



Whitebark Pine Monitoring: 2016 results from Crater Lake National Park and Lassen Volcanic National Park

Natural Resource Report NPS/KLMN/NRR—2017/1484



ON THE COVER

Whitebark pine growing from a rock at Lassen Volcanic NP, 2016.
Photograph by: Sean B. Smith

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Executive Summary

Whitebark pine trees (*Pinus albicaulis*, PIAL) in Lassen Volcanic National Park (LAVO) and Crater Lake National Park (CRLA) are vulnerable to several stressors such as exotic pathogens and climate change, and have been recognized as a high priority vital sign for the Klamath Inventory and Monitoring Network (KLMN). The distribution of whitebark pine ranges from the southern Sierra Nevada to British Columbia and the northern Rockies (Tomback et al. 2001), and occurs in a variety of habitats from montane, upper subalpine, and treeline zones. Currently, populations of whitebark pine are declining in the northern Cascades and Rocky Mountains, but Sierra Nevada populations are not showing similar declines (Nesmith 2015). Given that the Klamath Network is between these regions that are experiencing differing population trends and that similar stressors have been identified in KLMN parks, park managers are concerned about the future of these ecologically valuable communities in the Klamath Region. Monitoring white pine forest community dynamics will allow for the detection of downward trends and assist with identifying potential need for management intervention. KLMN has been monitoring PIAL since 2012 and this monitoring is being closely coordinated with monitoring of white pine species in other networks by using a common protocol (McKinney et al. 2012) (limber pine [*P. flexilis*] in the Upper Columbia Basin Network [UCBN]; whitebark pine and foxtail pine [*P. balfouriana*], in the Sierra Nevada Network [SIEN]). We are measuring forest community demographics and agents of PIAL mortality within 50x50 m (0.25 ha) plots. Thus, information from this monitoring project will contribute meaningfully to the broader regional assessment of the status and trends of white pine species across western North America.

This report describes the first year revisiting whitebark pine (*Pinus albicaulis*) monitoring sites established in 2013. We revisited 10 sites each at Crater Lake and Lassen Volcanic National Parks. This project implements methodology outlined by McKinney et al. (2012). Here we present data and observations from our 2016 monitoring effort, and where applicable we make comparisons between the 2013 and 2016 data. Whitebark pine trees comprised 3% of the basal area measured at Crater Lake and 12% at Lassen. On average, blister rust infected 23% and 11% of whitebark pine trees in plots at Crater Lake and Lassen, respectively. We found white pine blister rust (*Cronartium ribicola*) to be the main cause of death among recently dead whitebark pines. We estimate blister rust killed 50% at CRLA and 67% at Lassen of all dead PIAL trees (this includes trees with unknown cause of death). Several of the trees with an unknown cause of death (cause of death was obscured by weathering or decay) had inactive/active cankers in 2013; likely these trees died of blister rust, which would increase estimates of blister rust mortality to 83% and 100% at CRLA and LAVO, respectively. Of trees that died between 2013 and 2016, none appeared to have died as a result of pine beetle infestation, only one tree at LAVO had a beetle present. We found no significant difference between the 2013 and 2016 seedling densities.

Introduction

Whitebark pine (*Pinus albicaulis*) is best known for its stunted, twisted appearance near treeline, where it is a classic feature of the American West, familiar to anyone who has spent time in subalpine habitat. Rivaling the better-known bristlecone pine (*P. longaeva*), whitebark pine has a much larger range than other subalpine conifers (Figure 1), is found from the southern Sierra Nevada to British Columbia and the northern Rockies (Tomback et al. 2001), and occurs in a variety of habitats from montane, upper subalpine, and treeline zones (Arno and Hoff 1990; 1,370–3,660 m above sea level rangewide). Besides its inherent beauty, whitebark pine acts as a foundation species in high-elevation forest communities by regulating ecosystem processes, community composition and dynamics, and by influencing regional biodiversity (Ellison et al. 2005, Tomback and Kendall 2001). Whitebark pine plays a role in initiating community development after fire, influencing snowmelt and stream flow, and preventing soil erosion at high elevations (Tomback et al. 2001, Farnes 1990). The large, wingless seeds of whitebark pine are high in fats, carbohydrates, and lipids and provide an important food source for many granivorous (seed eating) birds and mammals (Tomback and Kendall 2001). Whitebark pine is a coevolved mutualist with Clark's nutcracker (*Nucifraga columbiana*), and is dependent upon nutcrackers for dispersal of its seeds (Tomback 1982, McKinney et al. 2009).

Unfortunately, whitebark pines are being affected by three of the most pressing threats that contemporary resource managers face: exotic pathogens, fire suppression, and climate change. White pine blister rust (*Cronartium ribicola*), an exotic fungus introduced a century ago, has begun to cause increasingly widespread mortality of whitebark pine over the past few decades (Murray 2005). In addition, fire suppression has allowed other conifer species to move higher in elevation, increasingly competing with whitebark pine (Ellison et al. 2005). And finally, the effects of a warming climate are predicted to increase stress on montane plants, though they are largely unstudied for whitebark pine (Warwell et al. 2007). A warming climate could also create an opportunity for native mountain pine beetles (*Dendroctonus ponderosae*) to invade, persist and thrive in high elevations they previously did not do well in (Bentz et al. 2010, Preisler et al. 2012). Increased population success of mountain pine beetles would likely lead to increased attack and death of already drought stressed trees.

