White Pine Blister Rust Hazard Rating for 265 Sites in Southern Oregon, USA

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Abstract—Sugar pine (*Pinus lambertiana*) and western white pine (*Pinus monticola*) are two important long-lived conifer species in forests of southwestern Oregon (USA) and elsewhere. Both of these white pine species have been in decline for decades due largely to the presence of the nonnative white pine blister rust, caused by the fungal pathogen *Cronartium ribicola*. Many land managers are interested in keeping these white pine species present in forest ecosystems or in managed forests, but the very high susceptibility of these species to the blister rust and the lack of information rating the landscape for rust hazard have prevented their full use. This study provides an overview of the rust infection levels at 265 sites in southwestern Oregon during the 1980s, including the frequency of cankered trees at each site and maps showing the geographic distribution patterns of the differing levels of infection. This information will assist land managers in plans for deploying seed from the blister rust resistance programs. All except one site had infected white pine species, and the mean percentage of trees with cankers over the 265 sites was 43.9 percent, with the average number of cankers per tree ranging from 0 to >11 per site. The mapping of the levels of infection showed some areas of notable low and high infection. Cankers tended to be within 2.4 m of the ground, suggesting that early branch pruning of planted trees might increase survival. This extensive one-time survey of sites is valuable in helping delineate areas of lowest and highest infection levels, but other data suggest that such surveys may underestimate the level of infection and should be complemented by a subset of permanent plots. With the widespread presence and impact of the rust, the continued development and use of genetically resistant sugar pine and western white pine seed will be vital in retaining or restoring these species to desirable levels in southwestern Oregon.

INTRODUCTION

Sugar pine (SP, *Pinus lambertiana*) and western white pine (WWP, *Pinus monticola*) are long-lived conifers that are important components of forest ecosystems in southwestern Oregon (USA). Both of these pines are very susceptible to the nonnative fungal pathogen *Cronartium ribicola*, cause of white pine blister rust (WPBR). Detailed knowledge of the geographic distribution of the rust and its intensity can be an important aid to managers developing restoration or reforestation prescriptions with these species.

The Medford District of the U.S. Department of the Interior, Bureau of Land Management (BLM) contains nearly 405,000 ha of forest land in southwestern Oregon, including many areas with sugar pine, and to a lesser extent, western white pine. In the mid-1980s, BLM personnel completed a WPBR hazard survey of 265 sites in southwestern Oregon. The objective of the survey was to document how common the rust was in this area and to provide information on relative levels of site hazard for rust over this area. This is the largest and most intensive WPBR rust hazard survey

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of an area for sugar pine, and perhaps any five-needle pine species. The information provided here will serve as a valuable tool for land managers in southwestern Oregon for use in determining where five-needle pine species may be used for reforestation and restoration, and where genetically tested resistant trees should be used for forest development projects.

In this paper, we quantify rust hazard over the landscape for the 265 locations surveyed. Hazard is quantified by hazard rating, as discussed by Geils et al. (1999) and Burns et al. (2008):

> *Forest disease outbreaks are described in the epidemiological terms of rates of spread and intensification, incidence, severity, damage, and ecological impacts. Hazard rating provides a means for combining these attributes into a relative index or classification for comparing disease potential among sites. Rust epidemiology is strongly influenced by genetics, abundance, and proximity of hosts and by microclimate… (Geils et al. 1999: 2).*
>
> *Hazard can be quantified several different ways, such as the proportion of infected trees, percent mortality, or the # and severity of cankers. By delineating rust hazard zones, managers can focus on white pine management in those areas where successful management is more likely to be heavily impacted (Burns et al. 2008: 9).*

We present hazard rating data in separate maps using proportion of trees affected, number of cankers per tree, and rust index.

