An Analysis of Adverse Growth Rate Effects due to White Pine Blister Rust (*Cronartium ribicola*) in Whitebark Pines (*Pinus albicaulis*) in Crater Lake and Lassen National Parks

Reese Crebbin and Amy Reynolds

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Abstract:

Whitebark pine (*Pinus albicaulis*) is a five-needle pine species native to alpine and subalpine regions of North America. The range and prevalence of this arguably keystone species has been significantly reduced due to climatic alterations, infection of an Asiatic fungus (*Cronartium ribocola*), and mountain pine beetle (*Dendrocrotanus ponderosae*) infestations. In this paper, we analyze the effects of white pine blister rust on whitebark pine growth rates. In Crater Lake and Lassen National Parks, samples of whitebark pines were taken in 20 different plots over six years. Using data collected, we analyze changes in pine DBH and height growth rates, as well as reproductive potential of infected versus non-infected specimens.

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Introduction:

Whitebark pine (*Pinus albicaulis*) is a 5-needled “stone pine” that is prevalent in high alpine and subalpine ecosystems in Western North America (Keane et al., 2012). The species is considered a keystone species in these alpine ecosystems for many reasons; including, their role as a nurse tree, and the source of nutrition they provide to species such as grizzly bear and the Clark’s nutcracker (Murray and Rasmussen, 2003). Whitebark pines are considered to have a mutualistic relationship with the Clark’s nutcrackers (*Nucifranga columbiana*), which will preferentially gather and cache whitebark seeds (IBID). In the past few decades, however, whitebark pine populations have been drastically declining and in some places in North America, mortality has been estimated at up to 90% (Murray and Rasmussen, 2003). Many contributing factors have been correlated to this decline in populations; including, mountain pine beetle (*Dendrocrotanus ponderosae*) infestations, fire suppression techniques, and the Asiatic fungus, *Cronartium ribocola*, which causes white pine blister rust (Keane et al., 2012).While white pine blister rust is the main disturbance factor that this analysis will be focusing on, it is important to note that invasive blister rust has been shown to exacerbate native disturbances that could affect growth and regeneration potential, such as mountain pine beetle (Buotte et al., 2016). Several studies have been aimed at determining the effects of blister rust infection, though few have examined Oregon residing specimens, where this study is located.

Many previously conducted studies of blister rust infections in whitebark pines have been focused on areas in the intermountain west, such as the Greater Yellowstone Ecosystem and northern regions of British Columbia, but fewer have looked at the effects of the spreading white pine blister rust as far west as south-western Oregon. This can be attributed to the disease's relatively new presence in Oregon, compared to forests further east (Shanahan et al., 2016, Smith-McKenna et al., 2013, Dooley and Six, 2015). Various studies focused in Crater Lake National Park have examined the decline in population of whitebark pines including Murray and Rasmussen's 2003 study that determined the main cause of decline in whitebark pine populations in the national park was due to white pine blister rust infection. Another study 2016 study by Jules et al., determined that the main cause of whitebark pine decline was due to the impacts of mountain pine beetle infestations. Despite both studies being conducted in the same general location (Crater Lake National Park), the research teams had very different conclusions across a temporal span. This will lead future research to examine whether white pine blister rust is more of a threat to whitebark pines, whether growing mountain pine beetle populations are more threatening, or whether the two factors are potentially related. Research conducted out of the intermountain West region focuses on another 5-needled pine species, the limber pine (*Pinus flexilis*). Since white pine blister rust affects all 5-needled pines, this research and others like it could be used as a proxy for potential impacts of blister rust on our focus species, whitebark pines. In 2017, Kearnes et., al used regression modeling to determine effects of white pine blister rust on another 5-needle pine species: the limber pine, in Wyoming and Colorado. White pine blister rust, according to the authors, was recently becoming established in Colorado in 2017. The results of the study showed that 41%-79% of limber pine in both Wyoming and Colorado are susceptible to infestation by white pine blister rust (Kearnes et al., 2017). If that statistic is even somewhat transferrable in terms of susceptibility of whitebarks, then the species will most likely face very high mortality rates as time goes on and as blister rust becomes even more prevalent in the Pacific Northwest. In Crater Lake National Park, white pine blister rust has been reported as early as 1935 in the vicinity of the park and is suspected of increasing mortality in this large population of whitebark (Murray and Rasmussen, 2003). Murray and Rasmussen, 2003, attempted to quantify the impact that the spread of blister rust has had on the national park since its first detection. The study concluded that white pine blister rust affects whitebark pines more than all other biotic factors in the region combined, with a reduction in population of up to 26% since first detection of blister rust. Though these findings were later challenged by Jules et al's 2016 study, concluding that blister rust didn't affect growth significantly while beetle infestations did negatively affect growth significantly in Crater Lake National Park.

