Whitebark Pine at Crater Lake and Lassen Volcanic National Parks

Stand Composition and Trends

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Abstract

Whitebark pine (*Pinus albicaulis*) - an endangered species providing critical ecosystem services - is vulnerable to a number of threats. Being the highest-elevation pine tree in the mountains of the western U.S and Canada, this species marks the treeline in these ecosystems. As a pioneer species that initiates succession after major disturbances, whitebark pine eventually becomes displaced by mountain hemlock (*Tsuga mertensiana*) -a late successional climax species-, slowly driving these ecosystems toward hemlock-dominated communities. Occasional stand-replacing fires are an integral component of these ecosystems, regulating the rate of ecological succession. As a result of systematic fire exclusion, these ecosystems - which are dependent upon regular fire intervals - are now undergoing accelerated successional changes under this pervasive fire exclusion regime. Without the reintroduction of fire, these whitebark pine ecosystems are likely to continue on their current trajectory, becoming increasingly displaced by mountain hemlock climax communities more rapidly than ever before. Differences in relative forest composition, growth rates, and annual population changes are articulated for both species, in order to determine the ecological trajectory of these communities.

Introduction

The whitebark pine is a keystone species currently under consideration to become an endangered species, resulting in considerable change in ecosystem dynamics upon its disappearance (Natural Resource Defense Council, 2008). This is due to the fundamental services it provides in subalpine ecosystems. It's pioneering status, large seed crop production, and critical snowmelt regulation make it essential to the initiation of ecological development in these regions (Ellison et al. 2005; Keane et al. 2012). Many threats to this species exist, including epidemics of mountain pine beetle (*Dendroctonus ponderosae*), the exotic fungal pathogen 'blister rust' (*Cronartium ribicola*) (McDonald and Hoff, 2011), ongoing fire exclusion, worsening climate change, and increasing competition with successional displacement (Keane et al. 2011, Millar et al. 2012). Should this species become locally extinct, deterioration of ecosystem services would occur, secondary succession would become significantly retarded, along with the irreplaceable disappearance of unique inter-species dynamics - most notably the characteristic Clark's Nutcracker (*Nucifraga columbiana*). This research will explore the relationship of augmented encroachment by mountain hemlock into sub-alpine habitat, its impact on the trajectory of whitebark pine population at Crater Lake (CRLA) and Lassen Volcanic (LAVO) National Parks, and the management regimes driving these changes.

As these habitats ascend toward climax communities dominated by mountain hemlock, whitebark pine populations are naturally displaced by their more shade-tolerant successors (Agee, 1996). Whitebark pine ecosystems are well-adapted to mixed-severity fire regimes, ranging widely in frequency and intensity (Agee, 1994). Occasional stand-replacing and small surface fires are a critical component of whitebark pine's fire ecology, allowing for stand regeneration, nutrient and biomass recycling, and most notably, regulating the encroachment of late-successional species like the mountain hemlock (Morgan, 2001). With extensive fire exclusion, late-successional species flourish - unchecked in their advance toward ecological dominance through the deprivation of natural regulating disturbances (Morgan, 1990). The current regime of fire management has artificially lengthened the fire-return interval, resulting in mountain hemlock becoming more dominant (Morgan, 1990), indirectly accelerating ecological succession in these sub-alpine ecosystems, threatening the sub-alpine populations of whitebark pine (Agee, 1996).

Declines in whitebark pine populations adversely impact forest composition and structure, succession, biodiversity, and ecosystem services (Tomback, 2010). These critical roles include the initiation of succession on barren sites after major disturbances, reduction in snowmelt rates during the warm season, reducing erosion through soil stabilization, and provision of large stocks of food for wildlife through their seed production (Tomback et al., 2001). Tolerant of the harshest conditions, whitebark pine grow at the highest treeline elevations, where their canopies shade snowpack and prolong snowmelt, regulating downstream flows. In these areas, tree roots hold soil and moisture, protecting soil from erosion, thus increasing water-holding capacity (Farnes, 1990). The open canopies of whitebark pine communities are thought to slow snowmelt and retain more snowpack than the closed canopies of late-succession communities (Farnes, 1990; Steele, 1983). Their roots stabilize soil, reducing erosion - particularly on steep, rocky slopes. Consequently, whitebark pine protects the watershed - vital for both agricultural and drinking water (Ellison et al. 2005).