The purpose of this project is to implement the Pacific West Region five-needle pine protocol (McKinney et al. 2012) for monitoring tree species composition, characteristics, and regeneration in Crater Lake National Park (CRLA) and Lassen Volcanic National Park (LAVO). Specific objectives of white pine monitoring are to determine status and detect trend in:

1. Tree species composition and structure
2. Tree species birth, death, and growth rates
3. Incidence of white pine blister rust and level of crown kill
4. Incidence of bark beetles
5. Incidence of dwarf mistletoe
6. Cone production of white pine species

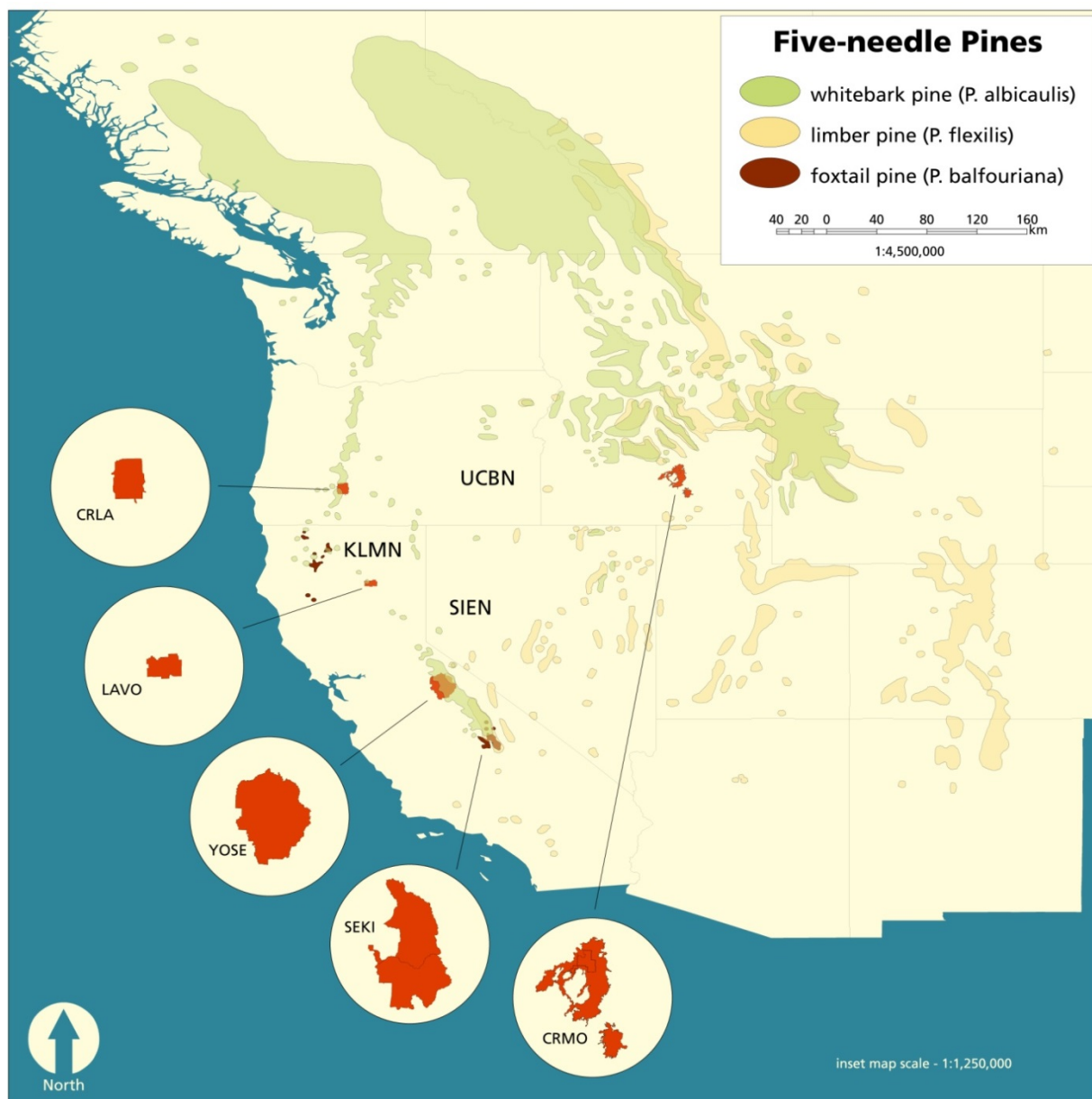


Figure 1. Distribution of whitebark pine, limber pine, and foxtail pine (from Little 1971) and locations of the three Pacific West Region networks and parks where this protocol is implemented.