While previous studies have examined white pine blister rust and its effects on mortality in whitebark pines, few researchers have examined the effects on these pines prior to outright mortality. In this project we examine the growth rate effects of blister rust on whitebark pines by calculating growth rates (diameter at breast height and height) of infected trees compared to non-infected trees. Although research has not yet found a definitive answer to reduction in whitebark pine populations, white pine blister rust has been shown to negatively affect whitebark pine trees in Crater Lake as well as Lassen National Parks. In addition, we measured the total cones produced by infected and non-infected trees to determine if there is an adverse effect on reproductive potential. Whether it be blister rust as a solo agent of disturbance, or rust infection exacerbating pine beetle effects, blister rust is an impact that should be measured and analyzed to understand completely the impacts on whitebark pines, a very important alpine species. We hypothesize that whitebark pines (*Pinus albicaulis*) infected with blister rust (*Cronartium ribocola*) will have a reduced growth rate and reduced cone counts.

Methods:

Data has been collected from Lassen and Crater Lake National Parks every 3rd year from 2012 to 2018 (2012, 2015, 2018). There are 20 plots total, 10 in each park, with each plot measuring 50m by 50m. All trees in plot were marked and labeled with metal tags at breast height and returned to at 3-year intervals. This study focused on whitebark pines (*Pinus albicaulis*) in these plots. Diameter at breast height (DBH), height, mortality, cone counts, presence of active blister rust, and signs of inactive blister rust was recorded for each whitebark pine residing in a plot. DBH was measured using standard technique (loggers tape or Biltmore stick) at 1.4 meters off the ground. Height was determined using a laser range finder. Cone counts for each tree were determined by visual estimation on all trees with live cones. Active blister rust was categorized by active aecia and fruiting body of *Cronartium ribicola* presence Trees with at least three signs of previous blister rust infection were labeled as inactive, and considered currently infected in this study. Inactive blister rust was categorized by the observation of at least 3 of the following inactive rust signs: chewing by rodents, flagging (individual dead branches), oozing of sap and resin, rough bark from old cankers, and old aecia. In terms of data analysis, T-tests were used to analyze differences between growth rates (DBH and height) of infected versus non-infected trees between 2012 and 2018 and linear regression analysis was used to determine if there was a strong correlation between higher growth rates and more cone counts per individual. Growth rates were calculated by averaging the difference of either height or DBH measurements from each 3 year increment measurement (i.e. [2015 DBH – 2012 DBH] + [2018 DBH – 2015 DBH]/2 = average DBH per 3 years). Some trees were either topped, not found, or dead, these trees were measured at “999” and these were excluded from our calculation. Also, due to measurement error, some individual trees had unrealistic calculated growth rates for 3 year periods. Trees with height averages of more or less than 4 meters and trees with DBH averages of more or less than 15 centimeters were excluded from data analysis. In terms of categorizing infection, trees with any active or at least 3 inactive signs of rust were determined infected and placed into a yes/no categorization.

Results:

Data was analyzed for 10 plots in Crater Lake National Park and 10 plots in Lassen Volcanic National Park with a data collection time period ranging from 2012-2018, measurements taken in 3-year increments (i.e. 2012, 2015, 2018). Analyzation methods included Student’s T-test, 2 tailed, unequal variances, to determine difference in means between infected and non-infected whitebark pine populations organized by park and linear regression analysis to determine whether growth rates were statistically correlated with reproductive success of whitebarks, using cone counts as a proxy for reproductive success. Statistically significant results were determined for average growth rates of height and DBH in Crater Lake National Park between infected and non-infected individuals, while no significance was determined in Lassen and no strong correlation between growth rates and cone counts was detected. Regression analysis for Lassen was not analyzed due to the lack of significant results from the Student’s t-test.

Tables 1-4. Descriptive statistics for average growth rates (height and DBH) of infected and non-infected trees in both parks. CRLA = Crater Lake National Park, LAVO = Lassen Volcanic National Park. N = non-infected, Y = infected

CRLA Height: N		*CRLA Height: Y*	
Mean	0.512955975	Mean	0.320025253
Standard Error	0.102955859	Standard Error	0.0618449
Median	0.55	Median	0.3375
Mode	0	Mode	-0.1
Standard Deviation	1.298223983	Standard Deviation	0.870234885
Sample Variance	1.685385511	Sample Variance	0.757308756
Kurtosis	4.543151623	Kurtosis	8.267460036
Skewness	-1.199844072	Skewness	-0.178548094
Range	8.65	Range	8.8
Minimum	-4.3	Minimum	-4.45
Maximum	4.35	Maximum	4.35
Sum	81.56	Sum	63.365
Count	159	Count	198