METHODS

The areas examined in this project were portions of southwestern Oregon, primarily BLM's Medford District forest lands, and some adjacent U.S. Department of Agriculture, Forest Service (USDA FS) and private timber company lands (fig. 1). All BLM sites selected were from the Medford District forest inventory database of young stands with a component of either SP or WWP. Generally, sites were included only if they had a minimum of 50 trees and ranged in size from 8 to 10 ac (3 to 4 ha), up to 100 ac (40.5 ha). Due to various factors, 71 of the 265 sites had fewer than 50 trees sampled (lowest number was 25), and 6 sites had more than 50 trees sampled (1 site had 100 trees sampled).

Sites were evaluated over a several-year period in the mid-1980s. Of the 265 sites, 244 sites contained a component of sugar pine, and 21 had western white pine present. The scatter of sites in this study provides a fairly systematic and representative coverage of sites in this area with white pine species. Wild/natural regeneration trees occurred on 255 sites, and another 10 sites had been previously planted (in the mid-to-late 1960s) with seedlings from putatively rust-resistant (RR) parent trees (RRSP and RRWWP). Between 67 and 2,780 trees were planted at the RR sites.

For the 255 naturally regenerated stands, field crews generally inspected 40 to 50 trees per site using a random path method (i.e., walk 50 paces and look left and then assess the nearest tree). However, in some sites where white pines were at very low frequency, most trees in sight were selected to achieve the objective of a 40- to 50-tree count. Dead trees were sampled if they fell into the random scheme (same as for live trees) provided that mortality was recent, and the number of cankers could be assessed. The 10 RRSP/RRWWP sites were sampled in a slightly modified manner to predominantly include only trees (marked or tagged) of the RR plot, but some control or natural trees were included in some sites.

For individual sample trees, measurements included age, height, number of cankers (main stem and branches), presence/absence of cankers on the main stem, and height of the highest canker. Tree age was approximated by counting whorls. For each site, aspect and elevation were noted, and township, range, and section were used to obtain latitude and longitude at the center of each section for mapping purposes.

Basic site criteria were that the trees should be at least 10 years old and generally less than 6 m in height to allow them to be potentially exposed to rust infection for a number of years, and to allow for proper identification and counting of cankers. Sites with steep slope allowed for taller trees to be assessed. Sites where pines were being suppressed by overstory or brush were not chosen for assessment.

The collected individual tree data for each site were used to calculate percentage of infected trees (PI). Rust index (RI), where RI = number cankers per 1,000 needles per year, was calculated by using a program