Whitebark pine ecosystems are valued highly as recreational destinations. Due to their ability to grow under harsh conditions where other trees can't, they remind people that life often persists, despite constant struggle - appearing symbolic of the difficulties that humans face in their lives, while simultaneously connecting people to nature. Tomback and Acuff (2010) note "our natural world would be spiritually impoverished without the white pine gate-keepers of forests and treelines." While the high-alpine forests in the Western US may not be an important source of timber or other market products, it does not mean they are not highly valuable. In Meldrum's study (2011), they estimate the non-market benefits of preserving high elevation forests in the Western US from the threat of white pine blister rust. A valuation survey collected information about attitudes, behaviors, and economic preferences related to high elevation forests, and threats posed to whitebark pine. The estimated values suggest high-elevation forests in the Western US provide the public with significant non-market benefits (Meldrum, 2011).

Whitebark pine plays a critical role in production of large seed crops for the Clark's Nutcracker, which disperse seeds throughout the subalpine habitat, and, are in part, responsible for the 'pioneering' status of whitebark pine (Tomback, 1982). Seeds of whitebark pine are notable for being large and nutrient-rich in fats, carbohydrates, and protein relative to most pines, and are therefore attractive for many animals (Fortin, 2013) - utilized by several bird and mammal species, including grizzly bears, and the Clark's nutcracker (Tomback et al., 2010). Because Clark's nutcrackers frequently cache seeds in open and disturbed areas (Tomback, 1982), and it's seedlings are hardy and tolerant of drought (McCaughey et al., 2001) whitebark pine is a pioneer species after stand-replacing disturbances - especially fire. By colonizing disturbed areas, whitebark pine contributes to community development by acting as a nurse tree, facilitating the growth of other establishing conifers and understory vegetation (Tomback et al., 2001).

Fire is one of the most important disturbances in western US ecosystems. Variations in frequency, intensity, and spatial scale strongly influence patterns of plant community regeneration (Forrestel, 2013). Two strategies allow whitebark pine to survive in fire-prone ecosystems: survival of large refugia trees, and postfire seedling establishment facilitated by Clark's nutcrackers. Whitebark pine seedlings commonly establish on open sites created by mixed-severity and stand-replacement fires (Lanner, 1980; Tomback, 1993; Vander, 1997). Late-successional species dominate when fire-return intervals are long, however historically, fires were likely to return before whitebark pine was successionally displaced (Morgan et al., 1990). Fire suppression in the last 60 to 80 years has contributed to stand conversion toward other species that out-compete whitebark pine (Arno, 2001), shifting succession away from whitebark pine to later-successional species (Agee, 1996). Murray and others (1998) suggest that livestock grazing in the 19th century reduced fire frequency even before fire suppression was practiced.

Under whitebark pine's highly variable fire regime, natural fire-return intervals range from 30 to 350+ years (Arno, 1990; Barrett, 1994; Morgan, 1994; Agee, 1994). Using fire records from the U.S. Forest Service's Northern Region, Arno (1968) estimated that less than 1% of the seral whitebark pine had burned in 1970-1985. At that rate, he calculated a theoretical fire-return interval of 3,000+ years, cautioning that in reality, wildfire inevitably returns to fire-prone ecosystems. Fuel build-ups resulting from long-term fire exclusion impose that when fire does inevitably return, it burns more acreage at greater severity than historically. Kendall and Keane (2001) claim that "whitebark pine will continue to decline if fire is not allowed to periodically set back the successional clock."

Early stages of succession are characterized by quickly colonizing "pioneer" species - thriving in disturbed areas, often in open and sunny environments with bare, exposed soil. Whitebark pine is an early-successional species, establishing in exposed micro-sites; small parts of ecosystems that differs significantly from its immediate surroundings. (Dobrowski, 2011; Bansal, 2011). Typically the first species found on sites prior to fire, or other deforesting disturbances, it is subject to successional replacement by more shade-tolerant conifers (Tomback, 2001). Gradually, pioneer trees change the environment by reducing the amount of sunlight reaching the forest floor, reducing the amount of soil moisture during critical times of the year, and altering the nutrient cycling regime. Conditions created by the pioneer species encourage and favor the growth of late-successional species like the mountain hemlock. Shade-tolerant species establish in the shelter of established whitebark pines, eventually displacing the pioneer species (Callaway, 1998; Lilybridge, 1995; Sala, 2001).

