



Klamath Network Whitebark Pine Pilot Study, Crater Lake National Park 2009



ON THE COVER

White pine blister rust (*Cronartium rubicola*) infection on whitebark pine tree, Crater Lake National Park, 2009.

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Abstract

In summer 2009, the Klamath Network Inventory and Monitoring Program conducted a pilot study at Crater Lake National Park to test the feasibility of co-locating whitebark pine monitoring with its broader vegetation monitoring protocol, and to compare present vs. past incidence of white pine blister rust, mountain pine beetle, and mistletoe on whitebark pine. The study also employed a rapid assessment approach for whitebark pine and evaluated two plot sizes for sampling. We found that sampling a plot for both whitebark pine and the vegetation protocol could be done in a day with ample time for travel to plots up to 1 km from a road or trail. Rapid assessment or smaller plots did not save much time since infection rates were low and cankers easy to count. However, rapid assessment did add information about the portions of whitebark pine trees most susceptible to infections, which were tree boles, particularly the upper portion, not tree crowns, which contrasts with findings in the Rocky Mountains. Active blister rust infections, mountain pine beetle, and mistletoe were all more common in 2009 than in 2001-2003. Factors related to blister rust and whitebark pine mortality were tree density, presence of alternative blister rust hosts (*Ribes* and *Castilleja*), and location of stands in the more humid and moist west side of the park.

Introduction

The Klamath Inventory and Monitoring Network identified both invasive and keystone species as top priorities for monitoring vital signs of ecosystem health. Whitebark pine was identified as a keystone species in subalpine areas of the Rocky Mountains by Tomback et al. (2005). This keystone species is threatened by an invasive pathogen, white pine blister rust (*Cronartium ribicola*), to which it is highly susceptible (MacDonald and Hoff 2001). Compounding the effect of the invasive pathogen are two native species that impact whitebark pine: an insect, mountain pine beetle (*Dendroctonus ponderosae*), and a parasitic plant, dwarf mistletoe (*Arceuthobium* sp.). Mountain pine beetle, in particular, has become an increasing threat to high elevation pines in the western US, likely due to climate change (Carroll et al. 2003). While the direct effects of climate change on the alpine tree-line ecotone whitebark pines inhabit maybe difficult to interpret (Kupfer and Cairns 1996, Walther et al. 2005), we can still gain valuable information from monitoring such ecotones (Kupfer and Cairns 1996). The Klamath Network also identified structure, function, and composition of vegetation as a vital sign. Therefore, it makes sense to co-locate planned high elevation vegetation and whitebark pine monitoring, especially considering the need to maximize the Network's limited monitoring resources.

The Network embarked on a pilot study in 2009 to determine: a) the efficacy of co-locating vegetation and whitebark pine monitoring, b) to test a rapid assessment approach to potentially use in lieu of counting cankers, and c) to evaluate two plot sizes. We selected Crater Lake National Park for the pilot study location, where whitebark pine monitoring from 2001-2003 provides some baseline information (Murray and Rasmussen 2003). The information on changes in whitebark pine mortality and infection percentage and dynamics at Crater Lake helps us understand the potential threats to this tree species and thus provides a basis to evaluate our rationale for selecting whitebark pine as a vital sign for monitoring. The information will also be of interest to park staff and partners, and other networks collaborating on five needle pine monitoring protocols.

Methods

Site Selection

To ensure even geographic coverage in sampling, we divided the park into four quadrants (NW, NE, SW, SE). We then stratified each quadrant into two elevation zones: above solid tree line (generally the highest elevation area immediately adjacent to the Crater Lake caldera) and below solid tree line (Figure 1). Our intention was to place three sites above and below solid tree line in each quadrant. After examining whitebark pine sites monitored by the park in the past and consulting with park experts, we navigated to known whitebark pine populations in each quadrant and visually searched on foot until a whitebark pine stand with ≥ 10 live and dead trees > 15 cm dbh (diameter at breast height = 1.4 m), within a predetermined plot size (either 10 x 50 m or 20 x 50 m, see Field Sampling section) was encountered. Then a random starting place was selected using a blind toss of a chaining pin. Not all quadrants contained an equal number of stands, nor were stands equally distributed above and below solid tree line; whitebark pine populations were clustered in the Southeast and Northwest quadrants and were typically above solid tree line (Figure 1).