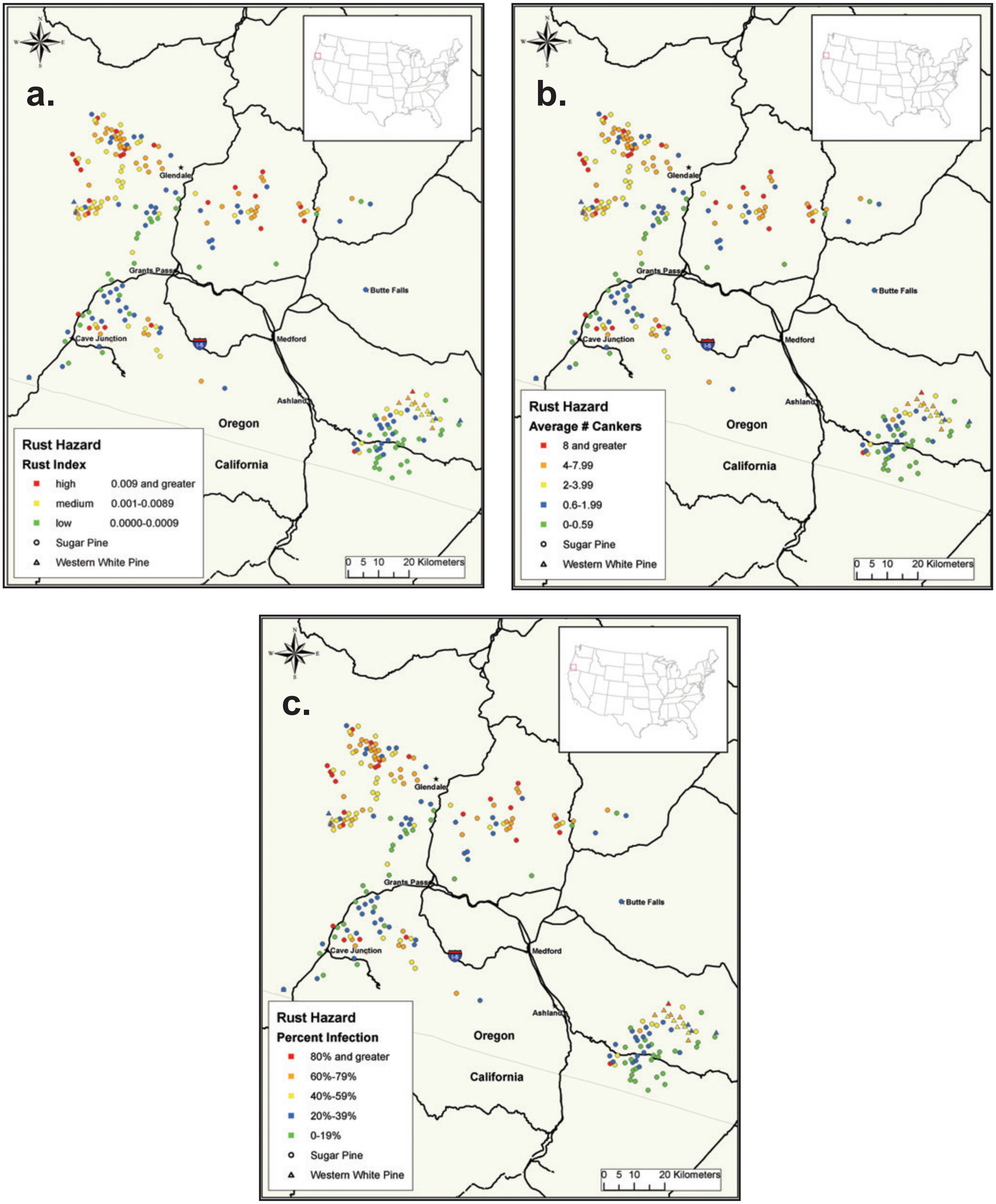

Figure 1—Geographic distribution of lowest to highest rust hazard sites, classified by (a) rust index, (b) average number of cankers per tree, and (c) percentage of trees infected. Sugar pine (*Pinus lambertiana*, 235 sites represented) and western white pine (*Pinus monticola*, 20 sites represented) are shown with filled circles and triangles, respectively. The map area is shown in the inset. Sites with improved stock were excluded. Datum used was North American Datum 1983; projection used was Albers Equal Area Conic. Maps were generated by Jennifer Christie.

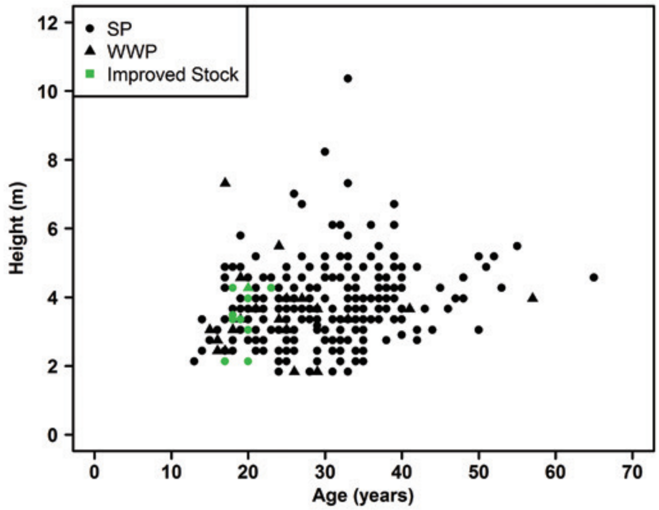

Figure 2—Relationship between tree height and age for 265 stands surveyed for rust hazard on BLM's Medford District.