The project was initially implemented through a collaborative effort between scientists from the National Park Service (NPS) Klamath Inventory and Monitoring Network (KLMN) and the Principal Investigator, Erik Jules of Humboldt State University (HSU) and his students. In 2015 the HSU cooperators stepped away from field sampling, but will maintain a role with data analysis and synthesis. This project will form the foundation of a long-term whitebark pine monitoring program at CRLA and LAVO and follows the methodology outlined by McKinney et al. (2012) for five-needle pines found in NPS lands in the western United States: limber pine (*P. flexilis*) in the Upper Columbia Basin Network (UCBN); whitebark pine and foxtail pine (*P. balfouriana*) in the Sierra

Nevada Network (SIEN). McKinney et al. (2012) place emphasis on blister rust infection rates and demographics of *P. albicaulis*, *P. balfouriana* (foxtail pine), and *P. flexilis* (limber pine).

Previous work at CRLA was conducted by Dr. Michael Murray, the park's terrestrial ecologist at the time (Murray 2010). Murray noted that mortality rates approached 1% per year in established reference stands, primarily caused by mountain pine beetles. These results were echoed in the pilot study conducted by the KLMN in 2009, reported in Smith et al. (2011).

Whitebark pines are known to occur at LAVO, but no monitoring or research had been conducted prior to initiating the McKinney et al. (2012) protocol in 2012. Results from the KLMN 2012-2014 monitoring effort (Jackson et al. 2015) found average infection of blister rust to be 51% at CRLA and 54% at Lassen. Causes of death reported at CRLA indicated that 40 (23%) died from mountain pine beetle, 28 (16%) from blister rust, two (1%) from mistletoe, 40 (22%) from bark beetles other than mountain pine beetle (i.e., not mountain pine beetle), and 1 (1%) died from a broken stem. The remainder (67 trees; 38%) died from unknown causes. PIAL mortality at Lassen included three (4%) from mountain pine beetle, eight (11%) from blister rust, 14 (19%) from other bark beetles, and 50 (67%) died from unknown causes.

Even though we initially knew little of the status of whitebark pine at LAVO, our results suggest the park's whitebark populations are in a similar position to those in CRLA with respect to whitebark pine blister rust infection and overall mortality.

Methods

Over the course of three years (2012-2014), 30 long-term whitebark pine monitoring plots (10 per year per park) were established at CRLA and LAVO (Appendix A). Plot design and sampling follow the NPS Pacific West Region five-needle pine protocol (McKinney et al. 2012), which employs a 50 × 50 m plot to track tree demographics and infestation rates. In 2015, we performed the first remeasurement of the 20 sites established in 2012. In 2016, we remeasured the sites established in 2013.

Sample Frame

The sampling frames for Crater Lake and Lassen were delineated using a combination of known whitebark pine locations and aerial photos. Sampling frames excluded slopes greater than 30 degrees, and locations <100 m or >1 km from a road or trail. The sampling points for all field seasons (2012, 2013, and 2014) were generated from within the sample frames using the Generalized Random Tesselated Stratified (GRTS) algorithm in GIS. In addition, an oversample of points was also drawn using the GRTS algorithm to support any eventual site rejections. Sites were rejected if (1) no whitebark pines were present, or (2) they would result in unsafe working conditions (e.g., terrain that was too steep to work on). The points generated by the GIS became the southwest corner of the 50 × 50 m plots if one or more whitebark pine trees >1.37 m in height were found within the plot boundary. If there were no whitebark pine individuals in a plot, an offset procedure was employed. We would select a direction at random and walk at that azimuth for a distance of 50 m from the original coordinates. This location was considered the new southwest corner. If the second plot did not contain whitebark pine, then a new random direction was determined and we would walk 50 m from the last offset coordinates. If the second offset procedure did not generate a usable plot the plot was rejected, and a new point was used from the oversample described above.

Plot Layout

Quarter hectare (50 x 50 m) macroplots, consisting of five subplots, are used to measure and track forest demographic parameters, disease, and insect occurrence, and the magnitude of their impact (Figure 2). The response design for this protocol is compatible with the *Interagency Whitebark Pine Monitoring Protocol for the Greater Yellowstone Ecosystem* (GYWPMWG 2007) but differs in some respects, most notably, plot size. Relative to the 10 x 50 m plots from the Yellowstone protocol, we increased plot size to accommodate the often sparse distribution of white pines in our PWR parks and to adequately address forest demographic objectives. This PWR design effectively represents five parallel 10 x 50 m subplots as used in the GYWPMWG and as proposed by the Whitebark Pine Ecosystem Foundation.

A total of nine square regeneration plots (3 x 3 m) are established within each macroplot to measure seedling regeneration (Figure 2). Regeneration plots are located at each corner (4), at each midpoint between corners (4), and in the middle (1) of the macroplot (Figure 2). The current design was chosen because it provides a reasonable balance among sampling time constraints, observer accuracy and precision, and total area sampled.