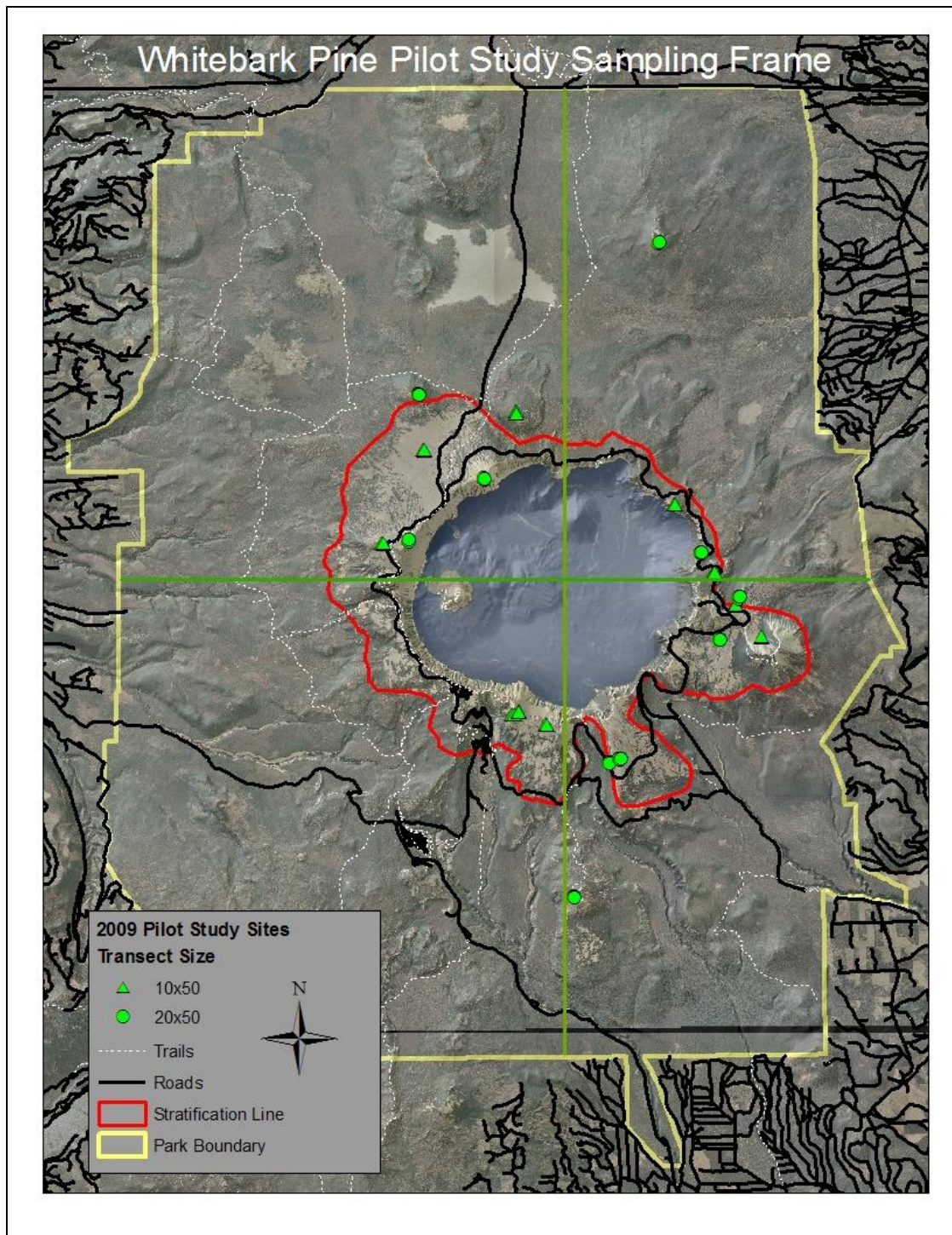


Figure 1. Sampling frame and location of sample sites in the Klamath Inventory and Monitoring Network whitebark pine monitoring pilot study.