developed earlier for western white pine (Hagle et al. 1989). Only the 255 naturally regenerated sites were used to create maps. For mapping rust hazard, rust index was divided into three groups, as follows:

Rust Hazard:

High: *Rust index ≥0.009 (~>70 percent of trees with cankers)*

Medium: *Rust index 0.001 to 0.009 (~50 percent of trees with cankers)*

Low: *Rust index up to 0.001 (~25 percent of trees with cankers)*

Rust index is a measurement of a tree's or site's rust infection level and therefore susceptibility to additional blister rust infections. According to the USDA FS Forest Health Technology Enterprise Team [n.d.], "The blister rust index, a measure of white pine blister rust infection level or potential for a site, area, or stand, drives the model. The initial value of the blister rust index can be provided by the user, calculated from current infections provided with inventory data, or calculated based on *Ribes* populations (white pine blister rust-*Cronartium ribicola*-is heteroecious and its alternate host is *Ribes*)."

For comparison, we also show maps of the relative rust hazard based on number of cankers per tree (using five categories) and percentage of trees with cankers (five

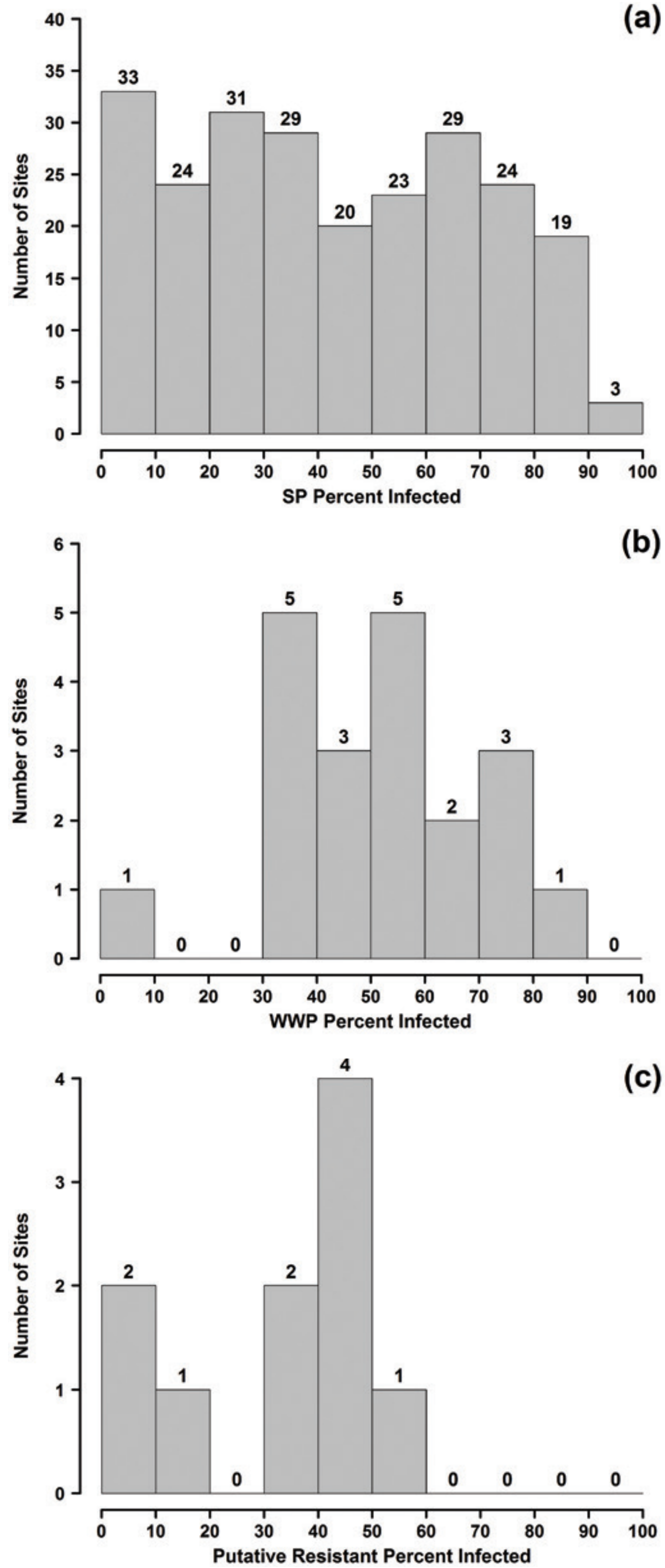

Figure 3—Distribution of percent infected with white pine blister rust for (a) sugar pine stands, (b) western white pine stands, and (c) sites planted with seedlings from putatively resistant parents.

Table 1—Summary information for 255 natural (n.s.) and 10 planted (RR) stands of sugar pine (*Pinus lambertiana*) and western white pine (*Pinus monticola*) assessed for blister rust in southwest Oregon.

Type of site	Number of sites	Measure	Elevation (m)	Average age	Average height (m)	Percent infected	Average number of cankers
SP n.s.	235	Ave	930	29.9	3.8	43.6	2.06
		Min	340	13	1.8	0	0.00
		Max	1,890	65	10.4	94	11.50
SP RR	9	Ave	1,000	19.2	3.3	37.2	1.70
		Min	680	17	2.1	6	0.16
		Max	1,250	23	4.3	60	3.41
WWP n.s.	20	Ave	1,470	24.9	3.5	51.8	2.20
		Min	640	15	1.8	4	0.06
		Max	1,740	57	7.3	86	5.04
WWP RR	1		1,100	20	4.3	16	0.46

categories). Mean plot data and calculated variables (such as rust index) generated after the survey were used in creating the map and graphs for this summary.

