Pruning Decreases Incidence of White Pine Blister Rust Infection in Sugar Pine

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Abstract White pine blister rust (*Cronartium ribicola)* is a major pathogen causing the dramatic decrease in populations of sugar pine trees (*Pinus lambertiana)* in the Sierra Nevada. This study presents pruning as a management tool to decrease the incidence of the blister rust on sugar pine. During 2000, pruning was implemented on uninfected trees at Blodgett Forest. Six years after pruning, the number of infected trees that were pruned was compared to the number of infected trees that were unpruned. The results show that 46% of the unpruned trees were infected and 26% of the pruned trees were infected. These results indicate that pruning can decrease the chances of sugar pine contracting blister rust. Tree volume was also recorded in order to study how pruning affects tree growth. The results of this study show no significant decrease in productivity of the pruned sugar pine. This research suggests that pruning may be an important tool in the maintenance and restoration of sugar pine in the Sierra Nevada.

Introduction

Cronartium ribicola, more commonly known as white pine blister rust, is the most devastating exotic fungal disease in North America (Smith, 1996). It has affected sugar pine in the 2.5 million acres of sugar pine stands, ranging from Oregon to Southern Sierra Nevada (Cermak, 1996). Blister rust originated in Asia and was brought to Europe in the 18th century (Maloy, 2001). It was then introduced to western North America at the turn of the 20th century where it continues to affect three important white pine hosts: whitebark pine (*Pinus albicaulis*), western white pine (*Pinus monticola*), and sugar pine (*Pinus lambertiana*)(Maloy, 2001; 1997).

White pine blister rust requires two hosts to complete its life cycle. This pathogen utilizes five-needle pines as its primary host, however, it also requires an intermediate host in the genus *Ribes* (Fig. 1) (Hagle *et. al.*, 1989). While on *Ribes*, the fungus develops basideospores. These spores come into contact with the tree through wind transfer or water drip and can infect trees up to 900ft away (Hagle *et. al.*, 1989). Pine needles are infected first when the spores enter through the stomata (Maloy, 2001). The rust then germinates, followed by mycelium growth through the needle, into the branch and finally into the bole of the tree (Devey *et. al*. 1995). The mature fungus is usually characterized by cankers on the infected branches and bark of the infected pine trees (Maloy, 2001).

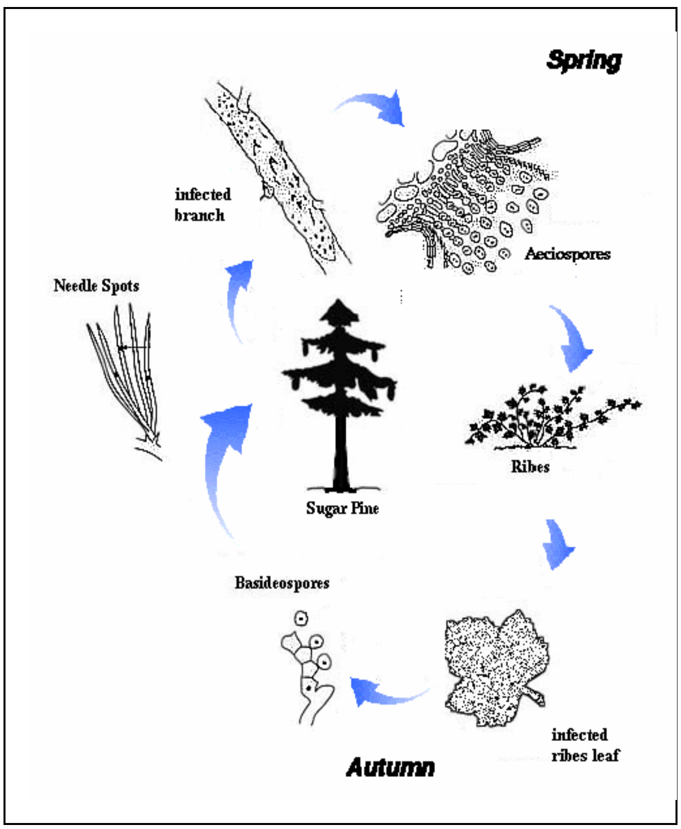

Figure 1: Life cycle of white pine blister rust
(Adapted from U.S. Forest Service www.fs.fed.us)