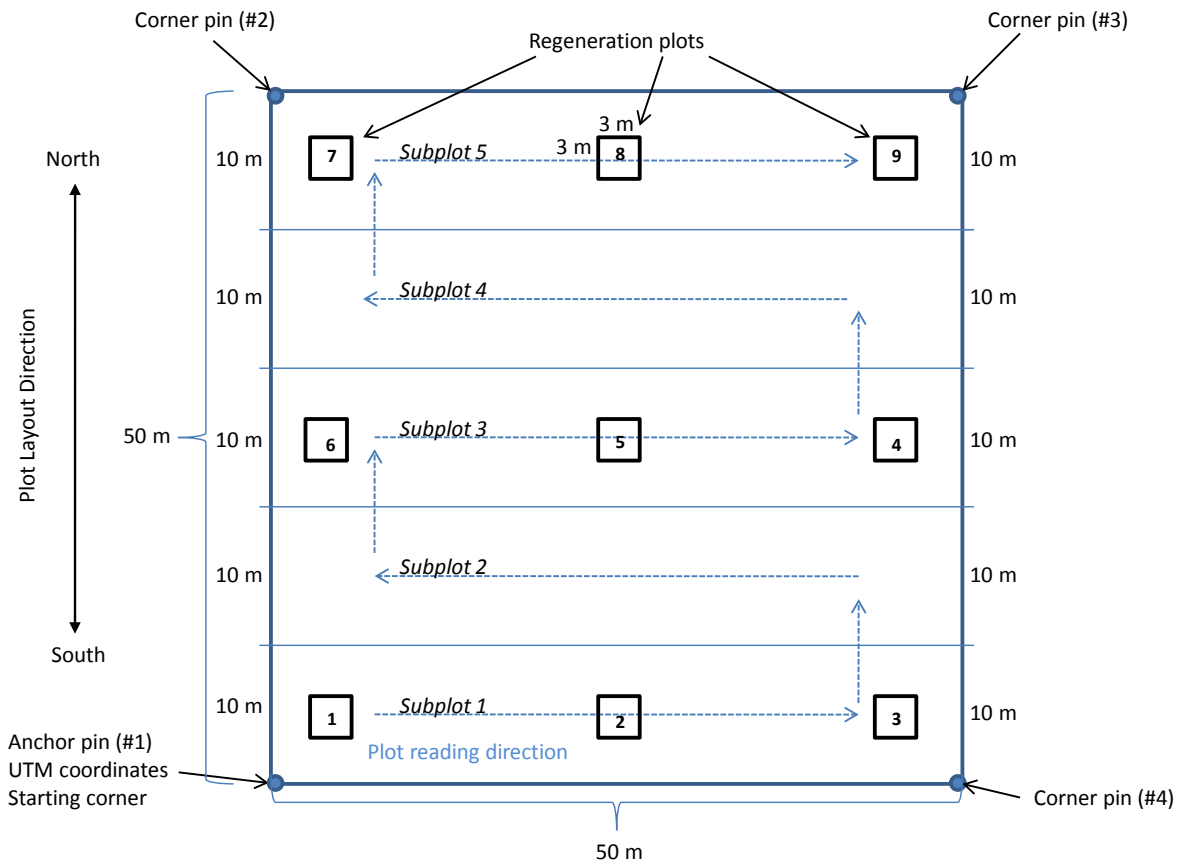


Figure 2. Layout of 50 × 50 m plot for monitoring whitebark pine.

Plot Measurements

Table 1 describes variables measured, raw data collected, summarized values, and the monitoring objectives addressed.

Within the entire 50 × 50 m plot, all trees >1.37 m in height were identified to species and tagged with a unique ID. The diameter at breast height (DBH) and height of each tree were recorded. In addition, white pine blister rust was assessed for all five-needle pines. The upper, middle, and bottom thirds of each tree were assessed separately and assigned to one of three conditions: (1) absent—no sign of rust infection, (2) active cankers (aeciospores present), or (3) no active cankers, but with the presence of three of the following six indicators of infection—rodent chewing, flagging, swelling, roughened bark, oozing sap, or old aecia. For all pines, mountain pine beetle activity was recorded if pitch tubes, frass, and/or J-shaped galleries were found. Appendix B summarizes the conditions, including some not mentioned here, that were recorded for each tree (see also McKinney et al. 2012 for details). During the first visit to a site dead trees >1.37 m in height were tagged with unique IDs also. During site revisits (beginning 2015) only live and recently dead trees were evaluated, trees recorded previously as recently dead or dead were not remeasured. Seedlings (trees <1.37 m in height) were counted by species and height classes: (1) 20 to <50 cm, 2) 50 to <100 cm, and 3) 100 to <137 cm. Seedlings <20 cm are not measured.

Table 1. Relationship among measured variables, data, and objectives for long-term monitoring of white pine communities in the Pacific West Region. (p/a) indicates presence/absence.

