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Assessment of Whitebark Pine Health on Eight National Forests in Oregon and Washington

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Pacific Northwest Albicaulis Project

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Whitebark pine *(Pinus albicaulis)* stands on the Wenatchee, Okanogan, Deschutes, and Winema National Forests in Oregon and Washington

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Assessment of Whitebark Pine Health in Oregon and Washington

Abstract

Surveys were conducted in 2005 in 29 whitebark pine stands on national forests in Oregon and Washington to assess the incidence of white pine blister rust infection, recent or current mountain pine beetle infestation, and overall mortality in whitebark pine. Surveys consisted of fixed-width (10-meter), variable-length belt transects. All whitebark pine trees 1.4 meters tall and taller within each transect were observed for status (live or dead), white pine blister rust and evidence of mountain pine beetle infestation. Study-wide, mortality from all causes was 21.3 percent. By transect, the percentage of trees that were dead ranged from 1.1 percent to 61.0 percent, with a median of 19.6 percent. Blister rust infections in live trees were observed in 23 of the 29 transects. Infection rates in those 23 transects ranged from 4.7 percent to 73.3 percent of live trees, with a median of 26.8 percent. The lowest infection rates were observed east of the Cascades in southern Oregon. Evidence of recent mountain pine beetle infestation was observed in 8 of the 29 transects; the rate of infestation in those transects ranged from 1.2 percent to 28.4 percent of all trees observed. A survey of seedlings within each transect was also conducted: study-wide seedling mortality was 3.8 percent, and 4.8 percent of live seedlings were infected with white pine blister rust.

The **Pacific Northwest Albicaulis Project** of the USDA Forest Service supports the conservation and restoration of whitebark pine ecosystems in Oregon and Washington through field and laboratory studies, publications, and development of management strategies. For more information on this project, contact Carol Aubry, geneticist, caubry@fs.fed.us.

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Cover photo: Garland Peak Trail survey site, Wenatchee National Forest (upper left);
Three Fools Pass survey site, Okanogan National Forest (upper right);
Ball Butte survey site, Deschutes National Forest (lower left);
Yamsay Mountain survey site, Winema National Forest (lower right).

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Introduction

Whitebark pine (*Pinus albicaulis* Engelm.) is a five-needle pine native to mountainous regions of western North America. The species plays a significant ecological role in the high-elevation ecosystems it inhabits. Whitebark pine is in decline throughout its range as a result of the combined influences of the introduced disease white pine blister rust, the native insect mountain pine beetle and, in the drier portions of its range, decades of fire suppression that have interrupted natural fire cycles and excluded fire from high-elevation ecosystems (Kendall and Keane 2001, Morgan and Murray 2001). In 1998 the International Union for Conservation of Nature and Natural Resources listed whitebark pine as vulnerable, meaning that the species faces “a high risk of extinction in the wild in the medium-term future” (IUCN 2006). In the Pacific Northwest, whitebark pine was listed in 2004 as a species of concern in western Washington by the U.S. Fish and Wildlife Service, Pacific Region (USDI Fish and Wildlife Service 2005).

Information about local and regional rates of white pine blister rust infection and mountain pine beetle infestation are necessary for the management and conservation of this important tree species. Until recently, most health assessments of whitebark pine were conducted in the Rocky Mountains (i.e., Tomback, Arno and Keane 2001; Schmidt 1990) but there is a growing body of data about the condition of the species in Oregon and Washington (Ward et al. 2006). This study adds assesses the health of whitebark pine on National Forest System lands in Oregon and Washington, with a focus on white pine blister rust and mountain pine beetle.

Background

Whitebark pine

Whitebark pine is the lone North American member of the *Pinus* subgenus *Strobus*, subsection *Cembrae*, known as the “stone pines.” It occurs only in western North America (figure 1). The other four stone pine species, Japanese stone pine (*P. pumila* Regel), Korean stone pine (*P. koraiensis* Sieb. and Zucc.), Siberian stone pine (*P. sibirica* Du Tour), and Swiss stone pine (*P. cembra* L.), occur in Europe and Asia. Stone pines are characterized by their large, wingless or nearly wingless seeds and indehiscent cones (Lanner 1990). Even at maturity, the cones of whitebark pine do not open far enough for the seeds to fall out on their own, and the cones generally do not fall from the tree. The stone pines rely on

Figure 1. Range of whitebark pine (U.S. Geological Survey 1999)

the *Nucifraga* genus of birds–the nutcrackers–for primary seed dispersal (Lanner 1990, 1996).

Whitebark pine has a nearly obligate mutualism with the Clark's nutcracker (*N. columbiana*) (Tomback and Linhart 1990), North America's only nutcracker (figure 2). Both the tree and the bird have evolved morphologically to enhance this mutualism (Lanner 1982). Nutcrackers have long, powerful, pointed bills that are used to pry open the whitebark pine cone scales and extract the seeds. They also have a sublingual pouch in which they carry seeds to caching sites. Nutcrackers use their sturdy bills to cache seeds by digging shallow holes or pushing seeds into loose substrates or crevices (Tomback, Hoffman, and Sund 1990). Whitebark pines, in contrast to most wind-dispersed pines, have a broad, rounded crown of upswept branches rather than a conical form. The round, dark purple cones are held upright or laterally on the ends of the branches, making them visible and providing easy access for the nutcrackers (Lanner 1980, 1982).

Figure 2. Clark's nutcracker (*Nucifraga columbiana*)

Nutcrackers harvest seeds directly from cones on the tree, and cache the seeds either nearby or at distances of up to 22 kilometers or even more, sometimes with considerable changes in elevation (Tomback and Linhart 1990). Each bird can harvest and cache an astonishing number of seeds–estimates range from 32,000 to 98,000 seeds per year, several times more than the bird will need to feed itself and its young (Tomback and Linhart 1990). Seeds in caches that are not retrieved and not raided by rodents or other animals may germinate. This nutcracker-driven system is the primary process of seed dispersal and regeneration for whitebark pine (Tomback 1982, Hutchins and Lanner 1982). Patterns of distribution and genetic structure of whitebark pine are strongly influenced by this mutualism (Jorgensen and Hamrick 1997, Rogers et al. 1999, Richardson et al. 2002).

Because Clark's nutcrackers show an affinity for caching seeds in open areas (Tomback 2001), whitebark pine is often the first species to colonize disturbed areas such as burn sites or avalanche slopes. A drought-tolerant, shade-intolerant species, whitebark pine is seral on warmer, wetter sites within its range, giving way over time to shade-tolerant species such as subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), or mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.). It can coexist in mixed stands with other shade-intolerant species such as lodgepole pine (*Pinus contorta* Dougl. ex Loud.), western white pine (*Pinus monticola* Dougl. ex D. Don), Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco), and subalpine larch (*Larix lyallii* Parl). Whitebark pine is a climax tree species on colder, drier sites, sites with poor or loose substrates, or at treeline. It is often the last tree species to occur before upper subalpine forest yields to open alpine tundra. On harsh, exposed sites and near timberline, whitebark pine often takes on a shrubby, stunted, krummholz form (Arno 2001).


Figure 3. Windswept whitebark pine, Wenatchee National Forest

Whitebark pine is considered a keystone species of high-elevation ecosystems (Tomback and Kendall 2001). The term "keystone species" was first used by Robert Paine to describe the central role of a low-abundance predator (a *Pisaster* sp. starfish) in maintaining biological diversity in a tidepool ecosystem (Paine 1969). A keystone species is a species whose presence is crucial in maintaining the organization and diversity of its ecological community, and whose effect on the community is disproportionately large relative to its abundance. (Mills et al. 1993, Power et al. 1996). Whitebark pine's keystone functions include retaining snowpack and regulating runoff; pioneering disturbed sites and initiating forest succession; providing microsites in which other vegetation can become established; and providing crucial food and shelter for wildlife (Tomback and Kendall 2001). Whitebark pine is also associated with back-country hiking and recreation and is highly valued for its aesthetic character (figure 3). On harsh or upper elevation sites where whitebark pine is the dominant or climax tree species, the loss of this species would result in a barren landscape and a loss of the important ecosystem functions and human values associated with whitebark pine.