Due to slow growth rates, whitebark pine is often outcompeted, but is capable of growing throughout the upper subalpine zone in absence of competition (Arno, 2001). Seedling and sapling subalpine fir are highly aggregated around mature whitebark pine on upper subalpine sites (≥ 8,580 ft / 2,600 m). On upper subalpine sites, mature subalpine hemlock adjacent to living or dead mature whitebark pine showed more rapid growth rates compared to mature subalpine fir growing in the open. Whitebark pine is becoming increasingly displaced by later-successional species (Kendall et al., 2001).

Longitudinal research is ongoing at multiple National Parks to determine the extent of whitebark pine mortality (McKinney et al. 2012), and the distribution of its causal agents, in order to better manage these populations for their conservation. This data will be used to examine growth, recruitment, and mortality rates for both hemlock and pine species. This research will be utilized to clarify the relationship between mountain hemlock encroachment into sub-alpine habitat, and the rate of whitebark pine decline exhibited at these parks. The primary purpose of this research is to interpret stand composition and structure within these sub-alpine Whitebark Pine communities. This will provide a method to estimate the trajectory of ecological succession for these communities, which may provide insight into more ecologically appropriate efforts.

It is hypothesized that there is a significant difference between Whitebark Pine and Mountain Hemlock growth rates and population trajectories within these communities. This is expected due to the numerous pressures afflicting Pine populations. Other scientific literature in this field suggests similar trends (Morgan 1990; Agee 1996; Keane et al. 1996; Tomback 2007; Dolan 2011)

Methods

The data analyzed for this research has been gathered using the Pacific West Region Five Needle Pine Protocol (McKinney et al., 2012). This protocol is currently being used to specify the extent of mortality and distribution of causal agents like blister rust, and evaluate patterns of disease and pest incidence that might aid in management of whitebark pine populations. At this point in time, 20 of the 30 sites at both CRLA and LAVO have two years worth of data sets - this is the data to be examined in this analysis. The study locations were established at CRLA and LAVO during the summers of 2012 - 2014.

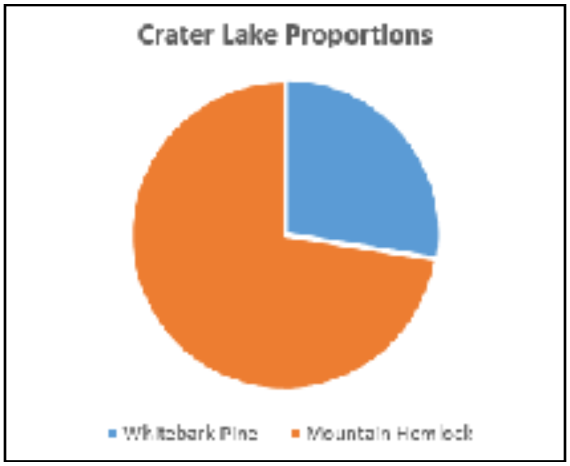
Over three years, 30 long-term whitebark pine monitoring plots were established in both parks, constructing 10 plots per year. Plot design and sampling followed the NPS Pacific West Region Five Needle Pine Protocol (McKinney et al., 2012). Sampling points were generated using the Generalized Random Tessellated Stratified (GRTS) algorithm in GIS (Stevens and Olsen, 2004) prior to plot establishment in the first year. The sampling frame was limited to exclude slopes greater than 30 degrees, and locations <100 m or >1 km from a road or trail. Sites were rejected if (a) no whitebark pine were present, or (b) they would result in unsafe working conditions (e.g., terrain too steep to work safely on). Points generated in GIS were used as the southwest corner of the 50 x 50 m plots, if one or more whitebark pine ≥1.37 m in height were found within the plot boundary. If there were no whitebark pine in a plot, an offset procedure was employed. Additional information on plot locations, oversample plots, and the GTRS algorithm can be found in McKinney et al. (2012) and Jackson et al. (2014). Information was gathered about every tree within each 50 x 50 m plot, recording species type, diameter at breast height (DBH), crown height, and dead/living status - additional information regarding disease & beetle presence were gathered for all Whitebark Pine within the plots.