Field Sampling

Trees were sampled using two plot sizes: a 10 x 50 m rectangular plot or a 20 x 50 m plot that consisted of two adjacent 10 x 50 m plots. The 20 x 50 m plot (or 0.1 ha) is the Network's standard vegetation monitoring (Odion et al. 2011) plot size (Figure 2) All plots were divided into 10 x 10 m modules (5 or 10), with two intensive modules per 10 x 50 m area and four per 20 x 50 m vegetation plot (Figure 2). Field sampling methodology was based on the Klamath Network draft vegetation monitoring protocol (Odion et al. 2011), augmented with a combination of blister rust rapid assessment methodology from Six and Newcomb (2005), and the Whitebark Pine Ecosystem Foundation's monitoring protocol (Tomback et al. 2005). Table 1 presents a list of the vegetation parameters measured in association with whitebark pine-specific measures described next.

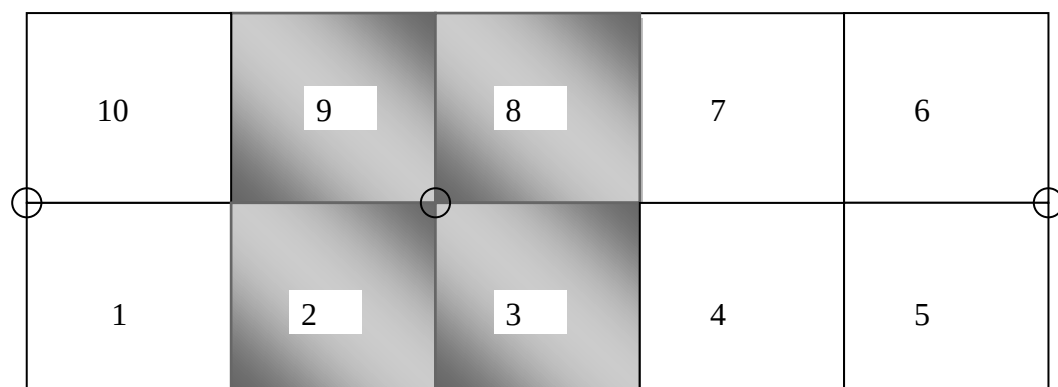


Figure 2. The 20 x 50 m site layout. Each numbered square (module) is 10 x 10 m. Shaded squares are the four intensive modules. A 10 x 50 m site would include squares 1-5 only.

Overstory whitebark pine trees >15 cm dbh were evaluated in all modules of a plot. Understory trees 1.4 m tall but <15 cm dbh were evaluated only in the intensive 10 x 10 m modules, and understory trees <1.4 m tall were evaluated only in 3.16 x 3.16 m submodules nested within the intensive modules.

To evaluate the presence or absence of blister rust and to count cankers on whitebark pines, a two person crew examined trees from all sides using binoculars. In dense patches of krummholz, the crew climbed into the canopy, when deemed safe, to get a better view of branches and boles where cankers are located. Cankers were counted and classified as active or inactive. Active cankers had fruiting bodies present. Following the Six and Newcomb (2005) method, the tree canopy and tree bole were divided into thirds and each third was given a score from 0-3 representing increasing surface area of canopy branches, or the bole occupied/affected by cankers. In this rating system, 0 = no infection, 1 ≤ 25% infected, 2= 25-50% infected, and 3 ≥ 50% infected. Ratings can be evaluated for whole trees or just tree crowns or boles by summing the applicable scores, or for upper, middle, or lower portions of crowns or boles. For whitebark pine < 15 cm dbh, we tallied the number of active, inactive, and uninfected trees. Presence-absence of mistletoe, mountain pine beetle, seed cones, and bark stripping on each whitebark pine >15cm dbh were also visually assessed in each module.

For dead whitebark pine that had not been colonized by bark beetles, but had residual symptoms of blister rust, we ascribed the cause of death to blister rust alone. When dead trees exhibited signs of bark beetle activity, we considered this the cause of death. When dead trees had signs of blister rust and pine beetle, we noted both as the cause of death. When trees had been dead for too long to have evidence of beetles or blister rust (the bark had fallen off), we considered cause of death unknown. Where *Ribes* spp. or *Castilleja* spp. were present at a site, we closely examined five or six leaves per plant, from one or two random individuals from each genus, for signs of blister rust infection.

