1** = ½- 1 mile walk
- **0** = > 1 mile walk

6. Thinning Considerations (multiply value entered in item #2):

- **2x#2** = Thinned within last 5 years (critical to prune if >10% WPBR infection)
- **1x#2** = Thinned within last 5 years but <10% WPBR infection
- **1x#2** = Thinning planned within next 2 years
- **0** = Other (not thinned or not needing thinning)

7. Economics/Efficiency:

Stand size and relative proximity to other stands that will be treated nearby; **(1-4)**

TOTAL POINTS