Variable	Raw Data	Summarized Data	Objectives Addressed
Species	Tree (nominal)	Trees per hectare (TPH); all spp., each spp., proportion of total by spp.	1. composition & structure
Diameter	Tree (cm)	Basal area (m ² /ha); all spp., each spp., proportion of total by spp. Mean diameter (cm) by spp. Diameter classes (5 cm); proportion and TPH by spp.	1. composition & structure 2. growth rate
Height	Tree (m)	Mean ht. (m); all spp. and by each spp. Height classes (3 m); proportion and TPH by spp.	1. composition & structure 2. growth rate
Status	Tree (live or dead)	Proportion live and dead; all spp and by each sp. TPH and proportion by 5 cm diameter classes in each condition; all spp and by each sp.	2. birth and death rates
Crown kill	Each of three parts of a tree (%)	Mean (%); individual white pine trees.	3. level of crown kill
Active canker	Each of three parts of a tree (p/a)	Proportion and TPH with active cankers by each white pine sp.	3. rust infection incidence
Inactive canker	Each of three parts of a tree (p/a)	Proportion and TPH with inactive cankers by each white pine sp.	3. rust infection incidence
Rust infection	Tree (p/a of active or inactive canker)	Proportion and TPH infected and healthy by each white pine sp. TPH by 5 cm diameter classes in each condition by each white pine sp.	3. rust infection incidence
Bark beetle	Tree (p/a)	Proportion and TPH with beetle sign; all spp and each sp.	4. incidence of bark beetle
Dwarf mistletoe	Tree (p/a)	Proportion and TPH with mistletoe sign; all spp and each sp.	5. incidence of dwarf mistletoe
Female cones	Tree (p/a)	Proportion and TPH with cones by each white pine sp.	6. cone production
Seedlings	9 m ² plot; number of each of three size classes by species	Mean (number per m ²); all spp and each sp for each size class.	1. composition & structure 2. birth rates

2016 Sampling Logistics

Data collection in 2016 was performed by KLMN botanist Sean Smith and SOU (Southern Oregon University) intern Byron Birss. Training and data collection began in mid-July and all target sites were sampled by late August.

Analysis

To compare differences in PIAL seedling density and presence of blister rust between 2013 and 2016, we performed paired t-tests using R version 3.0.3 (R Core Team 2014).

Data management

Data management followed procedures outlined in Standard Operating Procedure 1.1 of McKinney et al. (2012). Field data were collected on tablet computers and backed up nightly on a memory stick. Data were checked for accuracy by Sean Smith both during and after the field season and all errors were either corrected or removed and flagged. Summary statistics for the 20 plots measured in 2016 were created in both tabular and graphical form.

Results

During the 2016 season, we revisited and remeasured 10 monitoring plots each in CRLA (Figure 3) and LAVO (Figure 5). We documented a variety of characteristics for all trees and tree seedlings, by species, in monitoring plots established.

Tree Species Composition and Characteristics

Crater Lake National Park

A total of 1,024 live trees >1.37 m in height were found across the 10 CRLA plots, of which 159 were whitebark pine, 812 mountain hemlock (*Tsuga mertensiana*, TSME), 51 lodgepole pine (*Pinus contorta* var. *murrayana*, PICOM), and two red fir (*Abies magnifica*, ABMA). Whitebark pine represented 3% of the total basal area in the 10 plots, while mountain hemlock represented 91%, lodgepole pine 5%, and red fir <1%. Basal area percentages of individual trees species by site are shown in Figure 3. Note that basal area estimates are not precise because two trees (both TSME) had unmeasurable or problematic DBH values, and were omitted from these estimates. Table 2 (See Overall Seedling Comparison Section below) shows a summary of trees/ha by species.

Sixteen live trees tagged in 2013 were not found in 2016: four PIAL, eleven TSME, and one PICOM. These missing trees could have died and fallen over, but for whatever reason they could not be relocated. In 2015, 33 new trees were tagged: five PIAL, and 28 TSME. Our SOPs do not call for tagging trees <1.37m, and most of these newly tagged trees (19 of 33) were <2 m in height (Figure 4); thus they were likely present in the plot in 2012 and grew to a measurable height by 2015. Newly tagged trees in the larger height categories (≥ 2 m) were probably missed in 2012, as they were often found in clumps and were somewhat obscured.

A total of eight whitebark pine seedlings were found in three of the 10 CRLA plots. Seedlings are only assessed in regeneration plots, and these cover 81 m² in each 50 × 50 m plot (Figure 2). Extrapolating from densities in the regeneration plots, we estimate an average of 99 (S.D. 182) whitebark pine seedlings per hectare in the 10 plots from CRLA (See Table 2 in Overall Seedling Comparison Section below). Having been found in two plots, mountain hemlock was not the most frequently regenerating seedling, but had the highest estimated average of 284 (S.D. 741) seedlings/ha.

Lassen Volcanic National Park

In LAVO, a total of 1490 live trees >1.37m (four trees were measured under 1.37m in height but counted here) in height were found across the 10 plots, of which 259 were whitebark pine, 1222 mountain hemlock, four western white pine, one lodgepole pine, and four red fir. Whitebark pine represented 12% of the total basal area in the 10 LAVO plots, while mountain hemlock represented 88%, and red fir, lodgepole pine, and western white pine were all <1%. Basal area percentages of individual species by site are shown in Figure 5. Note that basal area measurements are not precise because two trees (all TSME) had unmeasurable or problematic DBH values, and were not included in the basal area estimates. Table 3 shows a summary of trees/ha by species.