Statistical analyses were conducted using R version 3.0.2 (R Foundation for Statistical Computing, Vienna, Austria). Natural log transformations were applied to the average number of cankers per site and the rust index values, and a logit transformation was applied to the percent infected data. Very low levels of infection (0 to ~5 percent) were rounded to 0.0000 on the rust index scale, so the seven sites with these values were dropped from linear regression analyses involving rust measures. The 10 sites with improved stock were also removed from all linear regression analyses because inference is desired for naturally regenerated stands.

RESULTS

Most trees surveyed here were less than 7 m tall, but the age of trees varied from about 12 years to more than 50 years old (fig. 2). There is strong evidence of an association between the average height and the average age of trees in the naturally regenerated stands (Pearson's correlation = 0.225, $P = 0.0003$). It is estimated that the mean height at a site is 0.97 m greater for each 10-year increase in average age (95-percent confidence interval from 0.44 m to 1.49 m or greater). Of the 265 sites surveyed, 264 had one or more trees with blister rust cankers; the mean across sites was 43.6 percent infection and 2.1 cankers per tree for the 235 SP natural stand sites (table 1; figs. 3, 4). The number of cankers per tree per site ranged from near 0 to >11 (fig. 4).

Percent infection and number of cankers per tree are strongly related to rust index (fig. 4). Rust index (as well as infection percentage and number of cankers per tree) varied widely among sites (figs. 1, 3, 4). The mean height of the highest canker was less than 1.8 m (6 ft) for most sites (fig. 5).

The natural logarithm of rust index is strongly associated with both the logit of percent infection (Pearson's correlation = 0.890, $P < 0.0001$, fig. 6a) and the natural logarithm of the average number of cankers per tree (Pearson's correlation = 0.930, $P < 0.0001$; fig. 6b). The mean rust index changes from low hazard to medium hazard and from medium hazard to high hazard at 28.5 and 78.0 percent infected trees, respectively. Similarly, the mean rust index changes from low hazard to medium hazard and from medium hazard to high hazard at an average of 0.58 and 4.85 cankers per tree, respectively.