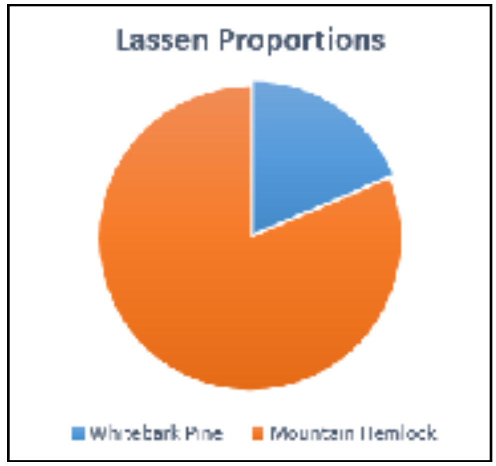
This data will provide successional information about stand conversion toward climax hemlock communities by comparing temporal information gathered using the same protocol in prior study years. By comparing this information with historical rates of succession and Whitebark Pine displacement, we may identify the synergistic effects of ecosystem management in tandem with environmental agents contributing to the decline of whitebark pine.

Using recruitment, growth, and death rates will provide an understanding of stand-conversion for the last five years at these locations. This data can be assessed as a resource flow - using annual **recruitment** as an input into the forest composition 'reservoir' and annual death rates as the output for each species - to conceptualize the ecosystem trajectory.
Other indicators of change in forest composition that will be evaluated include measurements of biomass, and population numbers of each species. Additionally, statistical analyses that demonstrate these differences in forest composition and trajectory will be utilized to determine any statistical significance in the data.

Results

The results of this analysis include forest composition, annual growth, and annual population change between the Whitebark Pine and Mountain Hemlock at Crater Lake and Lassen Volcanic National Parks.





Figures 1 and 2. Visualized in pie-charts, forest composition - as indicated by total number of species at the 40 repeated sites within the sampling frames at each location (Lassen and Crater Lake) is shown above. At LAVO, the Whitebark are outnumbered by Hemlocks 690 to 3011. Similarly at CRLA, Whitebark are outnumbered by Hemlocks 464 to 1219. These proportions were found to be statistically significant, where P = .000 during a Frequency Chi - Square analysis, where the null assumes equal proportions.

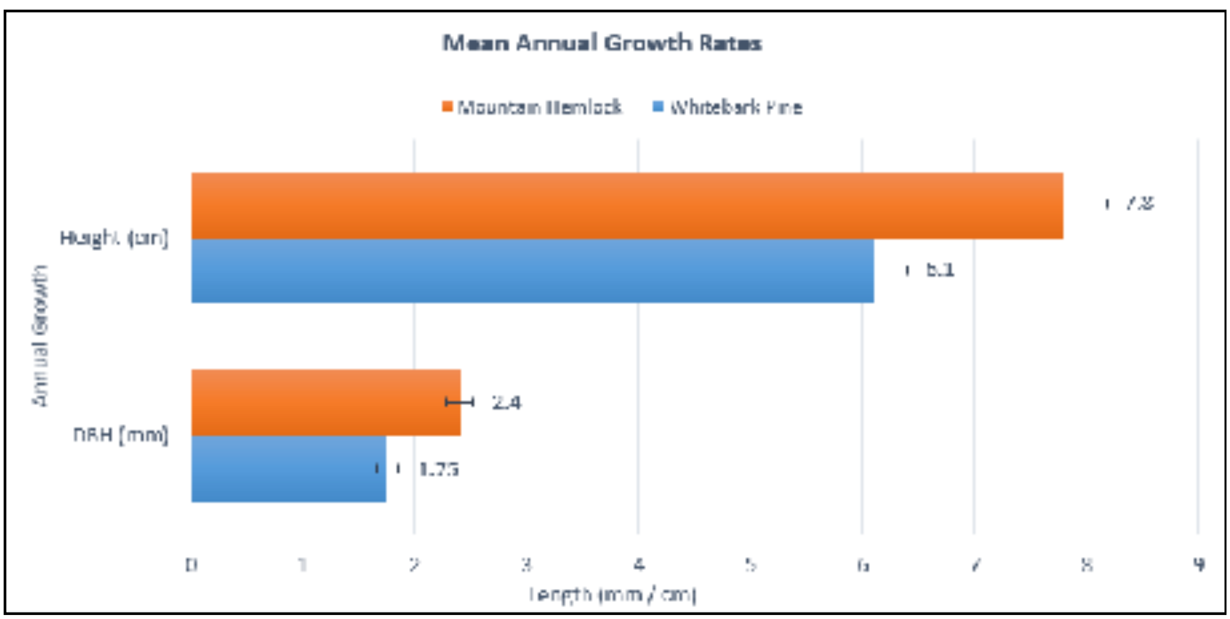


Figure 3. The mean annual growth rates in height (cm) and DBH (mm) are displayed in the above bar-graph. In the case of both Height and DBH, mean annual Whitebark