Threats to whitebark pine

White pine blister rust

Whitebark pine is vulnerable to infection by the non-native fungus *Cronartium ribicola* JC Fischer ex Rabenh., which causes the highly destructive disease white pine blister rust in five-needle pines (Maloy 2001). *C. ribicola* is native to Asia, and was first observed in eastern Europe in the mid-1800s, where it may have arrived with an introduction of infected Siberian stone pine. By 1900 white pine blister rust had spread throughout northern Europe, where the highly susceptible North American species eastern white pine (*Pinus strobus* L.) had been widely planted (McDonald and Hoff 2001). Forest nurseries in western Europe exported millions of eastern white pine seedlings to the United States in the late 1800s and early 1900s. White pine blister rust was first observed in eastern North America in the early 1900s. The pathogen was introduced to the west coast of North America in 1910, on a shipment of eastern white pine seedlings that were imported from France to Vancouver, British Columbia (McDonald and Hoff 2001). It spread rapidly from its point of introduction, and is now established throughout the range of whitebark pine. Whitebark pine has been heavily impacted by white pine blister rust, with high mortality and infection rates of up to 100 percent of living trees in some areas (Kendall and Keane 2001).

White pine blister rust has a complex, multiple-stage life cycle that requires two different vegetative hosts. The fungus is annual on the leaves of plants of the *Ribes* genus (currants and gooseberries) and has recently been confirmed on at least two species in the family *Orobanchaceae*–scarlet paintbrush (*Castilleja miniata* Dougl. ex Hook.) and sickletop lousewort (*Pedicularis racemosa* Dougl. ex Benth.) (McDonald et al. 2006). Infected plants of these deciduous host species show small rust-colored spots on the leaves. The spores that move from the *Ribes* or *Orobanchaceae* hosts to the five-needle pine hosts are called basidiospores. Basidiospores develop in late summer or early fall. These fragile, wind-borne spores can travel from about 300 meters (McDonald and Hoff 2001) to several miles if conditions are favorable (Maloy 2001). The process of basidiospore development, dissemination, and successful infection of a five-needle pine host requires a prolonged period of very high humidity and cool temperatures (Van Arsdel et al. 1956). The basidiospore germ tube enters the tree through a needle stomata. From the needle, the fungus moves into the branch of the tree and eventually spreads into the bole (figure 4).

Figure 4. Blister rust bole canker on whitebark pine, Okanogan National Forest. Note the branch flag to the left, and the large dead branch through which the canker entered the bole. This infection shows active orange aecia and considerable weeping of sap. A rodent has gnawed on the branch canker where the branch meets the bole.

White pine blister rust is perennial on its 5-needle pine hosts. Branch infections, called "cankers", are characterized by spindle-shaped swellings of the bark, often displaying either the blistery orange and white fruiting bodies (aecia) of the current year, or white remnants of the membranes of last year's aecia (Hoff 1992). The bark is ruptured as a result of the aecia erupting through it from the fungal hyphae growing in the cambium below. The end of the branch beyond the canker may be dead. The red needles of branches that have been recently killed by blister rust are symptomatic of the disease. These "branch flags" can often be seen from quite a distance. In contrast to the fragile basidiospores produced on the deciduous host plants, the hardy aeciospores produced on the five-needle pine hosts are thick-walled to resist desiccation, and are able to travel long distances to infect *Ribes* and *Orobanchaceae* hosts (Kinloch 2003, Maloy 2001).

Bole infections, or bole cankers, are also characterized by swollen, ruptured bark and aecia or remnants of aecial membranes. Both bole and branch cankers often weep large quantities of sap. Rodents are drawn to the sugars concentrated in blister rust cankers, and frequently gnaw living bark in the vicinity of active infections (Hoff 1992). On both bole and branch cankers, the outer margins of the infection are rusty yellow or orange. These orange margins are especially visible when the area around the canker is moistened with water. Bole cankers are typically diamond-shaped, spreading more rapidly up and down the bole than around it. When a bole infection girdles the tree it kills either the portion of the tree above the infection (topkill), or the entire tree. It is not unusual for a single whitebark pine tree to have multiple blister rust infections.

White pine blister rust poses a threat not only to individual trees, but also to the regeneration potential of the species as a whole. Whitebark pines of all ages and sizes are susceptible to white pine blister rust. Small diameter trees are likely to succumb quickly to the disease–within a few years–leading to an overall decrease in seedling survival. Larger trees tend to die slowly from the top down (Kendall and Keane 2001). Even though these larger infected trees may survive for several decades, death of the upper branches greatly reduces their cone-bearing potential (figure 5).

Figure 5. Blister rust-infected whitebark pine stand, Wenatchee National Forest. The top of the tallest tree has been killed by blister rust, and there are branch flags and blister rust topkill on several of the trees to its right.

Mountain pine beetle

Mountain pine beetle (*Dendroctonus ponderosae* Hopkins (Coleoptera: Scolytidae)) is a native bark beetle that infests most western pine species. It is considered to be the most destructive bark beetle in western North America (Bartos and Gibson 1990). Its range is generally comparable to the range of its principal host species, ponderosa pine (*P. ponderosae* Lawson) and lodgepole pine, and it is regarded as an important natural component of forest disturbance ecology (Logan and Powell 2001). Mountain pine beetles use a mass-attack strategy in which a large number of beetles attack an individual tree, overwhelming the tree's defenses. The beetles occupy the phloem of the host tree, girdling and killing it usually within a single season (figure 6). Mountain pine beetle populations typically occur at low, "endemic" levels, with periodic outbreaks of epidemic proportions that leave broad swathes of beetle-killed trees across affected landscapes (figure 7).

Figure 6. Mountain pine beetle larvae and galleries

Figure 7. Aerial view of severe tree mortality in lodgepole pine caused by mountain pine beetle

In epidemic years, mountain pine beetle outbreaks may move upward in elevation from lower-elevation forests into whitebark pine habitat (Bartos and Gibson 1990). Historically, mountain pine beetle was the primary agent of natural mortality in whitebark pine (Perkins and Roberts 2003). A widespread mountain pine beetle epidemic in the early 1900s ravaged whitebark pine in the western United States (Logan and Powell 2001), leaving a legacy of weathered old standing whitebark pine snags ("grey ghosts") (figure 8).

Figure 8. Old whitebark pine snag, Okanogan National Forest

Mountain pine beetles tend to preferentially attack larger diameter trees (Perkins and Roberts 2003). For whitebark pine, this means that large, cone-bearing trees less vulnerable to mortality from white pine blister rust are susceptible to mountain pine beetle attack, further threatening the cone-bearing and hence the regeneration capacity of whitebark pine populations. In addition, there is growing concern that global warming may result in both increased mountain pine beetle activity and improved success of mountain pine beetle in high-elevation ecosystems (Logan and Powell 2001).

Mistletoe

While considerably less significant range-wide than mountain pine beetle or white pine blister rust, dwarf mistletoe (figure 9) can still have a marked impact on whitebark pine stands on a local scale, contributing to stand mortality and decreasing the fitness of affected trees (Tomback, Arno, and Keane 2001).

Figure 9. Dwarf mistletoe on whitebark pine, Crater Lake National Park, Oregon

Materials and methods

Study Area

In 2004 and 2005, we conducted surveys on eight national forests in Washington and Oregon: the Colville, Okanogan, and Wenatchee national forests in Washington, and the Mt Hood, Willamette, Deschutes, Winema, and Fremont national forests in Oregon. Figure 10 displays the two-state region, and the boundaries of national forests and national parks in those states, and figure 11 shows study site locations. Of the 29 stands surveyed, 4 were on the Colville National Forest in the Selkirk Mountain Range in northeastern Washington; 21 were distributed throughout the Cascade Mountains, from the north end of the Okanogan National Forest in Washington (Gabril Creek) to the southern part of the Winema National Forest in the south (Pelican Butte); and 4 were in the northern Warner Range, on the Fremont National Forest east of the Cascades in southern Oregon. Survey site elevations ranged from 1,770 to 2,400 meters (5,800 to 7,860 feet). Site selection was non-random and was based on distribution across the two states, known presence of whitebark pine, and accessibility. Most sites were within a few kilometers of a drivable road. Access to survey sites in wilderness or roadless areas required one-way hikes of up to 24 kilometers (Gabril Creek).