Multiple attempts have been made to eradicate the disease from white pine stands because of the increasing damage. From 1909 to 1967, blister rust control involved the removal of *Ribes* plants from 20 million acres of private and federal lands in over 30 states, however, this method proved to be economically infeasible (Maloy, 1997). The few *Ribes* plants that remained continued to infect the pine stands with the same level of intensity (King, 1958). In addition, previously unknown alternate hosts have recently been found that may have been infecting susceptible species in the absence of *Ribes* (McDonald et. al., 2006). A second attempt to control blister rust aimed to immunize *Ribes* with the use of antibiotics, but this method also proved to be difficult and expensive and was discontinued after 1966 (Maloy, 1997). A more recent approach, which is still in use, is pruning of infected and uninfected trees. Pruning of infected trees decreases the chance of the rust spreading to the bole, where the infection becomes fatal. It is also often an economically feasible solution (King *et. al*., 1960).

The notion of using pruning to control the spreading of white pine blister rust originates from the concept that removing the most vulnerable branches will decrease the likelihood of a tree contracting the disease. Because pruned branches are the lowest to the ground, they are the most susceptible to white pine blister rust. White pine blister rust thrives on these branches because of their exposure to increased relative humidity. Furthermore, these branches are closest in proximity to the *Ribes* plants, the primary intermediate hosts for white pine blister rust. Due to the fact that a majority of infected trees have been sick on their lower halves, pruning to a final height of at least 2.4m usually protects trees from most potential infections (Van Arsdel, 1959).

Multiple studies have used pruning to decrease the risk of infection from white pine blister rust in western white pine and eastern white pine (*Pinus strobus*). Putnam (1956) pruned a 14-year old stand of eastern white pine in order to decrease infection of white pine blister rust. Each tree was pruned to half of its tree height. This treatment resulted in saving 91% of the test species from lethal infection. King et al. (1960), using an economic analysis of blister rust control in the Lake States, showed pruning to be beneficial not only for wood quality, but value as well. The pines saved due to the pruning treatment created revenue four times the cost of pruning. Pruning also exhibits protective benefits over time. Weber (1964) reexamined a stand controlled for blister rust 12 years after treatment, and found that 13% of the trees treated with pruning were lethally infected while 30% of the unpruned trees were lethally infected. An additional study in which eastern white pines were pruned biannually for eight years resulted in a 30% decrease of lethally infected trees (Weber, 1964). Hagle and Grasham (1988) also found that 98% of the trees on a 14 year old stand treated with pruning stayed free of lethal infection of white pine blister rust.

These studies support the use of pruning as a solution for treating white pine blister rust in western white pines and eastern white pines, however, no studies have been conducted to look at the effects on pruning of sugar pine as a treatment for white pine blister rust. In fact, of the three commercial species attacked by the disease, sugar pine is the most valuable due to its versatile use in the lumber industry (Devey *et. al*. 1995). Since its introduction, blister rust has killed numerous sugar pines and continues to infect sugar pines over most of their range, threatening their future (Smith, 1966). Past studies may have ignored sugar pine because of genetic resistance to the rust that is present in some of the trees. However, new genetic strains of the rust have been found that can attack trees with the white pine blister rust resistance gene (Smith, 1996). Therefore, it is imperative that more research is conducted on sugar pines due to their increasing vulnerability, and this study explores pruning as a management tool for the protection of sugar pine. The goal of this study is to determine if pruning procedures will have the same effects on sugar pine as they do on western white pine and eastern white pine. I hypothesize that pruning healthy sugar pine trees to at most 50% of their canopy, will decrease the severity and likelihood of future infections from white pine blister rust.