growth (Height: 6.1cm / yr ; DBH: 1.75mm / yr) is outpaced by Hemlock growth (Height: 7.8cm / yr ; DBH: 2.4mm / yr). The differences in Height growth rates are not found to be of significance, where P = .389 using a 2-tailed T test. The differences in DBH growth rates are found to be of significance, where P = .047 using a 2-tailed T test. Height displays more variability than DBH, with Standard Deviations for Height being 51 and 58, where Standard Deviations for DBH are 14 and 8 for Hemlocks and Pines respectively.

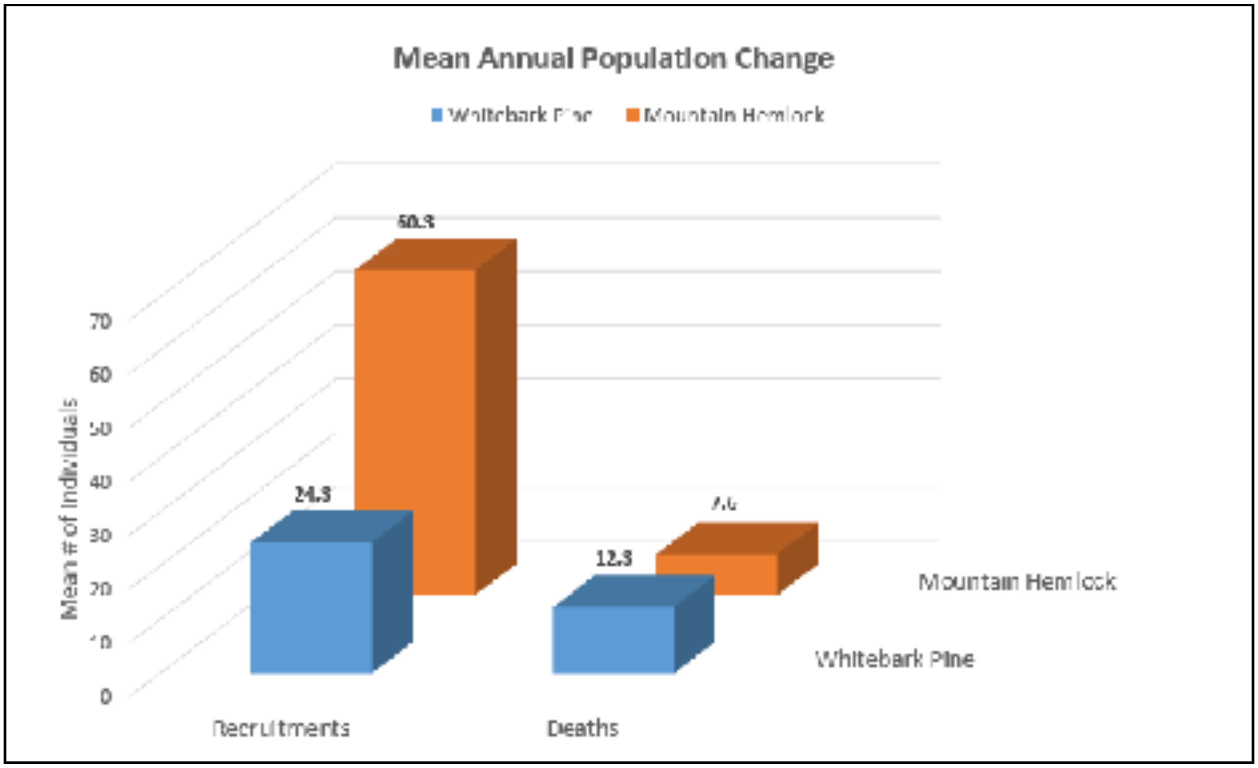


Figure 4. The mean annual recruitment and death rates within the combined sample frames are displayed above for each species. Mean annual recruitments show the largest variety, with Mountain Hemlock recruiting 60.3 new trees into the population annually, where Whitebark Pine gains 24.3 individuals annually. Mean annual death rates show that Whitebark lose on average 12.3 trees annually, where Hemlocks just lose 7.6 on average. Using a Frequency Chi - Square analysis, the difference in death rates between species was not found to be significant, where P = .071. However with the same analysis, the difference in species recruitment rates was found to be of significance, where P = .000.