There is strong evidence of an association between the average height of the highest canker in naturally regenerated stands with nonzero rust index and the average age of the stand (Pearson's correlation = 0.639, $P < 0.0001$, fig. 7). For each 10-year increase in the

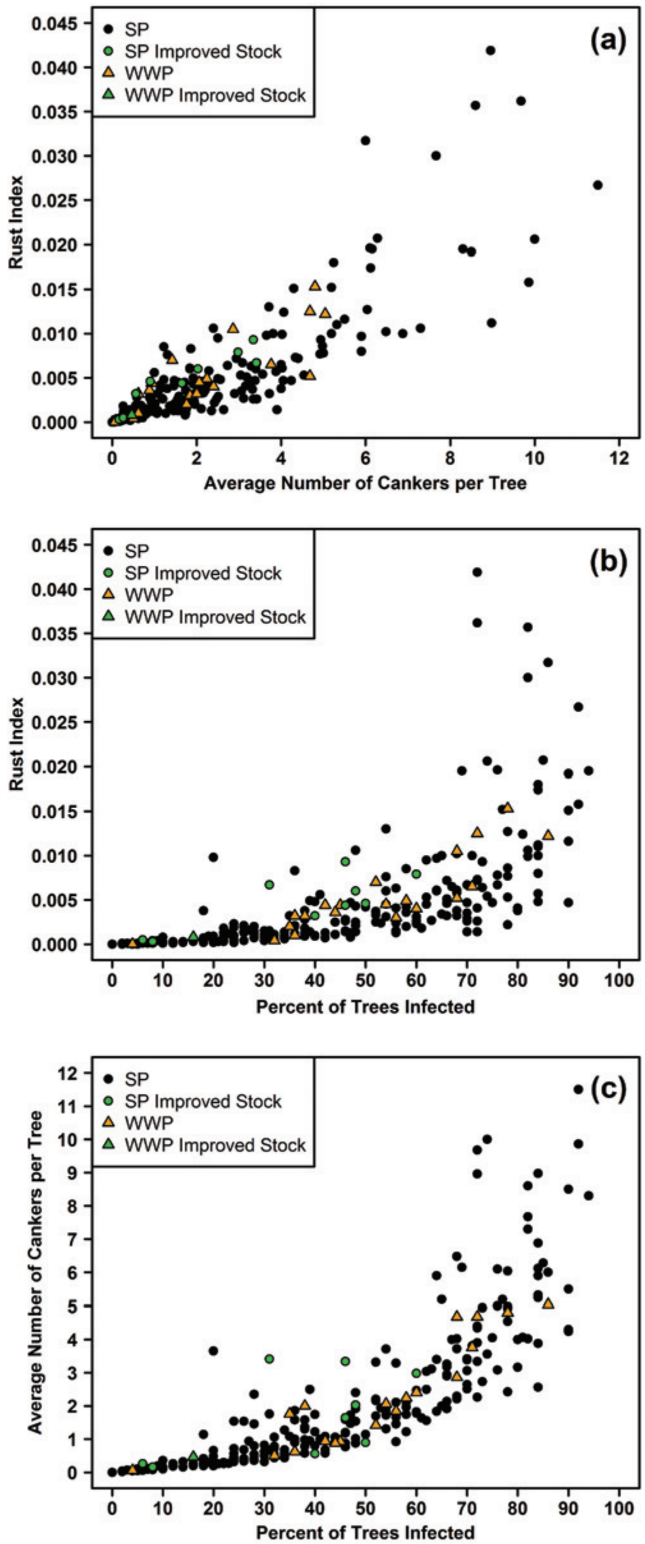

Figure 4—Relationship between (a) average number of cankers/tree and rust index (RI), (b) percent infected and RI, and (c) percent infected and average number of cankers/tree.

average age, the mean height of the highest canker is estimated to be 0.42 m higher (95-percent confidence interval from 0.36 m to 0.49 m higher). There is also strong evidence of an association between the percentage of trees infected at a site and the average age of the site ($P = 0.008$). Younger stands in general had a greater percentage of trees infected; the odds of infection were on average 52 percent greater at a site for each 10 years younger (95-percent confidence interval from 30 percent to 78 percent greater).