Table 1. Standard vegetation plot data collected during whitebark pine pilot study.

<u>Standard vegetation monitoring measurements</u>
1. GPS coordinates of transect corners
2. Slope
3. Aspect
4. Elevation
5. Photopoints
6. Microtopography
7. Macrotopography
8. Vascular plant cover by species (four height strata)
9. Ground cover
10. Shrub height
11. Seedlings saplings and small trees, <15cm dbh, by size class
12. Live trees, >15cm dbh, (dbh, height, canopy position and condition)
13. Dead trees (dbh, height, decay class)
14. Fine wood (< 7.6 cm diameter), by size class
15. Coarse wood (> 7.6 cm in diameter, size and decay class)
16. Litter and Duff: (depth/thickness)
<u>Additional measurements on whitebark pine</u>
17. Rapid assessment of blisters rust infection on whitebark pine >15cm dbh
18. Canker counts (bole and branch) on whitebark pine >15cm dbh
19. Presence-absence of mistletoe, mountain pine beetle, seed cones, and bark stripping on whitebark pine >15 cm dbh
20. Presence absence of active or inactive cankers on seedlings and saplings <15cm dbh

Data Analysis

We present summary statistics and other findings in tabular and graphical form. We used two sample independent t-tests to test the following null hypotheses: (1) that the number of trees infected in plots with *Ribes* (or *Castilleja*) are not different from the number of trees in plots lacking these co-hosts; (2) that crown infection rates do not differ from bole infection rates; and (3) that the number of trees infected is not greater on the west vs. east side of the park, as found previously by Murray and Rasmussen (2003). Plots in the SW and NW quadrants of the park were considered western, while those in the NE and SE were considered eastern (Figure 1). The first two of these hypotheses were 2-sided t-tests, and the third was one-sided, the alpha value of all tests was set at 0.05. Because data analyzed were percentages of trees infected in a plot, we arcsine-transformed the data. We then used a t-test for contrasts. We used a non-parametric Kruskal-Wallis test on rapid assessment rankings to test the null hypotheses that there is no difference in blister rust infection among the upper, middle, and lower portions of both tree crowns and boles. We used a chi squared test to test the hypothesis that cone presence on live trees infected with blister rust is no different than on uninfected trees.

Results

We completed a total of 20 plots, ten of each size. A total of 386 live and 118 dead whitebark pine trees >15 cm dbh, and 376 live whitebark pine <15 cm dbh were evaluated.

Time to Complete Sampling

The average time for monitoring each whitebark pine tree was 2-3 minutes. The average time required to complete all plot measurements was 4.6 hrs. The paucity of associated vegetation and species allowed the general vegetation measures to be done more rapidly than most vegetation plots sampled previously (Smith 2008). However, adding the whitebark pine measurements brought the time to complete sampling on par with most vegetation plots. While open grown trees took little time to assess, krummholz trees took up to 10 minutes. Because plot set up time was nearly equal for the two plot sizes, the additional time required to do a 20 x 50 m plot instead of the standard 10 x 50 m plot was mostly a function of additional trees. Mean canker count was highly correlated with infection percent found using the rapid assessment method developed Six and Newcomb (2005) (Figure 3). We qualitatively observed that doing both together took slightly longer than doing either method alone.