CRLA DBH: N		*CRLA DBH: Y*	
Mean	1.090506329	Mean	0.653846154
Standard Error	0.18043076	Standard Error	0.118367343
Median	0.95	Median	0.65
Mode	0.75	Mode	0.25
Standard Deviation	2.267979487	Standard Deviation	1.652909985
Sample Variance	5.143730952	Sample Variance	2.73211142
Kurtosis	20.20307597	Kurtosis	16.42285337

Skewness	-1.324704329	Skewness	-2.306647713
Range	25	Range	18.85
Minimum	-13.6	Minimum	-10.95
Maximum	11.4	Maximum	7.9
Sum	172.3	Sum	127.5
Count	158	Count	195

LAVO Height: N		*LAVO Height: Y*	
Mean	0.084482759	Mean	0.083418367
Standard Error	0.116064291	Standard Error	0.060876987
Median	0.1	Median	0.05
Mode	0.1	Mode	0
Standard Deviation	1.250050674	Standard Deviation	0.852277822
Sample Variance	1.562626687	Sample Variance	0.726377486
Kurtosis	0.910271339	Kurtosis	3.920716328
Skewness	-0.456085625	Skewness	0.270266468
Range	6.15	Range	6.3
Minimum	-3.5	Minimum	-2.95
Maximum	2.65	Maximum	3.35
Sum	9.8	Sum	16.35
Count	116	Count	196

LAVO DBH: N		*LAVO DBH: Y*	
Mean	0.916810345	Mean	0.514615385
Standard Error	0.26959764	Standard Error	0.131212734
Median	0.65	Median	0.4
Mode	0.1	Mode	0.25
Standard Deviation	2.903655447	Standard Deviation	1.832286114

Sample Variance	8.431214955	Sample Variance	3.357272403
Kurtosis	7.889474929	Kurtosis	24.2512122
Skewness	-0.620924614	Skewness	0.456687745
Range	23.55	Range	24.05
Minimum	-12.3	Minimum	-11.1
Maximum	11.25	Maximum	12.95
Sum	106.35	Sum	100.35
Count	116	Count	195

Table 5. Calculated p-values for differences in means between infected and non-infected growth rates of height and DBH in both parks, as well as difference in means for cone counts between infected and non-infected individuals.

T-Test Results: α = 0.05	P-value
CRLA Height	0.013263
CRLA DBH	0.043971
LAVO Height	0.993529
LAVO DBH	0.181578
CRLA Cones	0.243153
LAVO Cones	0.129557

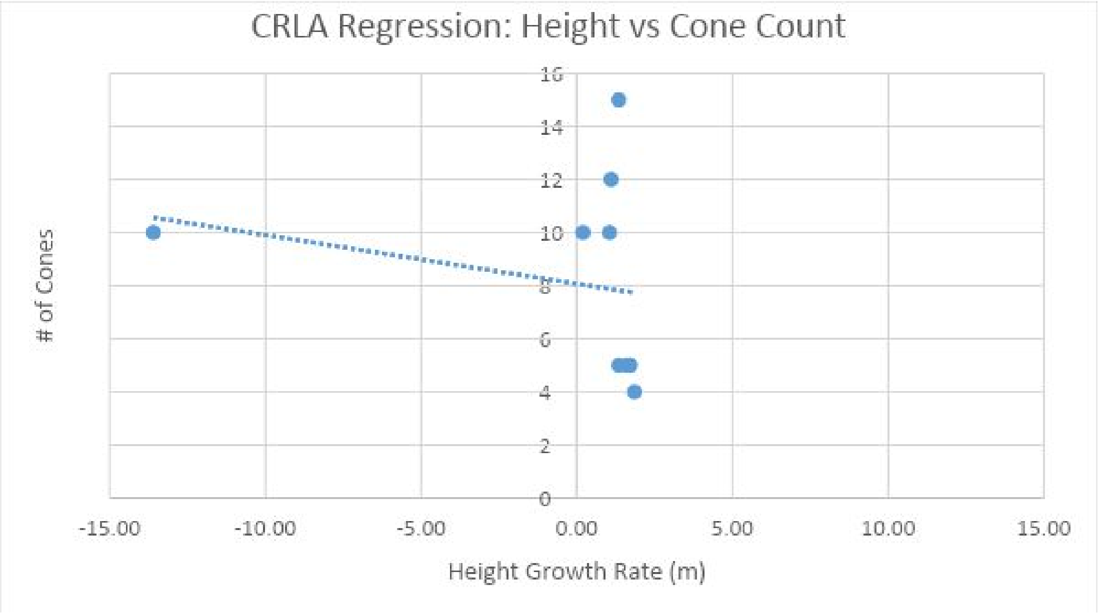

Figure 1. Linear regression analysis for average height growth rate compared with cone counts in Crater Lake.