DISCUSSION AND SUMMARY

The data summarized here and elsewhere (Goheen and Goheen 2014; Sniezko et al. 2012, 2013) indicate that the risk of blister rust is ubiquitous in the portion of southern Oregon in this study. However, the site rust hazard varies from low to relatively high (fig. 3). Some geographic clumping of low and mid-to-high hazard areas occurs (fig. 3). Land managers can use this information to guide the use of genetically rust-resistant stock, branch pruning, and restoration options.

Based on past observations, most of the trees with lower bole infections are expected to die. The impact of blister rust reported here is likely to be an underestimate due to the one-time survey of the stands. The survey excludes most trees that have previously died from rust, and obviously does not account for future infections. Other studies (Sniezko et al. 2012, 2013) suggest the impacts could be much greater over time. Further, the criteria for stand selection may have excluded areas of highest rust hazard due to low frequency of surviving WWP or SP in those areas.

On many sites, rust-resistant stock or pruning of branches, or both, will be needed to help maximize survival and keep these species as viable components in forest ecosystems or managed plantings. Sugar pine and western white pine will continue to decline in southwestern Oregon without the utilization of seedlots with genetic resistance to blister rust. The BLM and USDA FS manage seed orchards for sugar pine and western white pine and are involved in breeding and resistance testing to further increase the level of resistance (Sniezko et al. 2014; Waring and Goodrich 2012). Most of the cankers noted are generally within 2.4 m of the ground (fig. 5), suggesting that branch

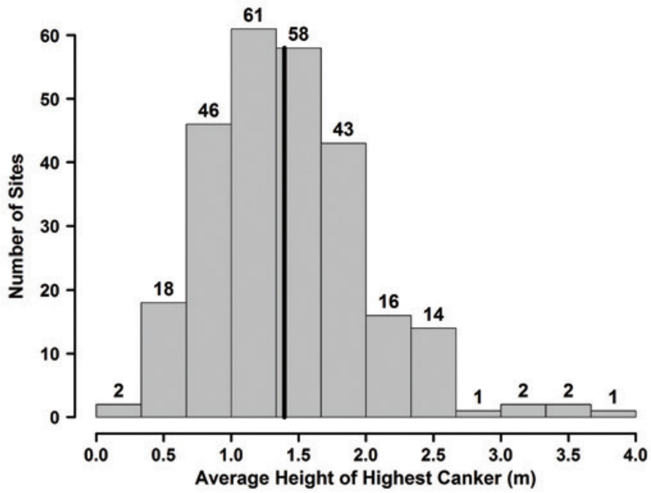

Figure 5—Frequency histogram denoting the average height of the highest canker at each of the 264 sites with a canker present. The vertical black line shows the overall average.

pruning (and removing needles attached directly to the main bole) could potentially be effective in any reforestation or restoration plantings in these areas. Several studies to examine efficacy of pruning are now underway. Note that this would help survival for current trees on the landscape, but not the ensuing generations. Only an increase in durable resistance will provide that ongoing benefit.

The maps and data summarized here provide a planning tool to land managers wishing to retain these species in forest ecosystems, restore these species, or use them in managed forests. The value of such maps has been touted elsewhere:

> *Hazard maps provide a tool for management planning at forest and project scales, a basis for stratifying landscapes for damage and impact surveys, and a foundation for additional epidemiological and ecological studies (Geils et al. 1999: 2).*

From a practical standpoint, the number of cankers per tree or percentage of trees with cankers provides a useful rating of site rust hazard when rust index is not calculated.