Blister Rust Infection

Infection percentages of live whitebark pine trees > 15 cm dbh varied by site (Table 2). Three of the twenty plots had no blister rust infection. The mean blister rust infection for all live trees >15 cm dbh was 25% (range 0-67%). The mean percentage of active cankers was lower than that of inactive cankers, seven and 18%, respectively. Trees >25 cm dbh had a mean infection rate of 30%. The five size categories of whitebark pine <15 cm dbh all had mean infection percentages less than the infection percent of trees >15 cm dbh (Table 3). We did not observe any blister rust infection on the alternative hosts of *Cronartium ribicola*: *Ribes* spp. and *Castilleja* spp. There was a 35% mean infection rate of whitebark pine trees >15 cm dbh in plots where *Ribes* occurred (n = 11) and 12% in plots (n = 9) with no *Ribes*. This difference was significant ($P = 0.006$), and thus, we rejected the null hypothesis that disease level is not different between whitebark pine stands associated with *Ribes* and those without *Ribes*. The relationship between *Castilleja* and blister rust infection was not significant ($P = 0.15$), but there was a 32% mean infection rate on trees <15 cm in plots with *Castilleja* spp. (n = 9) and 19% without (n = 11). When present, *Castilleja* tended to occur with *Ribes* (8 out of 9 plots).

There was no difference between the percentages of trees infected in plots in the western (28.7%, n = 9) versus eastern (21.6%, n = 11) portions of the park. However, active cankers were more common on the west side (11%) vs. the east (4%) ($P = 0.04$). The number of inactive cankers was nearly identical (17.7% vs. 17.5%). We found a significantly higher ($P = 0.002$, $t = -3.14$) rating (Six and Newcomb 2005) of infection in tree boles than in crowns (Figure 4). We found a significant infection difference between bole thirds ($P < 0.000$, $H_{(2)} = 20.972$). Bole tops had the highest infection rate. Crown infection patterns differed from bole infection patterns; we found a marginally significant difference in infection ratings among crown thirds ($P = 0.061$, $H_{(2)} = 5.601$), but with lowest infection in crown tops (Figure 4).

Whitebark Pine Mortality and Reproduction

Whitebark pine trees > 15 cm dbh exhibited 23% mortality. We could not determine the cause of death for 54% of these trees. The most common cause of death was mountain pine beetle, estimated to have killed 21% of trees. Beetles were present at 45% of sites and there was a strong correlation between the percentage of live trees colonized by beetles and the percent of dead trees ($r = 0.56$). Blister rust alone accounted for 20% of the dead trees. Five percent of dead trees had a combination of white pine blister rust and mountain pine beetle. Our estimate of whitebark pine mortality was likely an underestimate, as many of the whitebark pine trees with an undetermined cause of death exhibited no evidence of beetles, and thus were probably victims of blister rust.

Three sites had dwarf mistletoe infection: Crater Peak (5%), Scott Bluffs (7%), and Northeast 1 (92%). One tree at had succumbed to dwarf mistletoe (*Arceuthobium* sp.). This was at Northeast 1. Significantly fewer infected trees had cones than uninfected trees ($X^2 = 5.032$, $P = 0.025$).

Table 2. Percentage of trees > 15 cm dbh at each site with active, inactive, and total infection percent.

Location 10 x 50 m Plot	Canker activity	% Live trees infected	Total infection %	Location 20x50m Plot	Canker activity	% Live trees infected	Total infection %
Applegate 1 (n=31)	Active	19	58	Crater Pk 1 (n=21)	Active	5	48
	Inactive	39			Inactive	43	
Garfield Pk 1 (n=17)	Active	0	0	Dutton Ridge 1 (n=20)	Active	25	40
	Inactive	0			Inactive	15	
Garfield Pk 2 (n=16)	Active	19	19	Dutton Ridge2 (n=23)	Active	0	4
	Inactive	0			Inactive	4	
Grouse Hill 1 (n=7)	Active	0	14	Hillman Pk 1 (n=44)	Active	16	41
	Inactive	14			Inactive	25	
Northwest 1 (n=9)	Active	22	33	Llao Rock (n=45)	Active	16	38
	Inactive	11			Inactive	22	
Northeast 1 (n=12)	Active	0	0	Red Cone 1 (n=17)	Active	0	18
	Inactive	0			Inactive	18	
Northeast 2 (n=11)	Active	0	2	Scott Bluffs 2 (n=22)	Active	0	14
	Inactive	2			Inactive	14	
Scott Bluffs 1 (n=15)	Active	0	27	Skeel Head 1 (n=15)	Active	7	67
	Inactive	27			Inactive	60	
Whitebark pine picnic area (n=10)	Active	0	0	South Cloud Cap (n=25)	Active	8	28
	Inactive	0			Inactive	20	
Williams Crater 1 (n=13)	Active	8	38	Timber Crater 1 (n=13)	Active	0	8
	Inactive	31			Inactive	8	

Table 3. Mean percentage of seedlings, saplings, and pole sized trees having blister rust (*Cronartium rubicola*) infections.