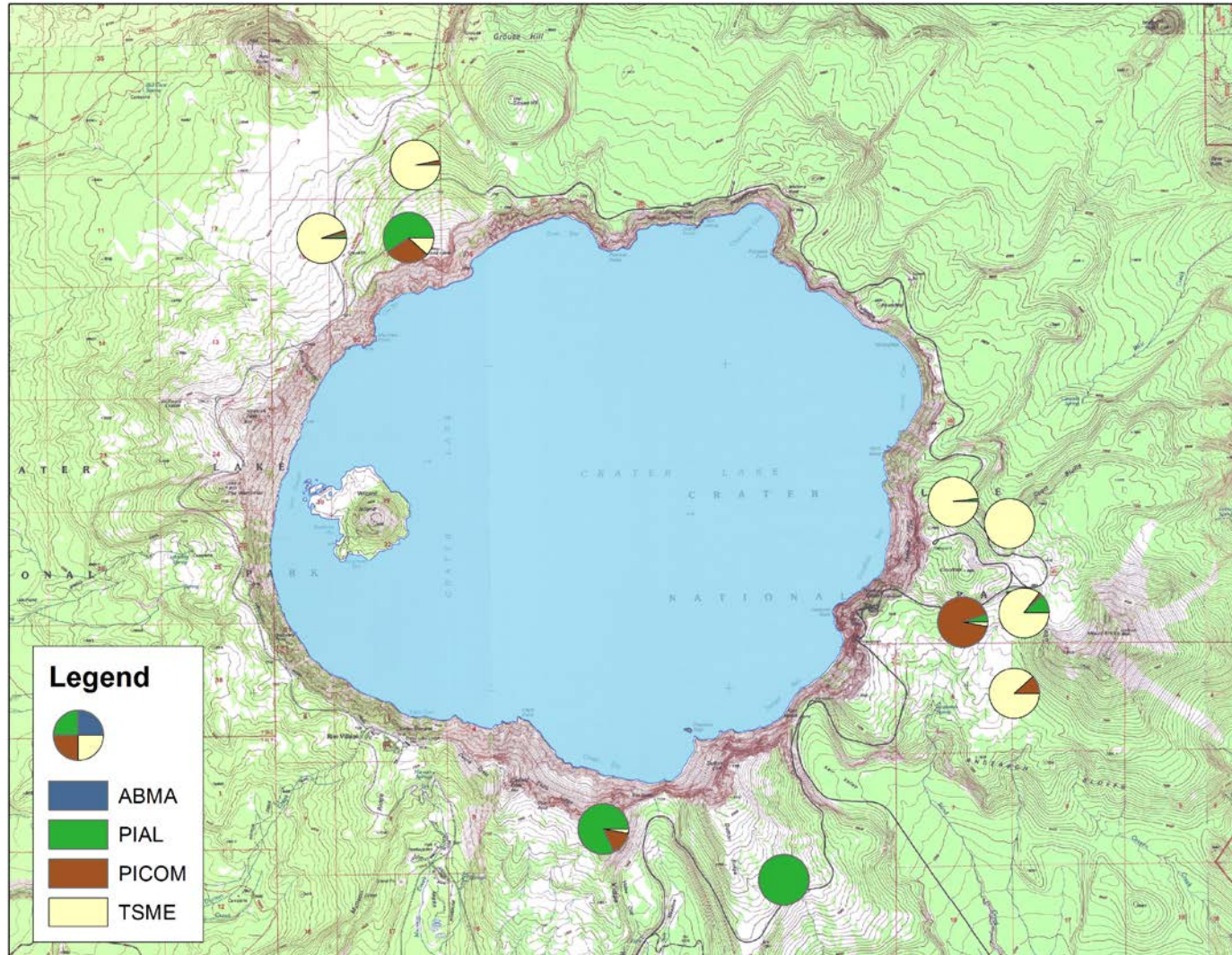


Figure 3. Relative proportion of basal area by species at monitoring sites in Crater Lake NP, 2016. ABMA = *Abies magnifica*; PIAL = *Pinus albicaulis*; PICOM = *Pinus contorta* var. *murrayana*; and ; TSME = *Tsuga mertensiana*. At sites where trees from one species (e.g., PIAL) make up a very small percentage of the basal area, the species percentage is not visible in the pie chart.