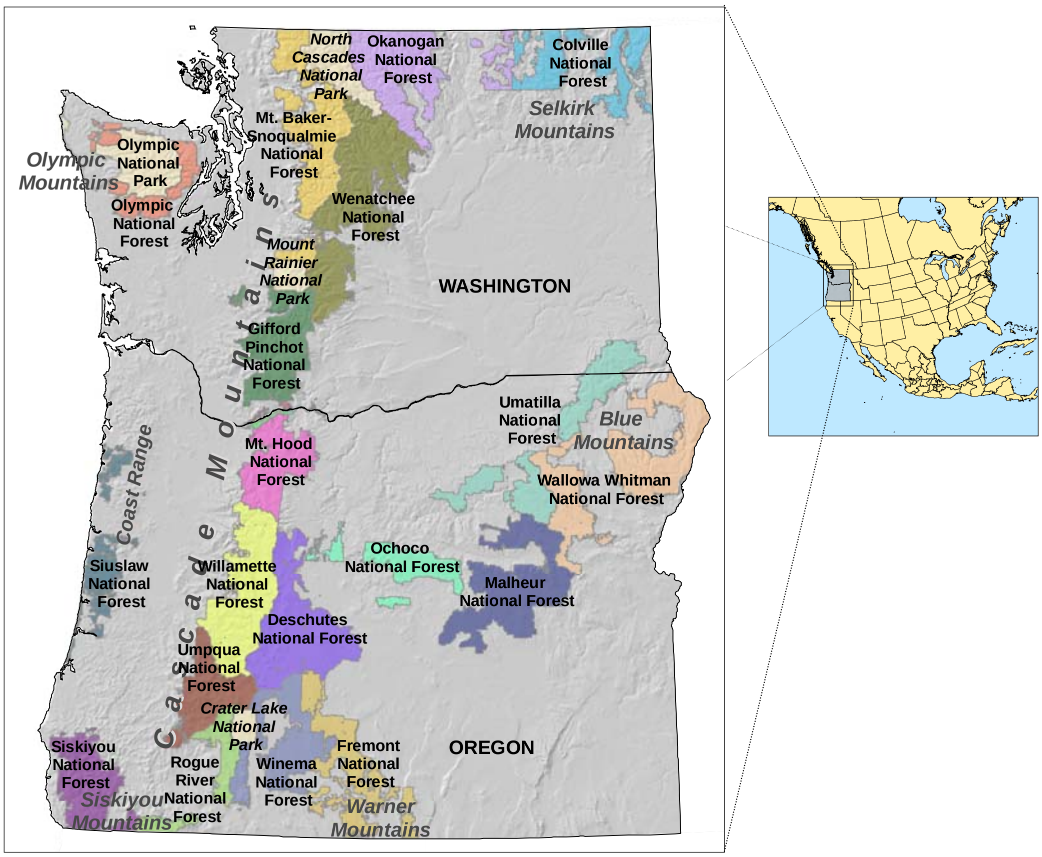

Figure 10. Map of Oregon and Washington showing major mountain ranges, national parks, and national forests

The stands surveyed varied from open-canopy stands dominated by whitebark pine (Lake Augusta, Ollalie Butte) to relatively dense, mixed-species stands (Three Fools Pass, Lake Ethel). No surveys were conducted on sites that were dominated by the shrubby krummholz form of whitebark pine.

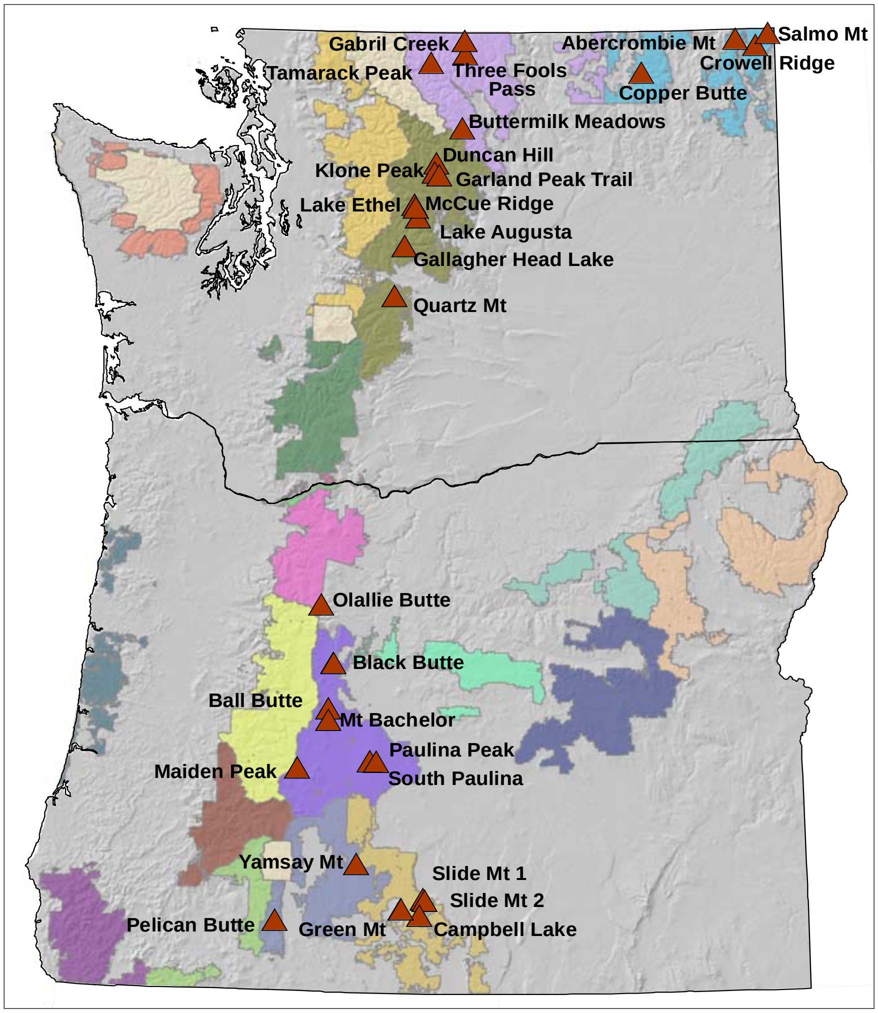

Figure 11. Study site locations

Methods

Surveys consisted of 10 meter-wide belt transects. The survey protocol was similar to that of Smith and Hoffman (1998) and to the survey methods promoted by the Whitebark Pine Ecosystem Foundation (2004). One transect was conducted in each stand. Each transect was placed in a representative portion of the overall stand. Transect length was allowed to vary from a fixed minimum of 50 meters to whatever length was necessary to incorporate a minimum of 50 whitebark pine trees 1.4 meters (4.5 feet) tall and taller, of which at least 30 were alive. At each survey site we recorded elevation, slope, and aspect; total overstory tree cover and percent overstory cover by species; and identity of dominant undergrowth (non-tree) plant species. GPS coordinates were recorded at the beginning and end of each transect. Within each transect, all whitebark pine trees 1.4m in height or taller were closely observed and the following data recorded:

- diameter at breast height (dbh, 1.4 meters (4.5 feet) above ground level);
- tree status (live or dead), and cause of death if dead;
- presence and severity of blister rust branch and bole cankers on live trees;
- evidence of recent or current mountain pine beetle infestation on live and dead trees (active infestation, pitch tubes, frass, the characteristic "J"-shaped galleries beneath the bark of recently killed trees)
- presence of dwarf mistletoe (*Arceuthobium* sp.) infestation.

Field crews recorded the presence of white pine blister rust, mountain pine beetle, and mistletoe only if symptoms were definitive. For dead trees, if mortality was not clearly attributable to white pine blister rust or mountain pine beetle, cause of death was recorded as "unknown."