Tree Size class	Healthy Tree %	Active canker %	Inactive canker %
<20cm tall (n=19)	100	0	0
20cm-<1.4m tall (n=12)	92	0	8
1.4m-5cm dbh (n=164)	90	2	7
>5cm dbh- 10cm dbh (n=110)	81	3	16
>10cm dbh- 15cm dbh (n=71)	75	8	17

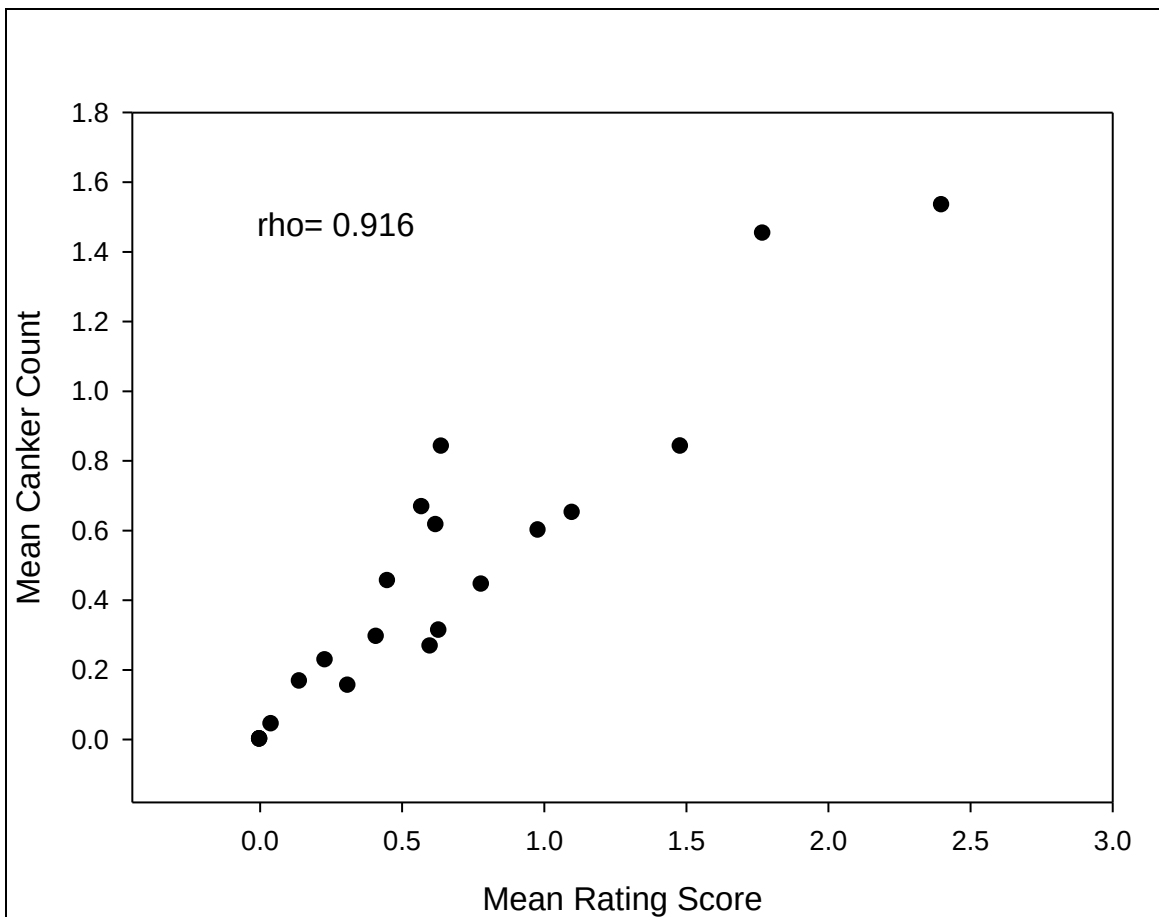


Figure 3. Relationship between mean canker count and mean white pine blister rust infection rating score in 2009 at Crater Lake, as tested using the Spearman Rank Order Correlation Coefficient, ρ .