Discussion

The results found in these analyses support the hypothesis that there *is* a significant difference between the growth rates and population trajectories of Whitebark Pine and Mountain Hemlock at Crater Lake and Lassen Volcanic National Parks. This research contributes to furthering the understanding of Whitebark Pine ecosystems and their response to a changing environment with relation to the Mountain Hemlock. The findings of this research are congruent with the findings within other relevant literature in the field (Morgan 1990; Agee 1996; Keane et al. 1996; Tomback 2007; Dolan 2011).

Due to the recent initiation date for this study as a limiting factor, there is little historical data to compare these results to for these precise locations. For this reason, the continuation of this research is not only exciting, but essential in order to understand precise trajectories and trends of these communities, rather than simply a snapshot from the last five years. As data from this research becomes more and more available, we will not only have a more precise understanding of the nature of this successional relationship under these changing conditions, but a more accurate idea of the trajectory of these unique ecosystems and how to properly manage them.

As illustrated in *Figures 1 and 2*, stand composition of these Whitebark Pine communities are dominated by Mountain Hemlocks. While this composition is natural and expected due to the ecology of these communities, future data will be valuable in assessing the rate of community transition from Whitebark Pine towards late-successional climax communities dominated by Mountain Hemlock (Agee, 1998; Morgan et al., 1990).

As indicated in *Figure 3*, Whitebark Pine growth is outpaced by their Hemlock competitors in both Height and DBH. This information may be used as a proxy in determining the rate of succession between these two species - as the growth rates become increasingly unequal, the successional displacement of Whitebark Pine is likely to increase accordingly. As noted in the literature, this has already begun - Mountain Hemlock have been increasing the rate at which they displace Whitebark Pine in these sub-alpine communities (Kendall et al., 2001). Future data will become continually valuable, as these rates may continue to increase.

In *Figure 4,* it becomes apparent from both annual deaths and recruitments, that the Whitebark Pine populations are on a declining trajectory, while the Mountain Hemlocks are becoming increasingly abundant within these communities. These findings are coincide with the outside literature on the topic, where the seral Whitebark Pine communities are becoming increasingly displaced by their Hemlock competitors (Kendall et al,. 2001).

Conclusion

The results of this research corroborate the findings of other research, and similarly, indicate that there is a need for proper management of these unique and sensitive communities should these ecosystems be preserved for the future. While this research limits its analyses to the relationship between Whitebark Pine and Mountain Hemlock encroachment, it provides an excellent demonstration of the need for further research. Current losses to whitebark pine populations and synergistic effects of advancing succession from fire suppression, disease, and pests currently, and under future climate warming scenarios, threaten its continued existence - qualifying it for consideration as endangered under the ESA (Natural Resource Defense Council, 2008). Climate-linked vegetation models predict a major reduction of subalpine and alpine vegetation over the next 100 years, through replacement by lower-elevation vegetation (Dolan, 2011). Suggestions for restoring damaged whitebark pine communities include selectively thinning trees that compete with whitebark pine, conducting prescribed burning to reduce competition, and planting of rust-resistant seedlings alongside preparation of seedbeds for natural regeneration (Keane et al., 1996; Tomback, 2007).

Despite dangers of landscape-level fire to whitebark pine populations, returning fire to the landscape is the best way to restore whitebark pine. Kendall and Keane (2001) state “It is important to note that fire exclusion has a far greater negative than positive consequence for whitebark pine. In the absence of fire, atypical amounts of fuel accumulate that foster more fires that are lethal to mature whitebark pine trees.” Prosperous long-term outlook for whitebark pine cannot be accomplished without returning fire to subalpine landscapes. Keane and Arno (2001) state “maintenance of native fire regimes is the single most important management action to ensure conservation of whitebark pine.”

Appendices

Equipment Used

A.

B.

C.