We also conducted a seedling survey in each transect. All living and dead whitebark pine seedlings (trees less than 1.4m tall) encountered within the transect were counted, and live whitebark pine seedlings were coded for blister rust.

White pine blister rust infections (cankers) were rated according to the Forest Service's FSVEG blister rust severity ratings (table 1). In this system, cankers are ranked by their distance from the bole of the tree. Code 1 and 2 cankers are the least severe, each canker affecting only a single branch. Code 3 and 4 cankers are likely to be eventually lethal to the infected tree. Each tree or seedling on which blister rust was detected received a single rating based on the most severe infection observed.

Table 1. FSVEG Damage Agent Severity Ratings for white pine blister rust*

Severity	Description
1	Branch infections located greater than 60 centimeters (24 inches) from bole
2	Branch infections located between 15 centimeters (6 inches) and 60 centimeters (24 inches) from bole
3	Bole infections or branch infections located within 15 centimeters (6 inches) of bole
4	Topkill due to blister rust

** Adapted from USDA Forest Service 2005, p.2-305*

Results

Summary

Table 2 summarizes transect length, number of trees observed, tree diameter, tree status, white pine blister rust infection in live trees, and mountain pine beetle symptoms in all trees for each transect. For consistency, transect data in tables and figures in this report are arranged geographically from the northernmost survey site (Salmo Mt, Colville National Forest) to the southernmost (Pelican Butte, Winema National Forest), with the exception that the four Colville National Forest sites in the Selkirk Mountains of northeast Washington are grouped together (Salmo Mt, Abercrombie Mt, Crowell Ridge, Copper Butte).

Table 2. Summary of survey data by transect

	Transect location						Tree status		Blister rust infection (percent of live trees)	Mountain pine beetle infestation (percent of all trees)
Site name	National Forest	UTM* Northing	UTM* Easting	Transect Length (m)	Number of trees	Mean dbh (cm)	Live (percent of all trees)	Dead (percent of all trees)		
Salmo Mt	Colville	5440126	931664	262	38	9.1	78.9	21.1	23.3	0.0
Abercrombie Mt	Colville	5434446	906646	61	51	8.1	80.4	19.6	26.8	0.0
Crowell Ridge	Colville	5430362	922628	50	67	5.6	67.2	32.8	31.1	0.0
Copper Butte	Colville	5403970	833592	50	69	7.9	79.7	20.3	43.6	0.0
Gabril Creek	Okanogan	5424037	693534	188	85	9.0	94.1	5.9	46.3	0.0
Three Fools Pass	Okanogan	5413571	694251	50	71	4.9	70.4	29.6	54.0	0.0
Tamarack Peak	Okanogan	5405395	667557	50	55	6.1	54.5	45.5	73.3	0.0
Buttermilk Meadows	Okanogan	5353285	694516	153	37	22.1	86.5	13.5	31.3	0.0
Duncan Hill	Wenatchee	5324308	674956	50	73	20.3	79.5	20.5	25.9	0.0
Garland Peak Trail	Wenatchee	5316799	673722	104	104	7.7	73.1	26.9	43.4	0.0
Klone Peak	Wenatchee	5314598	677687	70	59	7.2	86.4	13.6	13.7	0.0
Lake Ethel	Wenatchee	5289996	658834	50	87	8.7	78.2	21.8	41.2	0.0
McCue Ridge	Wenatchee	5287733	660163	50	94	6.9	80.9	19.1	52.6	0.0
Lake Augusta West	Wenatchee	5279645	662092	50	109	10.2	52.3	47.7	26.3	0.0
Gallagher Head Lake	Wenatchee	5256090	652192	50	46	7.9	82.6	17.4	36.8	0.0
Quartz Mt	Wenatchee	5215516	646056	52	52	18.4	65.4	34.6	26.5	0.0
Ollalie Butte	Mt Hood	4963616	597693	50	102	7.7	68.6	31.4	35.7	0.0
Black Butte	Deschutes	4916639	608923	82	77	18.6	39.0	61.0	26.7	11.7
Ball Butte	Deschutes	4879478	606437	50	80	15.3	81.3	18.8	15.4	26.3
Mount Bachelor	Deschutes	4870396	606497	50	101	12.8	93.1	6.9	12.8	0.0
Paulina Peak	Deschutes	4838291	640467	50	67	18.3	64.2	35.8	4.7	28.4
South Paulina	Deschutes	4837815	645610	50	83	4.5	97.6	2.4	0.0	1.2
Maiden Peak	Willamette	4830808	583518	50	149	14.2	72.5	27.5	24.1	1.3
Yamsay Mt	Winema	4754265	632954	84	66	21.5	95.5	4.5	0.0	4.5
Slide Mt 1	Fremont	4727737	686490	50	66	10.0	87.9	12.1	0.0	25.8
Slide Mt 2	Fremont	4726545	687735	50	55	10.3	94.5	5.5	0.0	3.6
Green Mt	Fremont	4718909	669252	50	81	10.0	98.8	1.2	0.0	0.0
Campbell Lake	Fremont	4714437	683943	50	90	7.4	98.9	1.1	0.0	0.0
Pelican Butte	Winema	4706940	570118	50	93	15.5	88.2	11.8	24.4	0.0

** Map coordinates of transect origin: Universal Transverse Mercator, Zone 10N; North American Datum 1927*

Transect length and number of trees observed

Across all survey sites, a total of 2207 trees 1.4 meters tall and taller were observed. Final transect length depended on the density of whitebark pine in the stand. Twenty transects were 50 meters long. The nine longer transects ranged from 52 meters to 262 meters. In three cases less than the minimum number of trees (50 trees of which at least 30 were live) was encountered: severe weather caused the survey crew to terminate the transect at Gallagher Head Lake (37 trees, 32 live) and at Buttermilk Meadows (46 trees, 38 live); and the transect at Salmo Mountain was terminated due to time constraints (38 trees, 30 live). Because all 29 transects met the requirements of a minimum length of 50 meters and contained a minimum of 30 live whitebark pine trees 1.4 meters tall or taller, data from all the transects were used in this report. The number of whitebark pine trees observed in each transect ranged from 37 to 149 with an average of 76.1.

Tree diameter

Diameter at breast height ("dbh," measured at 1.4 meters or 4.5 feet) ranged from 0.25 centimeters (0.1 inch) to 91.4 centimeters (36.0 inches), with an average of 11.1 centimeters (4.4 inches). Figure 12 shows minimum, maximum, and average tree diameters by transect. Study-wide, diameter distributions of live and dead trees were similar. In all transects, smaller diameter trees made up a greater proportion of the trees observed than did larger diameter trees.