Methods

Study Site This study was conducted at Blodgett Forest Research Station. Blodgett Forest is located on the Georgetown Divide, in Georgetown, California (Fig. 2). The vegetation of Blodgett Forest consists of high site, mixed-conifer forest, oak forest, and brushland gradients. Blodgett Forest is considered one of the more productive mixed conifer forestlands in California, dominated by Cohasset soil. This soil promotes productive growth of the conifers, with height growth ranging from 27-34m and diameter growth ranging from 46-66cm. The climate at Blodgett forest consists of an average annual precipitation of 166cm, and an average annual snowfall of 254cm. Summer temperatures range from 14-27ºC, and winter temperatures range from 0-9ºC. This research forest is separated into compartments to facilitate management. These compartments are generally mixed-species plantations with some natural regeneration. The study trees were located in seven of the ninety compartments (Fig. 3).

Figure 2: Blodgett forest in northern California (Google Earth).

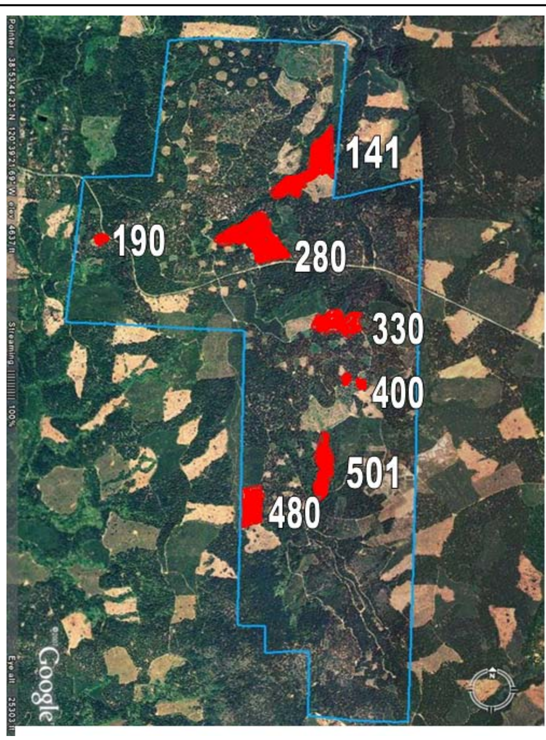

Figure 3: Blodgett Forest Research Station, with locations of the compartments used in this study. (Google Earth).

The compartment numbers that the study trees were located in are 141, 190, 280, 330, 400, 480, and 501. Compartment 141 was a plantation from 1990 and is located in the northeast section of Blodgett Forest. The 58 study trees in this compartment were dispersed throughout the compartment. Most were planted, though there was some natural regeneration. Compartment 190 was treated by group selections and is located in the northwest section of Blodgett Forest. The 24 study trees in this compartment were located in group selection "C" and all were planted after the original harvest. Compartment 280 was managed with a shelterwood technique and is located in the center of the northern half of Blodgett Forest. The 16 study trees in this compartment were dispersed throughout the compartment and all were naturally regenerated. Compartment 330 was a plantation in the center of Blodgett Forest. The 25 study trees in this compartment were located on the eastern side of the compartment and all were originally planted except one, which was naturally regenerated. Compartment 400 was managed through group selections and is located in the southern half of Blodgett Forest. The 29 study trees in this compartment were located in group selections "D" and "E" and all were planted, except two, which were naturally regenerated. Compartment 480 is a plantation located in the southeast of Blodgett Forest. The 54 study trees were dispersed throughout the entire compartment and were all planted. Compartment 501 was a plantation from 1988 and is located in the center of the southern half of Blodgett forest. The 30 study trees in this compartment were dispersed throughout the entire compartment.