The effect of a changing climate on the incidence and intensity of blister rust infection is unknown. The data for this study were collected decades ago. However, recent studies suggest that blister rust continues to be

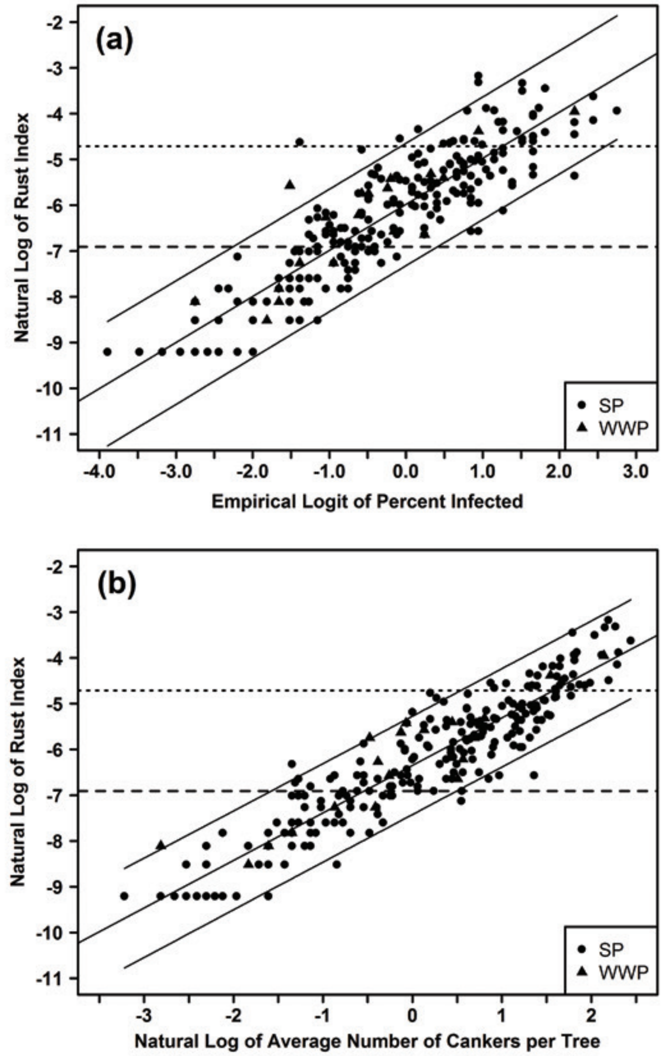

Figure 6—Fitted regression line and 95% prediction intervals for estimating the natural logarithm of rust index from (a) the logit of percent infected and (b) the natural logarithm of the average number of cankers per tree. The dashed line is the boundary between low and medium rust hazards, while the dotted line is the boundary between medium and high hazards.

very active in southwestern Oregon (Sniezko et al. 2012, 2013). Permanent plots would provide a better tracking of the impacts of blister rust dynamics, and would complement a large-scale one-time survey such as this.

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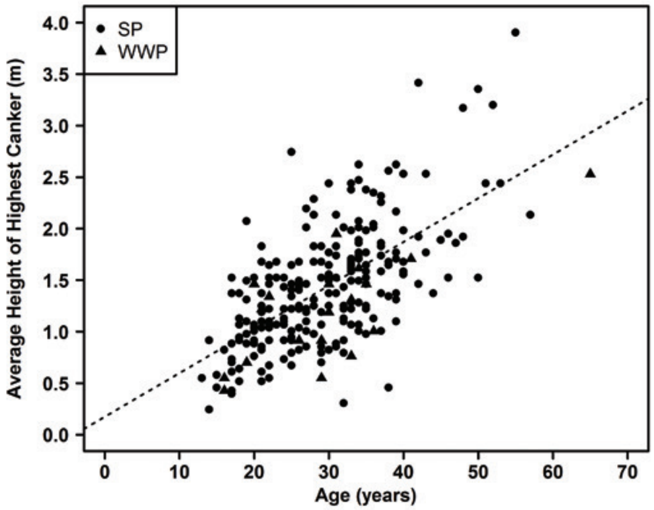

Figure 7—Relationship between the average height of the highest canker and the average age of the stand for natural stands with nonzero rust indices. The linear least squares regression line is shown with a dotted line.

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