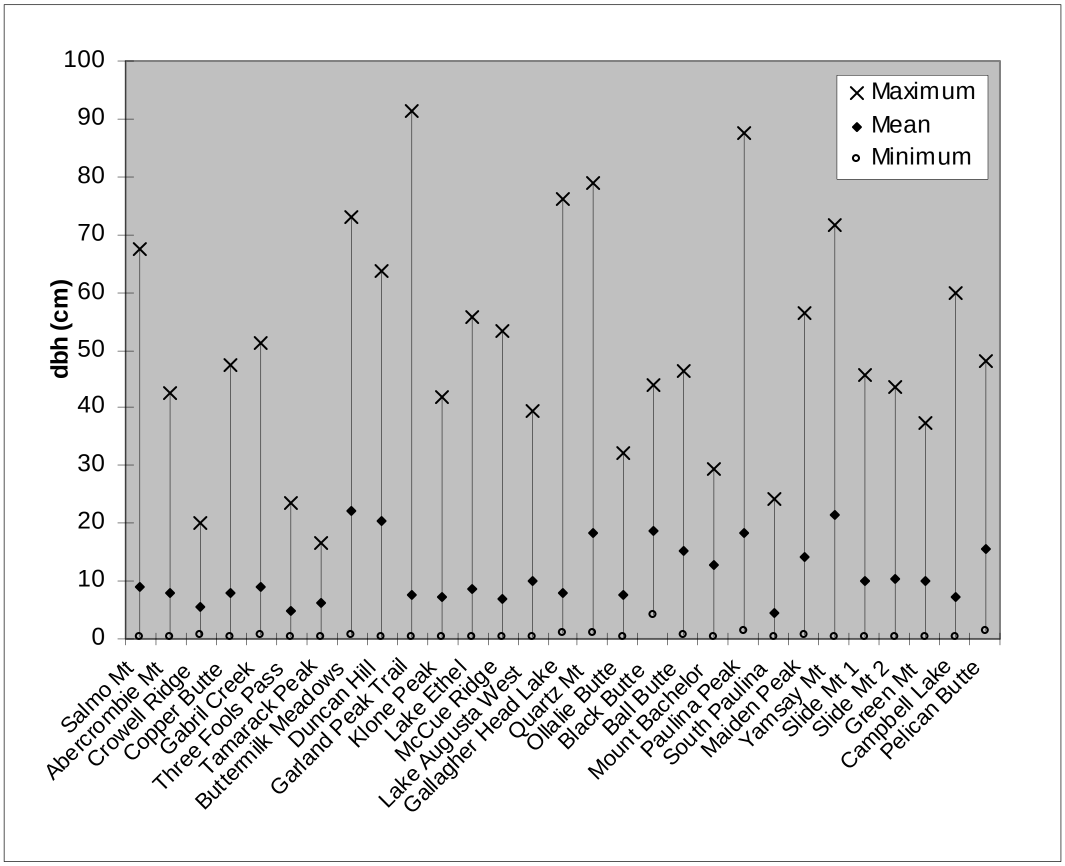

Figure 12. Maximum, minimum, and mean tree diameters

Environmental conditions in whitebark pine's high-elevation habitat can vary considerably from stand to stand (Weaver 2001; Arno 2001). While tree diameter data provide a sense of the structure and appearance of an individual stand, diameter is not a reliable surrogate for tree or stand age comparisons between different locations (King 2005). Given the harsh, exposed conditions of many whitebark pine stands–steep, rocky, windswept sites with short annual frost-free periods–some trees may be considerably older than their relatively small diameters might imply, while younger whitebark pines on more moderate or protected sites may be a great deal larger.

Mortality and cause of death

Of the 2,207 trees observed across all transects combined, 21.3 percent (471 trees) were dead. Cause of death is often difficult to determine, especially for older dead or "grey ghost" trees that have been dead long enough to have lost their bark and most of their fine branch structure. Field observers attributed cause of death to blister rust or mountain pine beetle only if there was definitive evidence to support that conclusion, so the values reported here are very conservative.

Of the 471 dead trees, it was clearly evident that 19.7 percent (93 trees) had been killed by white pine blister rust and 3.4 percent (16 trees) by recent mountain pine beetle infestation. The cause of mortality for the remaining dead trees was recorded as unknown. By transect, the percentage of trees that were dead ranged from 1.1 percent (Campbell Lake) to 61.0 percent (Black Butte), with a median of 19.6 percent (figure 13).

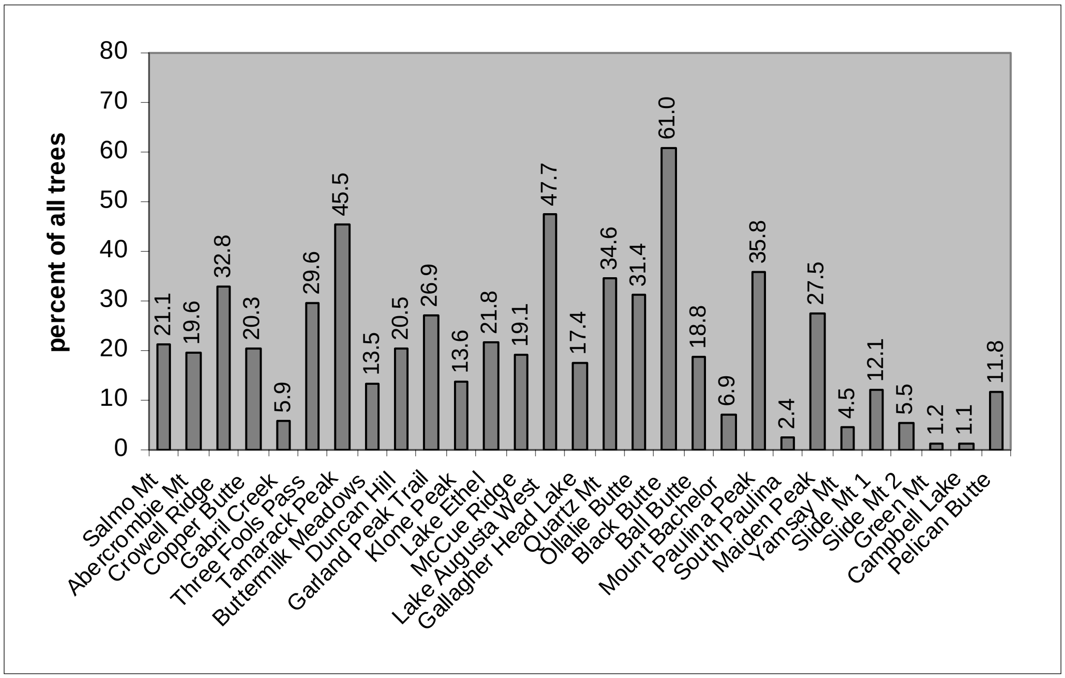

Figure 13. Mortality from all causes

White pine blister rust infection and severity

Across all transects combined, white pine blister rust branch or bole cankers were observed on 23.9 percent of live whitebark pine trees (416 of 1736 live trees). Blister rust infections in live trees were observed in 23 of the 29 transects (figure 14). Infection rates in those 23 transects ranged from 4.7 percent (Paulina Peak) to 73.3 percent (Tamarack Peak), with a median of 26.8 percent. The lowest infection rates were found in the southern part of the study area. Of the 6 transects in which no rust was found, 5 (Yamsay Mt, Slide Mt 1, Slide Mt 2, Green Mt, and Campbell Lake) are in the southern portion of the Cascades in Oregon, or in the Warner Range slightly to the east. The other (South Paulina,) is slightly north, but also in the southern Oregon Cascades.

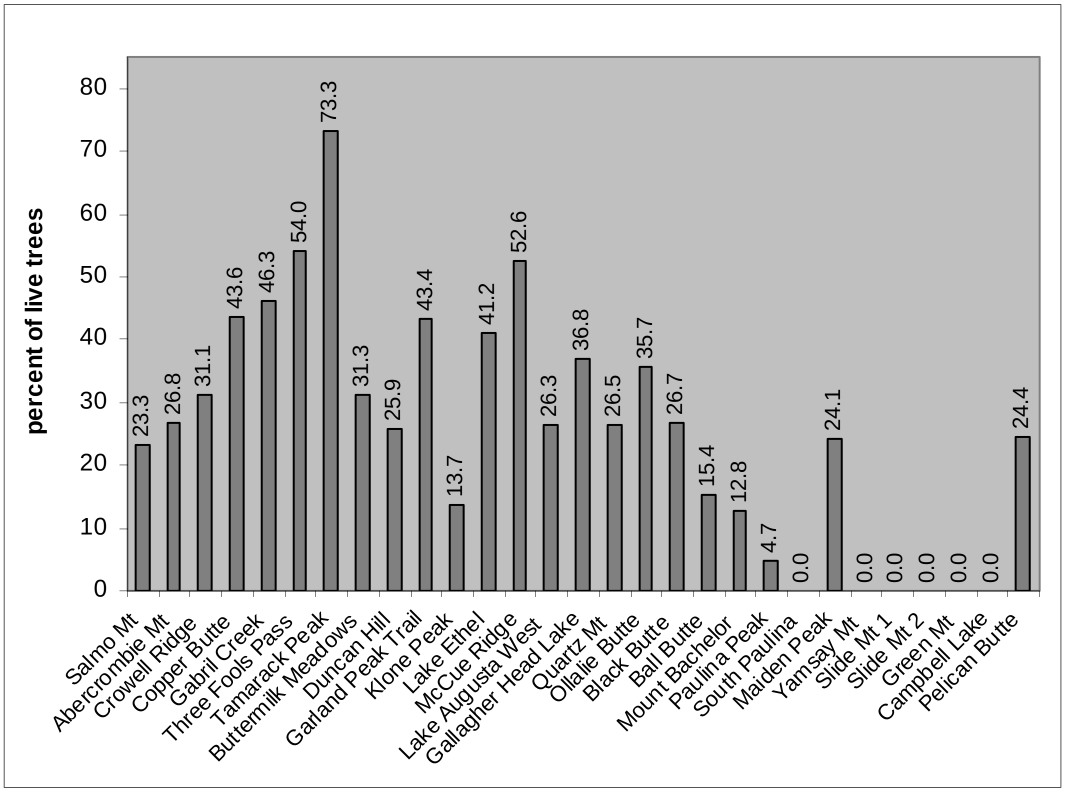

Figure 14. White pine blister rust infection in live trees

Many of the live trees on which white pine blister rust cankers were detected had multiple infections. Each tree received a single rating based on the most severe infection observed (see table 1 above). Table 3 displays the distribution of severity ratings for all 416 infected trees. A similar distribution of canker severity occurred within transects in which blister rust infection was observed.