Tree Selection In 2000, the sugar pine trees selected for this study were 2.44 to 6.1 meters-tall. Sugar pine trees are more susceptible to blister rust at these heights. In addition, trees of this height are tall enough so that pruning alone will not cause extensive damage or mortality. Each tree was assessed for damage and disease. All trees in this study were initially free from infection. Trees with severe damage due to logging, thinning, and animal use were excluded. Any tree with a blister rust canker on the stem was excluded, as well. Additionally, if a tree had a branch canker within 7.6cm of the stem it was also excluded because the risk of contracting blister rust could not be assessed if the tree was already damaged. All trees in the compartment that were free of damage were tagged and included in the study. There was a total of 234 trees included in this study.

Tree marking Every sample tree, whether, pruned or unpruned, was tagged with an aluminum numbered tag. Tags were attached by nailing one to the bole of the tree at breast height (for trees greater than 7.6cm diameter at breast height (dbh)) or attaching the tag to a branch with a cable-lock tie (for trees less than 7.6cm dbh). A spot of paint was placed on the stem at breast height to mark the location of diameter measurement. In addition, the branches were flagged with silvicultural boundary tape that could be seen from a distance. Each tree was also marked on a map either by hand or with a GPS unit in order to facilitate finding the trees in the future.

Tree measurements All study trees were measured for diameter at breast height (dbh) with a d-tape, total height using a height pole or a clinometer, height to base of live crown before and after pruning using a height pole or a clinometer, and breast height age. The height to base of live crown is the height from the ground to the lowest branches with living foliage. The breast height age was determined by counting branch whorls from the top of the tree, with each whorl representing one year. These measurements were taken to assess how pruning affected tree growth. Observations were also made on whether the tree was pruned or unpruned ("P" or "U"), natural or planted ("N" or "P"), crown class (Dominant "D", Co-Dominant "CD", Intermediate "I", or Suppressed "S"), and description of any blister rust infections on the tree at the time of pruning (e.g. number and size of infections). The crown class of the tree was determined to be dominant if the crown of the tree was receiving direct light on all sides of the crown, co-dominant if the crown was receiving direct light on top and filtered light on one or more sides, intermediate if the tree sometimes gets direct light only on the top of the crown, and suppressed if the crown only receives filtered light. Tree measurements were taken at the time trees were first chosen in 2000 and again in 2006, to determine if pruning had long-term effects.

Tree Pruning Treatment Every tagged sugar pine tree that had an odd number, regardless of natural or artificial regeneration, was pruned to half its total height or up to 2.4m. Pruning beyond 2.4m could cause a decrease in tree growth so great that its livelihood could be compromised. Loppers were used to remove branches outside the branch collar. All live and dead branches were removed including those near the ground. Additionally, all needle fascicles were removed from the main stem up to the pruning height. This is especially important because these needles, if left behind, could become infected with blister rust.

Data Analysis All pruned and unpruned trees were compared in 2003 and 2006 for disease development. Infection frequencies for both years were analyzed to directly compare the two groups of trees to make inferences about pruning as a legitimate long-term management tool. A chi-squared test, or 2x2 contingency table of infected and uninfected versus pruned and unpruned, was then used to determine if the differences in the infection rates between pruned and unpruned trees were statistically significant.

In order to determine if pruning height had an effect on contraction of blister rust, a t-test was conducted to compare the base to live crown heights of the healthy pruned trees versus the infected pruned trees.

An ANOVA test and a t-test were used to determine if the pruning process affects tree growth. The t-test only examines how healthy trees responded, while the ANOVA test compares the responses of both healthy and infected trees. Tree growth was determined by calculating the change in tree volume from the pruning in 2000 to data collection in 2006. Two different dimensions of the tree were used to calculate total tree volume. The equation for volume of a cylinder (volume=basal area × 1.37m) was used from the ground to breast height (1.37m). From breast height to the tip of the tree, the volume was determined using a paraboloid equation (volume = 0.5 × basal area × (height - 1.37m)). These two calculations for partial tree volume were added to arrive at total tree volume (m^3). Tree volume calculations were repeated for each sample tree on the pre-pruning date in 2000 and again during data collection in 2006. The difference between these two values was defined as tree growth.