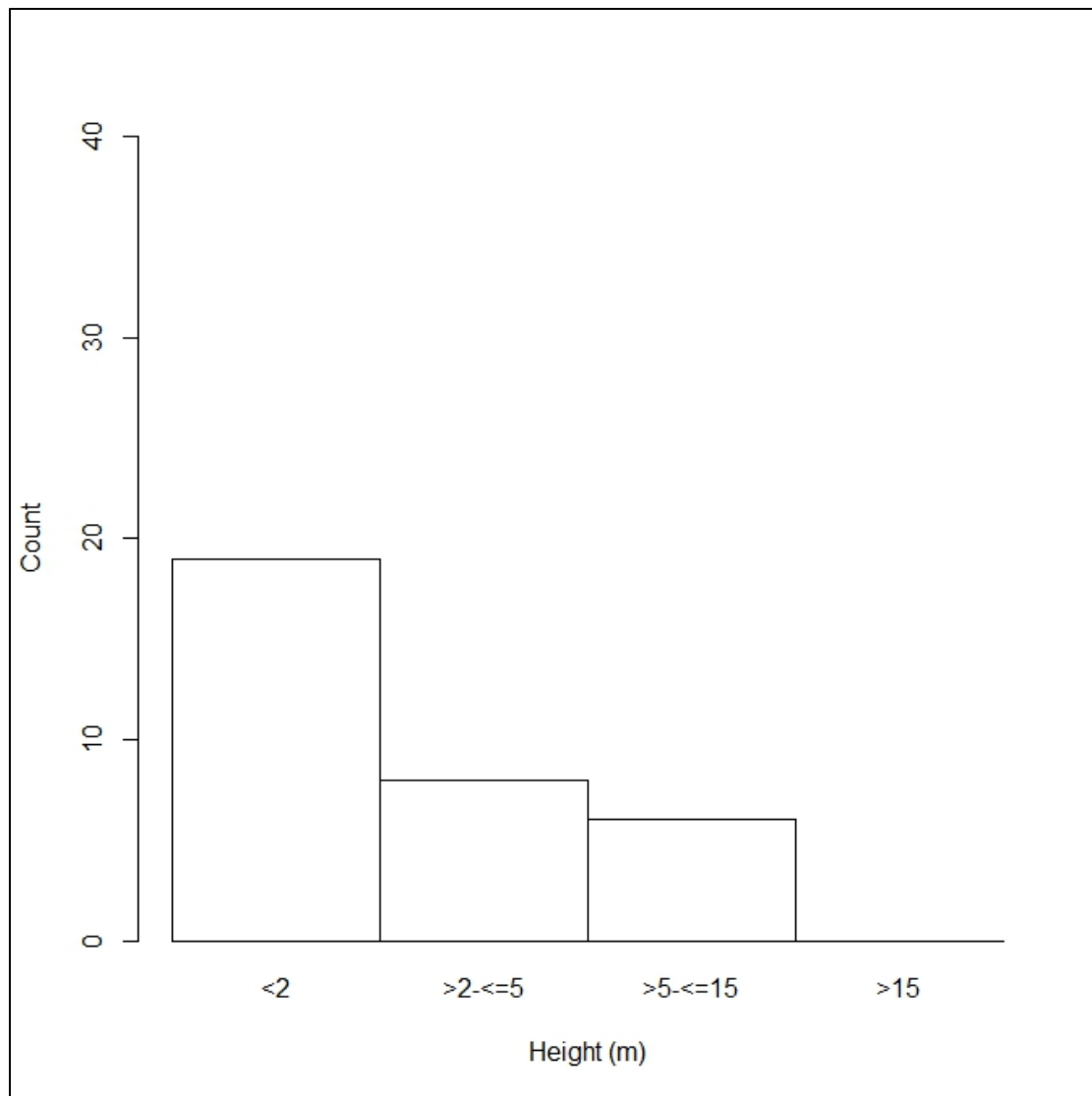


Figure 4. New trees at Crater Lake NP tagged in 2016, by height class.