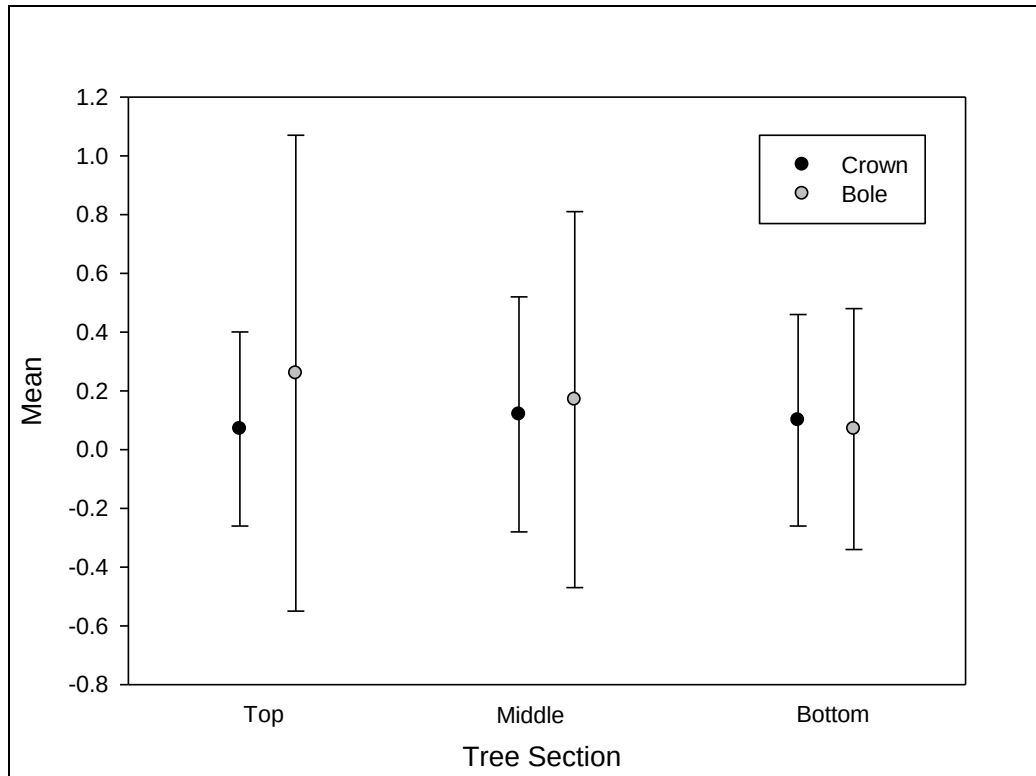


Figure 4. Mean and standard deviation for rapid assessment rating scores (Six and Newcomb 2005) from trees sampled at Crater Lake. 0 = no infection, 1 $\leq$ 25% infected, 2= 25-50% infected, and 3 $\geq$ 50% infected.

Species Composition

The most commonly encountered species from the pilot study are listed in Table 4. Eighty seven species or subspecies were observed during this project.

Table 4. Twenty most common species observed in the pilot study, listed in decreasing percent frequency of occurrence in the 20 plots. Taxonomy from Zika (2003).

Species name	Frequency %	Species name	Frequency %
<i>Pinus albicaulis</i>	100	<i>Ericameria greenei</i>	50
<i>Eriogonum umbellatum</i>	95	<i>Lupinus lepidus</i>	50
<i>Elymus elymoides</i>	85	<i>Poa wheeleri</i>	50
<i>Achnatherum occidentale</i>	80	<i>Lomatium martindalei</i>	45
<i>Arabis platysperma</i>	80	<i>Castilleja arachnoidea</i>	40
<i>Carex rossii</i>	80	<i>Calyptridium umbellata</i>	40
<i>Polygonum newberryi</i>	75	<i>Pinus contorta</i> var. <i>murrayana</i>	40
<i>Tsuga mertensiana</i>	65	<i>Ribes erythrocarpum</i>	40
<i>Lupinus andersonii</i>	55	<i>Abies X shastensis</i>	35
<i>Luzula hitchcockii</i>	55	<i>Carex inops</i> ssp. <i>inops</i>	35