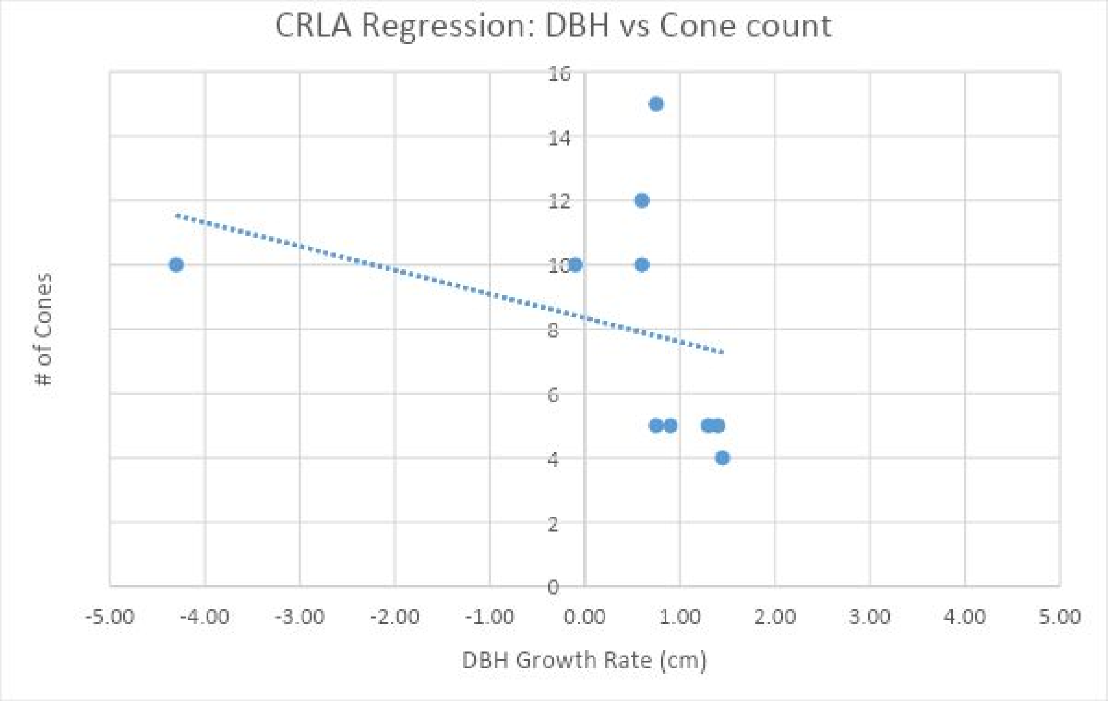

Figure 2. Linear regression analysis for average DBH growth rate compared with cone counts in Crater Lake.

Discussion:

The findings of this analysis supports, in part, our hypothesis that whitebark pines (*Pinus albicaulis*) infected with white pine blister rust (*Cronartium ribocola*) would have reduced growth rates. Infected trees had a statistically significant difference (p=0.044, n=355) in diameter at breast height growth when compared to healthy trees, resulting in a small (0.437cm), but significant reduction in growth in our Crater Lake plots. Additionally, there was a significant difference found in height growth between infected and healthy trees (p=0.013, n=355) at the Crater Lake sites. There was, however, no significant difference in DBH or height growth (p=0.182, p=0.994, n=311, respectively) at our Lassen National Park site. In both Crater Lake and Lassen, there was no correlation between growth rates and cone counts (Figure 1, R^2 =

0.053, Figure 2 $R^2 = 0.110$), nor was there a significant difference of cone production at either sites between infected and non-infected trees (p-values = 0.243, CRLA, = 0.130, LAVO). The results suggest that in Crater Lake National Park, blister rust infection is at least a partial cause of reduced tree vigor. This does not mean that blister rust infection does not negatively affect whitebark pines in Lassen, as it can still be attributed to premature mortality.

There were many data points which reflected negative tree growth in both tree sample types (infected and non-infected) at both Crater Lake and Lassen. This is likely due to failures in data collection accuracy. The lasers used to measure tree height have a margin of error of approximately one meter, making it difficult to make reliable conclusions about height differences of older trees; as many of our samples were recorded to have less than one meter of growth over three years. In addition, trees were labeled with markers in the beginning of data collection in order to ensure that DBH was measured at the same height each year. The labels, however, did fall off a number of trees and DBH was measured at a slightly different height. It is our assumption that these data collection errors are responsible for our somewhat inconclusive results between different sites.

Appendix:

This project was completed by Amy Reynolds and Reese Crebbin, partnering with the Klamath Inventory and Monitoring Network of the National Parks Service.

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