Table 3. FSVEG severity codes for most severe white pine blister rust cankers observed

Severity code*	Number of infected trees	Percent of infected trees
1	16	3.8
2	38	9.1
3	179	43.0
4	183	44.0

** See table 1 for severity code descriptions*.

Tree status, blister rust infection, and cause of death

Figure 15 depicts tree status, blister rust infection, and cause of death for dead trees. This figure is presented to provide a sense of the distribution of tree status and condition within each transect and for comparison between transects. To allow the columns in Figure 15 to total 100 percent of the trees observed in each transect, each of the 5 data categories displayed has been calculated as the percent of all trees, live and dead combined, encountered within each transect. Hence, the values for blister rust infection depicted in Figure 15 are slightly lower than the rates of blister rust infection in live trees reported in Table 2 and in figure 14.

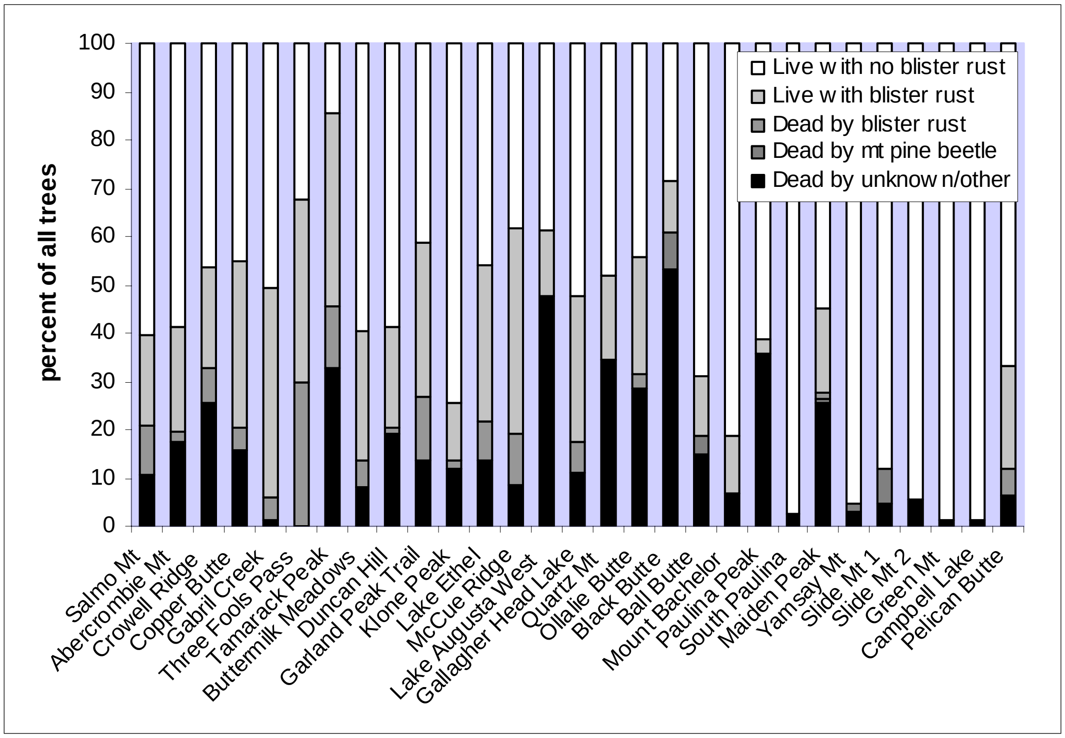

Figure 15. Tree status, blister rust infection, and cause of death as percent of all trees observed

Mountain pine beetle infestation

Current or recent mountain pine beetle infestation was observed in 8 of the 29 transects (figure 16). All 8 of these transects were in Oregon. Rates of infestation for those 8 transects ranged from 1.2 percent (South Paulina) to 28.4 percent (Paulina Peak) of all trees observed. Of the study-wide total of 74 affected trees, 43 were still living or recently dead, and 31 were older dead. In contrast to the overall average tree diameter of

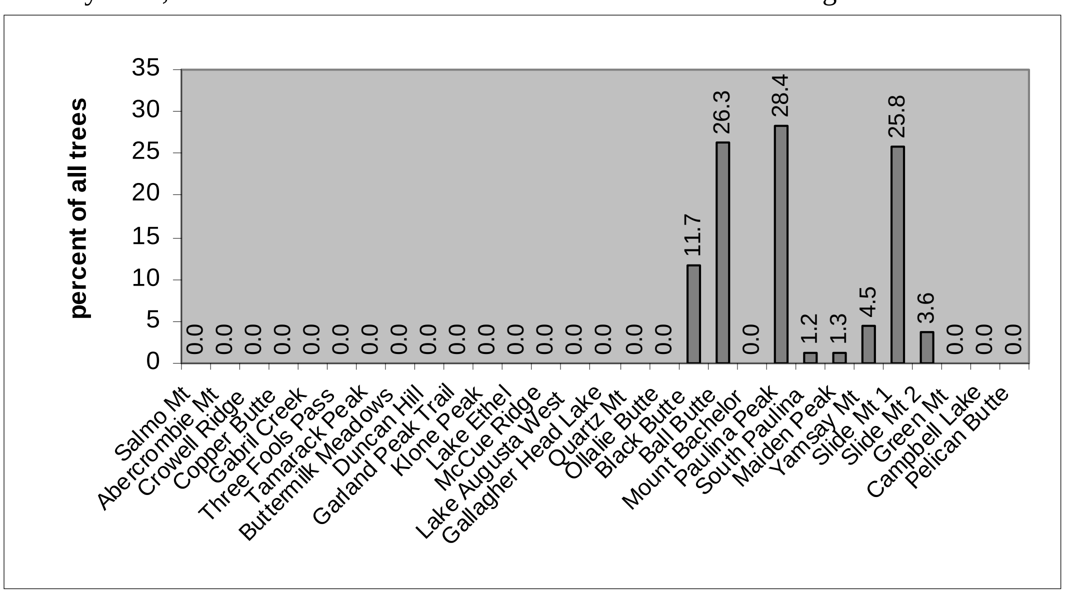

Figure 16. Recent mountain beetle activity in all trees

11.1 centimeters (4.4 inches) for all transects combined, the average diameter of trees with current or recent mountain pine beetle infestation was 25.2cm (9.9in). This is consistent with the observation made by Perkins and Roberts (2003) that mountain pine beetles preferentially attack larger diameter trees.

Mistletoe

A high incidence of dwarf mistletoe was reported on whitebark pine at one site, South Paulina, on the Deschutes National Forest in Oregon. Mistletoe was present on 25 (30.1 percent) of the 83 trees observed. Mistletoe was not observed on whitebark pine in any of the other transects.