A: *TruPulse 200 Laser Rangefinder* was used to measure the height of trees

B: *Diameter Tape* was used to measure the diameter of trees at breast height (DBH)

C: *Logging Tape* was used to establish / mark site boundaries

Advisors

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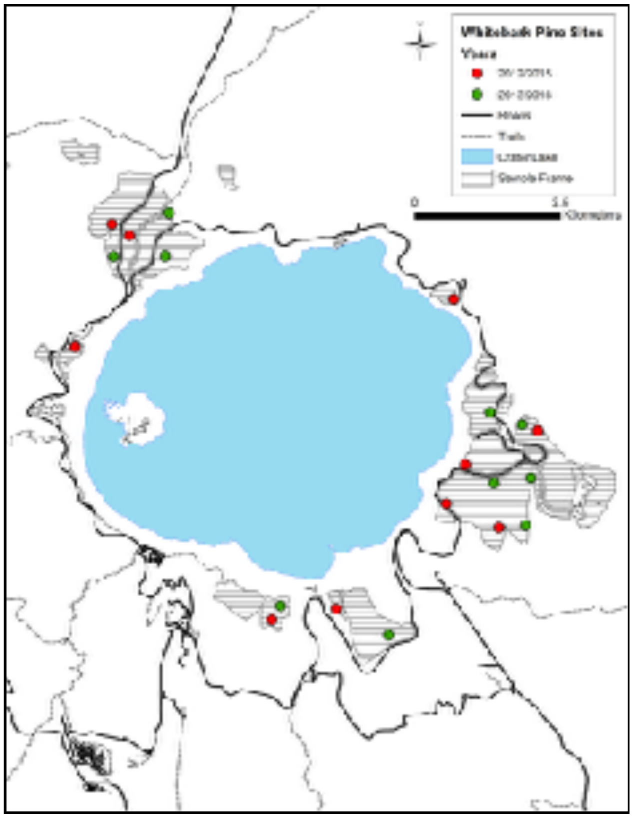
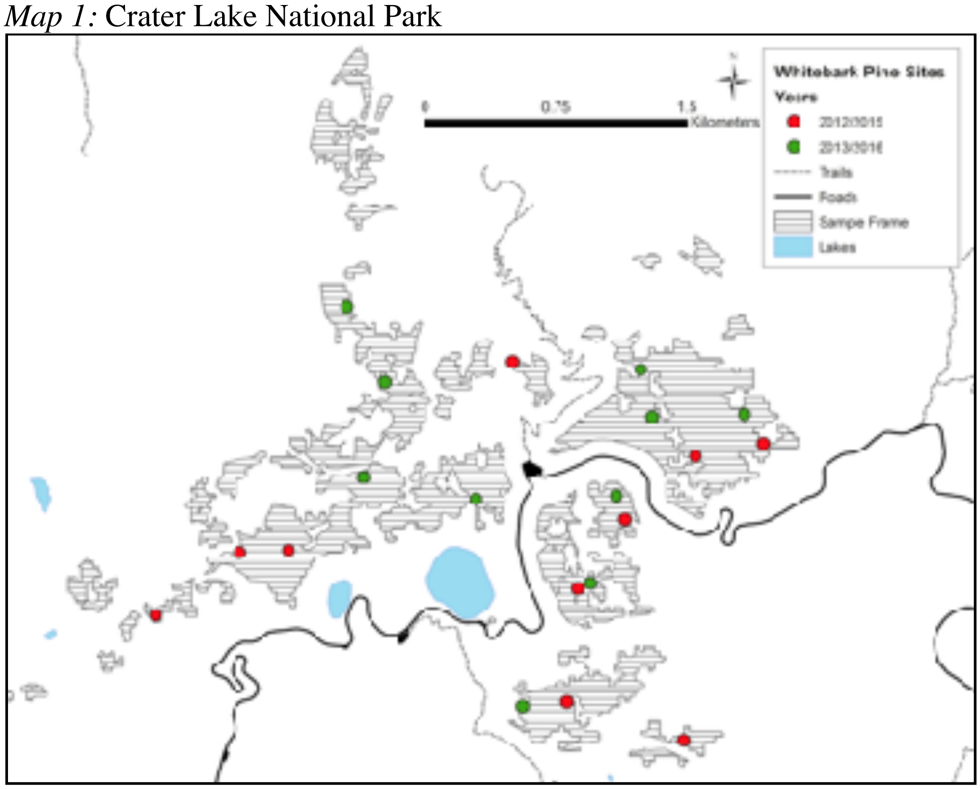
Site Maps



Map 1: Crater Lake National Park



Map 2: Lassen Volcanic National Park

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