Results

Pruning of trees significantly decreased disease prevalence. In 2003, the white pine blister rust infection rate of pruned trees was significantly lower than that of unpruned trees ($p<0.001$). In 2006, the percentage of infected pruned trees increased, but remained almost half the number of infected unpruned trees (Table 1). With treatment the trees displayed a significant increase in health when pruned between 8 and 20 years of age ($p=0.0019$). White pine blister rust infection also decreased with an increasing base to live crown height. Pruned trees that contracted the disease had been pruned to an average height of 1.68m, while the trees that remained healthy had been pruned to an average height of 1.98m, resulting in a significant reduction in infection ($p<0.001$).

Table 1: The percent of pruned and unpruned trees infected three and six years after treatment.

	Percent Trees Infected 2003	Percent Trees Infected 2006
Pruned	5% *(n = 6 of 112)*	26% *(n =30 0f 114)*
Unpruned	24% *(n = 28 of 115)*	46% *(n =55 of 120)*

The affects of tree pruning on productivity were not as clear (Fig. 4). Of all healthy trees, unpruned sugar pines showed greater productivity than the pruned sugar pine trees. Of the unhealthy trees, pruned sugar pines displayed the lowest productivity increase, while the unpruned trees displayed productivity increases consistent with those of healthy pruned trees. The unhealthy pruned trees showed the lowest absolute increase in productivity (Fig. 4). However, of the healthy trees the pruned trees did not show a significant decrease in productivity compared to the unpruned trees ($p>0.1$). In addition, none of the other relationships between pruning, disease, and tree growth were statistically significant in any combination ($p>0.3$).

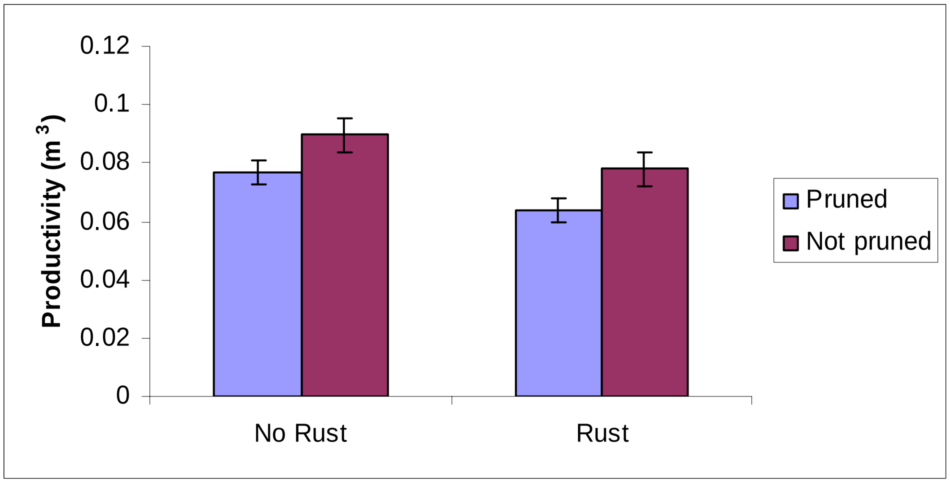

Figure 4: Average tree productivity six years after pruning for all trees by health and pruning status.

Discussion

White pine blister rust poses a severe threat to Oregon and California's sugar pines and is spreading quickly throughout the Sierra Nevada. With increasing likelihood that the disease will continue on its course south, it is beneficial to know that pruning is a useful and legitimate management tool for the prevention of white pine blister rust. We demonstrated that pruning sugar pine trees between the ages of 8 and 20 years will almost halve the trees' chances of infection by removing the susceptible branches on the tree. Furthermore, we show that increasing the base to live crown height through pruning significantly decreases infection in sugar pine trees. Using pruning as a management tool should significantly increase the health of the stand and allow for more sugar pine to reach a merchantable volume and reproductive maturity. With a higher number of trees able to reproduce, pruning can aid the restoration process by increasing overall populations of sugar pine throughout the Sierra Nevada.