Seedling survey

Seedlings (defined as trees less than 1.4 meters tall) were encountered in 28 of the 29 transects, with an study-wide total of 1,385 seedlings observed (Table 4). No seedlings were encountered in the Buttermilk Meadows transect. The number of seedlings in the

Table 4. Summary of seedling survey data

Site name	Number of seedlings observed	Number of live seedlings without blister rust	Number of live seedlings with blister rust	Blister rust infection (percent of live seedlings)	Number of seedlings dead from blister rust	Number of seedlings dead from other causes
Salmo Mt	13	7	2	22.2	3	1
Abercrombie Mt	24	21	2	8.7	0	1
Crowell Ridge	59	51	4	7.3	4	0
Copper Butte	6	3	0	0.0	2	1
Gabril Creek	24	21	3	12.5	0	0
Three Fools Pass	43	30	2	6.3	6	5
Tamarack Peak	8	6	2	25.0	0	0
Buttermilk Meadows	0	-	-	-	-	-
Duncan Hill	15	14	1	6.7	0	0
Garland Peak Trail	58	49	5	9.3	3	1
Klone Peak	27	27	0	0.0	0	0
Lake Ethel	110	98	5	4.9	7	0
McCue Ridge	125	116	7	5.7	1	1
Lake Augusta West	54	51	0	0.0	0	3
Gallagher Head Lake	34	30	1	3.2	2	1
Quartz Mt	47	41	2	4.7	3	1
Ollalie Butte	93	60	27	31.0	4	2
Black Butte	9	9	0	0.0	0	0
Ball Butte	25	25	0	0.0	0	0
Mount Bachelor	53	53	0	0.0	0	0
Paulina Peak	80	80	0	0.0	0	0
South Paulina	208	208	0	0.0	0	0
Maiden Peak	44	44	0	0.0	0	0
Yamsay Mt	49	49	0	0.0	0	0
Slide Mt 1	14	14	0	0.0	0	0
Slide Mt 2	25	25	0	0.0	0	0
Green Mt	68	68	0	0.0	0	0
Campbell Lake	48	48	0	0.0	0	0
Pelican Butte	22	17	4	19.0	1	0

other transects varied widely, with a maximum of 208 at South Paulina and a minimum of 6 at Copper Butte. Seedlings ranged in height from a few centimeters to just under 1.4 meters. Study-wide, blister rust infection in live seedlings was low: 5.0 percent. Mortality was also low: 3.8 percent, although two-thirds of this mortality was attributed to blister rust. Cause of death is easier to determine in smaller trees than in larger trees, so the proportion of cases in which the cause of death was unknown was much lower in the seedling survey than for the trees 1.4 meters tall and taller.

Although the seedling sample sizes varied widely from transect to transect, white pine blister rust infection in live seedlings roughly paralleled that in live trees 1.4 meters tall and taller, with the lowest rates of infection on the east side of the Cascades in southern Oregon, and in the Warner Range (figure 17).

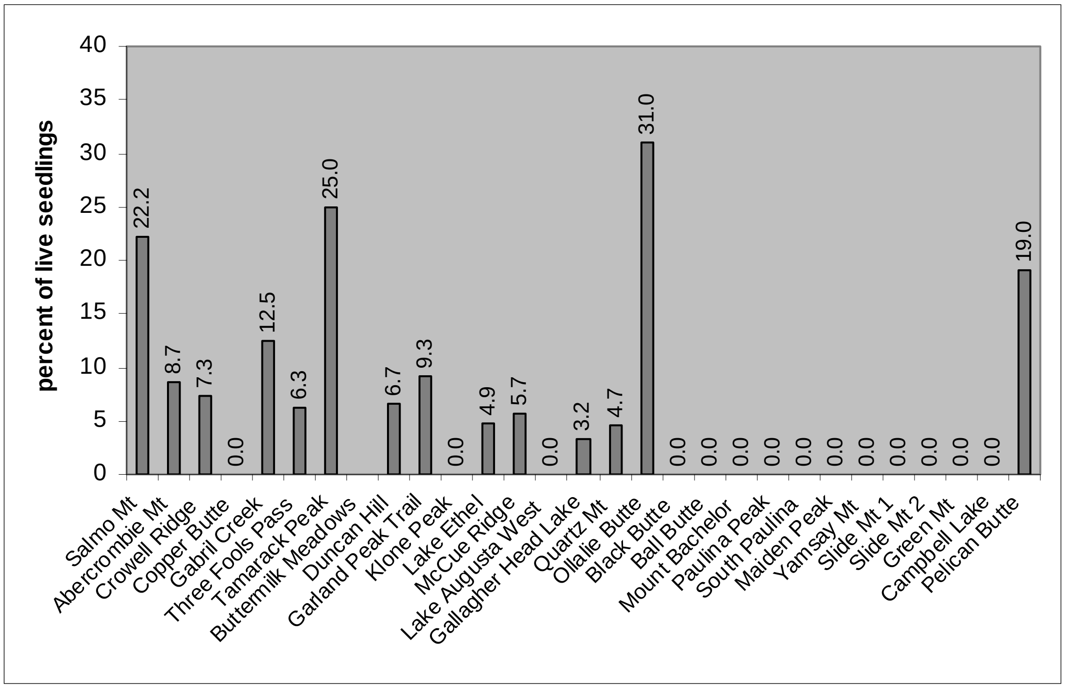

Figure 17. White pine blister rust infection in live seedlings

Discussion

Study design

This study was designed to provide a snapshot of current whitebark pine health on National Forest System lands in Washington and Oregon. The non-random site selection prompted concerns about potential confounding influences, particularly as a result of soil and vegetation disturbances that might be associated with roads, trails, or established camping areas. To minimize any potential impacts, transects were located away from roads and other disturbed areas. In the few instances where transects intersected trails, transect dimensions were adjusted as necessary to exclude the width of the trail corridor itself.

White pine blister rust

The white pine blister rust infection rates in whitebark pine reported in this study are comparable to rates recently reported by others in the two-state region (Doede 2004, Erickson 2004, Goheen et al. 2002, Murray 2005, Murray and Rasmussen 2003, Shoal and Aubry 2004).

A trend toward lower rates of white pine blister rust infection in whitebark pine in southern Oregon, east of the Cascade Crest on the Deschutes and Fremont-Winema National Forests is evident in these 29 transects. Although the correlation is not strong ($R^2 = 0.56$), it concurs with field observations that incidence of white pine blister rust on 5-needle pine hosts is rare in that vicinity (Stubbs 2006). However, surveys conducted by the authors in previous years found low rates of blister rust infection–0.0 percent to 10.0 percent–in transects on five similarly dry sites also east of the Cascade Crest but considerably farther north, on the Entiat Ranger District of the Wenatchee National Forest in Washington (Shoal and Aubry 2004). White pine blister rust infection rates in whitebark pine in Oregon and Washington may be influenced more by variations in local environmental conditions such as precipitation, airflow, and topography (Quick 1962) than directly by latitude, with generally lower infection rates associated with extremely dry local conditions. Figure 18 displays blister rust infection rates in live trees observed in this study against a background of average annual precipitation.

The deciduous host plants of white pine blister rust are widespread throughout the region, and it can be reasonably assumed that the wide-ranging aeciospores of *C. ribicola* are ubiquitous in the two states. It is likely that the very dry conditions