Discussion

Our primary goal in this study was to determine the feasibility of co-locating whitebark pine and general vegetation sampling. If completing one plot, including travel time, were to take more than a day, it would disproportionately lower efficiency and require adjustments to the sampling design. However, we found that plots of both sizes sampled could be done within a day with travel time to locations within 1 km of a road or trail. Moreover, we found that both canker counting and the rapid assessment method (Six and Newcomb 2005) could be accomplished with little additional time expended. We therefore plan to use both assessment methods in our monitoring because the information from each is complementary. If the number of cankers reaches very high levels, such as Six and Newcomb (2005) encountered, the rapid assessment method could take precedence in the future.

Our second major goal was to compare our findings with previous monitoring results from 2000-2003 reported by Murray and Rasmussen (2003). They only considered trees infected if they had active cankers (Michael Murray, Personal Communication). Murray and Rasmussen (2003) found that 8% of trees > 25 cm dbh and 12% < 25 cm dbh were infected, while saplings (trees smaller than 1.4 m tall) had 3% infection. They found only 0.67% of trees had inactive or dead cankers. We found 9% of trees both greater and less than 25 cm dbh had active infections, and a substantially larger number of trees (18%) with inactive cankers. It therefore seems conceivable that active infections increased after the sampling done by Murray and Rasmussen, and many of these infections have since become inactive, leading to far more trees with inactive cankers and a similar number with active cankers in 2009. One reason such a pattern could occur would be that the most susceptible trees have died and the remaining trees are better able to deactivate or kill infections. However, the discrepancy between the findings by Murray and Rasmussen and ours may also be related to different plot location and subjectivity regarding the identification of inactive cankers. Our other findings also differed from those of Murray and Rasmussen, who found mountain pine beetle and mistletoe in just one area at Crater Lake, Wizard Island, while we found both to be more widespread. Thus, mountain pine beetles appear to have become a much more potent threat recently.

Consistent with Murray and Rasmussen we found more trees infected with active cankers on the west side of the park, which they attribute to the somewhat moister conditions in the west. The lifecycle of *Cronartium ribicola* is favored by moist conditions in spring and fall (MacDonald and Hoff 2001).

Our data show that tree boles were significantly more affected by blister rust than tree crowns. Six and Newcomb (2005) observed the opposite infection pattern in two of their five sites in the Rocky Mountains of Montana and Idaho. They hypothesized blister rust spores were being carried from lower elevation *Ribes* spp. and being deposited on the upper crown, leading to higher infection rates in the crown. Our findings of a higher infection rate in bole tops perhaps support this hypothesis. However, we found that the infection rate in crowns was lowest in tops. This contrary finding may be supported by the patterns we found between blister rust infection and on-site *Ribes* spp. that suggest a different pattern of spore distribution at Crater Lake than suspected by Six and Newcomb. We hypothesize that the higher upper bole infection reflects long distance spore dispersal processes and the lower crown infection reflects local dispersal

processes, since *Ribes* spp. and whitebark pine often grow in close association at Crater Lake. We observed significantly fewer infected trees with cones. In the Rockies, McKinney and Tomback (2007) observed similar results after controlling for dbh.

Conclusions

We conclude that co-locating the whitebark pine and vegetation sampling is a fruitful approach. In addition to being feasible and efficient, we found that that active infection rates are consistent with those from 2000, and that considerable mortality is occurring in whitebark pine from both infections and mountain pine beetle. With this mortality, significant vegetation change can be expected in these high elevation communities. Accordingly, the Network's rationale for selecting whitebark pine as a vital sign is supported. The results of the pilot study exercise also highlight landscape factors associated with whitebark pine susceptibility to blister rust and other mortality or stress agents. Wetter location and occurrence of *Ribes* spp. are the factors most strongly associated with increased blister rust infection of whitebark pine at Crater Lake National Park.

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