These findings are strongly in accordance with multiple studies that have shown pruning to be a feasible and helpful management tool in decreasing incidence of white pine blister rust in western and eastern white pine (Hagle, et al. 1988; Hagle, et al. 1989; King, 1958; van Arsdel, et al. 1959). Now, however, it is clear that pruning is a technique that can be used on all three of the five needle pines that are commercial tree species. Furthermore, there was a significantly lower population of pruned healthy tress than unpruned healthy trees in both 2003 and 2006. This, along with a 12 year pruning study by Weber (1964) and a 14 year study by Hagle and

Grasham (1988), indicates that pruning has the long-term ability to decrease the incidence of white pine blister rust on its hosts.

Pruning as a management tool has been shown to consistently decrease the number of sugar pine trees killed by blister rust. And, unlike efforts to breed sugar pine for resistance, pruning does not decrease genetic variability of the species, nor does it promote selection pressure on the fungus to override the resistance gene (O'Hara et. al., 1995). Furthermore, pruning aids efforts to promote natural regeneration, instead of planting genetically resistant seedlings from a nursery, which could potentially be economically beneficial to a private landowner (O'Hara et. al., 1995). The results from this study broaden the collection of management possibilities to help forest managers make the proper decisions in order to promote tree and forest health.

Health, however, is not the only concern. The effects of pruning on productivity are important to the development of a forestland for timber production. Unfortunately, pruned trees, both infected and uninfected, do exhibit lower growth, but not significantly lower than unpruned trees. These results were not surprising. Decreased productivity as a result of pruning does follow a trend with many previous pruning studies, but unlike other studies, the decreased growth in this case did not prove to be statistically significant (Viquez et. al., 2005; Waring et.al., 2005). This lack of significance could be caused by a number of factors. For example, a significant decrease in growth may be less evident after only a six year period, and the trees may need more years of biomass production to show a significant change. In addition, Blodgett Forest is such a high quality site that the trees may have had enough resources to overcome pruning. Additionally, no previous studies have been published on the productivity rates of sugar pine, and this species might not have the same stresses due to pruning. What is evident from these data is that more research is necessary to determine the general response of sugar pine to pruning activity.

The results of this study demonstrate that pruning results in a decrease in infection of white pine blister rust, but this change is coupled with a decrease in productivity. These results could raise some questions for decision makers on whether this management technique is in the best interests for sugar pine trees in the long run. From an ecological perspective, this pruning strategy will ultimately increase the number of healthy sugar pine trees, while maintaining a biologically diverse population. From a production standpoint, a reduction in tree growth may be a hindering factor. However, the growth decrease in this study was not significant and smaller healthy trees could make more money than unmerchantable or dead trees due to infection. Pruning trees at an early age will also increase the amount of clear wood which produces a more aesthetically-pleasing type of lumber (King et. al., 1960). Furthermore, this treatment could ultimately result in a higher financial return than inaction, because the trees that remain healthy due to pruning could potentially compensate up to four times as much money as was spent on pruning itself (King et. al., 1960).

In order to further help managers make more appropriate decisions for the treatment of their sugar pine trees, alternate pruning techniques, such as repeated pruning after a certain number of years or age-sensitive pruning studies should be conducted. Additionally, pruning in compliance with other management techniques, such as breeding and planting for blister rust resistant trees could possibly lead to an even greater increase in stand health compared to just one of the treatments alone. Finally, a more current study of the economic repercussions of pruning should be explored.

Pruning is a relatively simple and effective way to increase the health of a sugar pine stand. This study confirmed that hope remains for those who want to reproduce sugar pine on their land without the threat of growing an overwhelmingly unhealthy stand. Pruning may not be a perfect solution, but it is a huge step forward in developing the management strategies necessary to treat this ongoing loss of sugar pine populations in the Sierra Nevada.

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