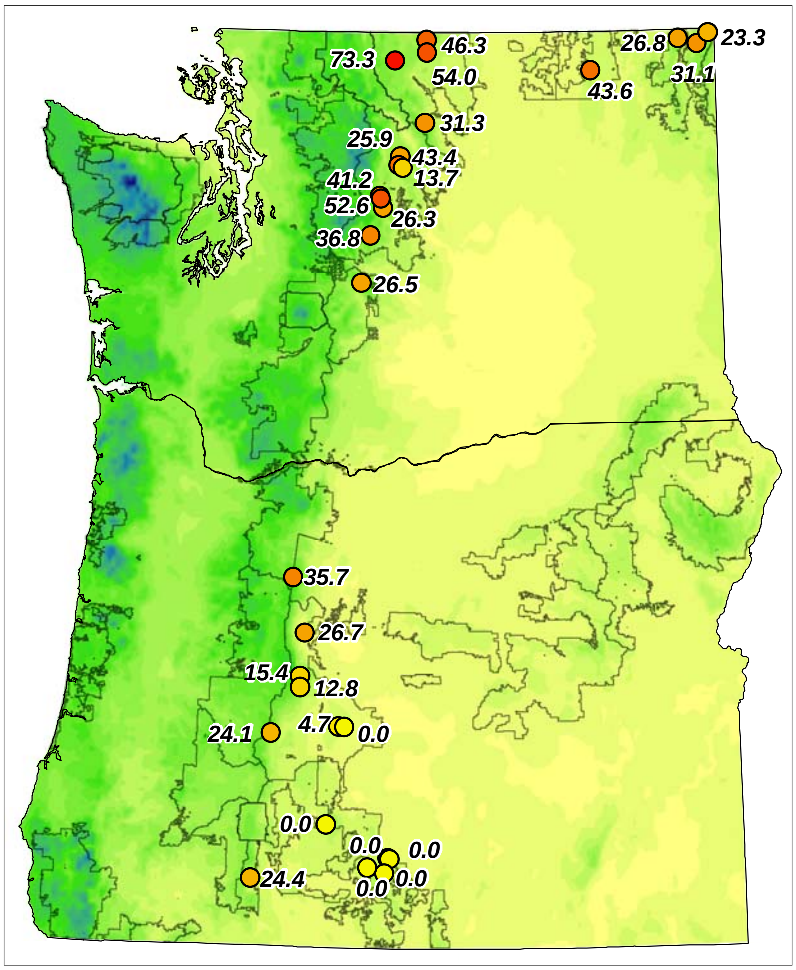

Figure 18. White pine blister rust infection in live trees and average annual precipitation. Precipitation (inches per year) ranges from 5 (pale yellow) to 270 (dark blue). Blister rust infection by transect ranged from 0.0 percent (gold) to 73.3 percent (red) of live trees observed.

prevalent in southeastern Oregon and some portions of the eastern Cascades in Washington are not conducive to successful development, dissemination, and germination of basidiospores on five-needle pine hosts (Van Arsdel et al. 1956), while wetter sites closer to the Cascade Crest more regularly experience the combination of high humidity and low temperatures required for basidiospore success. Correspondingly, in this study there is also a general trend toward higher rates of infection near and west of the Cascade Crest and in Washington's northern Cascades, where conditions are often cool and humid. All 9 sites with rates of white pine blister rust infection greater than 35 percent of live trees follow this pattern. Where infection rates are currently lowest, it is possible that a single extended period of unusually cool and damp conditions occurring while infections on the deciduous hosts of *C. ribicola* are capable of producing basidiospores could result in a "wave year" (Kinloch 2003) of white pine blister rust infection in five-needle pines, with cankers growing to detectable size in a few years.

The prevalence of code 4 (topkill) infections means that the crowns of at least 10.5 percent of the 1746 live trees observed in this study have been killed by white pine blister rust. This translates into a significant reduction in the cone-bearing potential of the species in the study area, especially in the areas with the highest rates of blister rust infection. Assuming that most of the code 3 (bole) infections will intensify into code 4 infections, the cone-bearing potential of an additional 10.3 percent of existing live trees is also at risk. With at least 4.2 percent (93) of the 2207 trees observed having died as a result of white pine blister rust, a minimum of 24.9 percent of the trees in this study have been severely adversely impacted by white pine blister rust. The actual numbers are likely to be considerably higher, especially in the realm of tree mortality.

Mountain pine beetle

All recent mountain pine beetle activity encountered in this study occurred in Oregon, with the highest rates in the drier portions of the state. While no recent mountain pine beetle infestation was recorded in the transects on the Okanogan and Wenatchee National Forests, significant recent mountain pine beetle activity was observed in whitebark pine in stands visible from both the Lake Augusta (figure 19) and Lake Ethel sites, and at several other locations during the 2005 season. Surveys conducted in previous years documented the presence of current or recent mountain pine beetle activity in whitebark pine in 10 of 28 survey transects in other stands on these forests (Shoal and Aubry 2004). These observations negate any apparent trend in the current study toward an absence of mountain pine beetle impacts to whitebark pine on the more northerly forests. Our

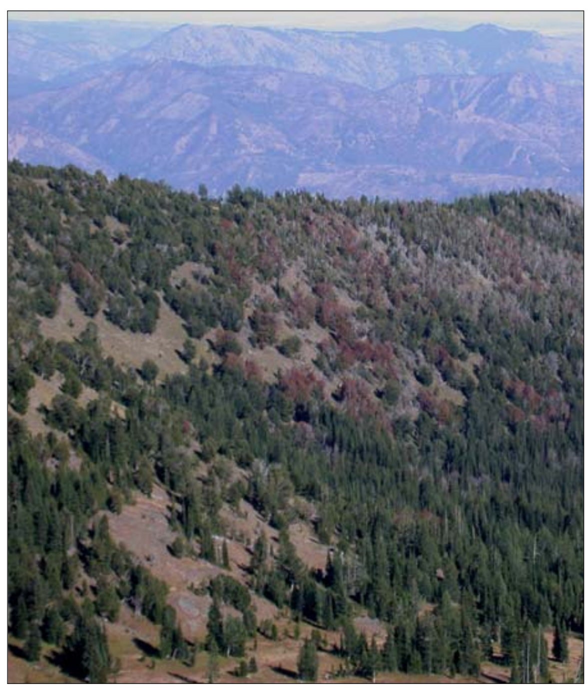

Figure 19. Mountain pine beetle in whitebark pine near Lake Augusta, Wenatchee National Forest, 2005

observations that mountain pine beetle infestation in whitebark pine is increasing in Oregon and Washington are supported by recent observations in Crater Lake National Park (Murray 2006). It is likely that the 31 older dead trees observed in the current study were killed by mountain pine beetle, and that many of the long-dead whitebark pine "grey ghosts" across the two states succumbed to mountain pine beetle during the widespread epidemics of the early 1900s (Perkins and Roberts 2003).

Mistletoe

Dwarf mistletoe is not currently widespread in whitebark pine in Oregon and Washington, and it does not appear to pose an immediate threat to the species as a whole. However, on sites where it does occur, like the South Paulina site in this study, it can have a significant negative impact.

Seedling survival

The number of whitebark pine seedlings observed varied widely from transect to transect, and generally corresponded with the forest type encountered on the site. The only transect within which no whitebark pine seedlings were encountered (Buttermilk Meadows) was conducted on a site that supported a mature, mixed-species stand with a high canopy cover. Whitebark pine was a minor component of this stand, which contained few seedlings of any species. Sites having the most seedlings tended to be open stands dominated by whitebark pine, and with a relatively loose, rocky substrate. White pine blister rust infection in live seedlings followed a weak geographic trend similar to that of infection in trees 1.4 meters tall and taller. Although infection rates were low compared to those in larger trees, white pine blister rust was the leading cause of mortality in these young trees (figure 20).

Figure 20. Whitebark pine seedling killed by blister rust, Colville National Forest

Conclusion

The levels of infection and mortality due to white pine blister rust along with the increasing occurrence of mountain pine beetle in whitebark pine threaten the reproductive and regenerative potential of whitebark pine across Oregon and Washington. Where white pine blister rust and mountain pine beetle occur simultaneously, the species is especially at risk from the combined impacts of these two damaging agents. While health assessments should continue, it is imperative that we address the need to conserve and restore whitebark pine communities as soon as possible. The next logical step for the Pacific Northwest is the development of a conservation strategy: a management plan that prescribes standards and guidelines that if implemented provide a high likelihood that the species will continue to exist well-distributed throughout the planning area (Streamnet 2006). In order for this plan to be successful, it must be followed by the development of a restoration guide for land managers. This guide would provide decision making guidelines for prioritizing whitebark pine stands and selecting restoration techniques

(Jenkins 2005, Vesely and Tucker 2004). Non-fire-related restoration techniques include planting locally-collected seed or seedlings grown from local seed collections, planting locally-adapted rust-resistant whitebark pine seedlings, and girdling or thinning competing vegetation (Tomback et al. 2001). Given the challenges we will encounter in implementing these techniques, it is imperative that we evaluate all options before committing limited available resources.

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