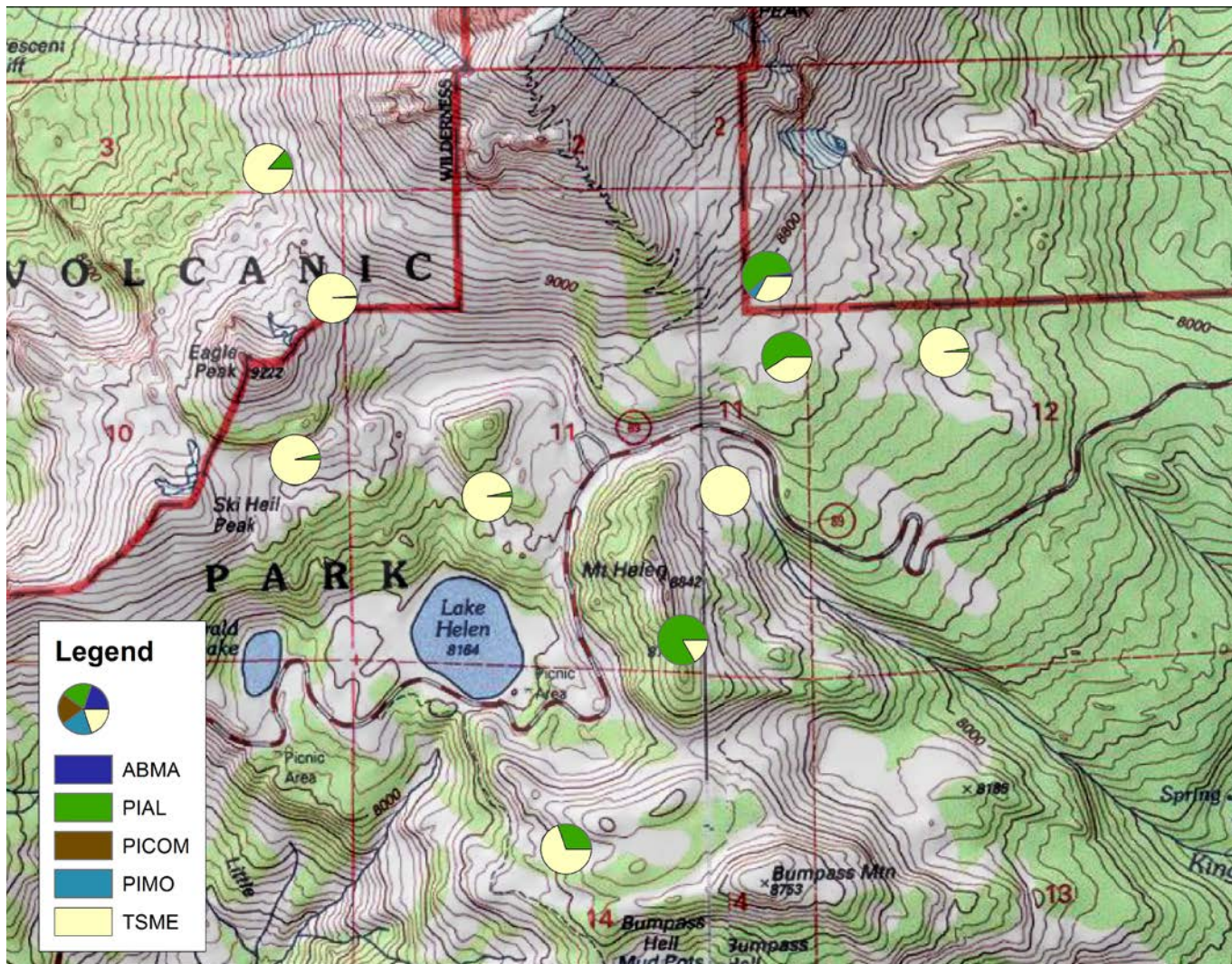


Figure 5. Relative proportion of basal area by species at monitoring sites in Lassen Volcanic NP, 2016. ABMA = *Abies magnifica*; PIAL = *Pinus albicaulis*; PICOM = *Pinus contorta* var. *murrayana*; PIMO = *Pinus monticola*; and TSME = *Tsuga mertensiana*. At sites where trees from one species make up a very small percentage of the basal area (e.g., PIAL), the species percentage is not visible in the pie chart.

Three live trees tagged in 2012 were not found in 2015, all TSME. In 2016, 72 new trees were tagged: 24 PIAL and 48 TSME. Our SOPs do not call for tagging trees <1.37m, and just under half (34/74) of these newly tagged trees were <2 m in height (Figure 6); thus they were likely present in the plot in 2013 and grew to a measurable height by 2016. Newly tagged trees in the larger height categories (≥ 2 m) were probably missed in 2013, as they were often found in clumps and were somewhat obscured.

A total of five whitebark pine seedlings were found in three of 10 LAVO plots. Seedlings are only assessed in regeneration plots, and these cover 81 m² in each 50 × 50 m plot (Figure 1). Extrapolating from the regeneration plots, we estimate an average of 62 (S.D. 105) seedlings per hectare in the 10 LAVO plots (Table 3). Mountain hemlock was the most frequent and abundant, found in six plots with an estimated average of 679 (S.D. 1064) seedlings/ha.

Overall Seedling Comparison

Although we did not do a statistical comparison, seedling densities are generally greater for mountain hemlock than for whitebark at both parks, with almost three times as many TSME than PIAL at CRLA and 10 times more at LAVO (Tables 2 and 3). Within each park, whitebark pine seedling counts were not significantly different between 2013 and 2016 (paired t-test $p=0.3$ for CRLA; $p=0.7$ for LAVO). Tables 4 and 5 show 2013 and 2016 PIAL seedlings/ha comparisons.

Table 2. Summary table for trees/ha and seedlings/ha at Crater Lake NP. ABMA = *Abies magnifica*; PIAL = *Pinus albicaulis*; PICOM = *Pinus contorta* var. *murrayana*; TSME = *Tsuga mertensiana*.

Species Code	Avg trees/ha (SD)	Range	Avg seedlings/ha (SD)	Range
ABMA	0.8 (2.5)	0-8	0	N/A
PIAL	63.6 (68.9)	4-188	98.7 (182.1)	0-493
PICOM	20.4 (42.7)	0-140	0	N/A
TSME	324.8 (414.8)	0-1248	283.9 (740.9)	0-4814

Table 3. Summary for trees/ha and seedlings/ha at Lassen Volcanic NP. ABMA = *Abies magnifica*; PIAL = *Pinus albicaulis*; PICOM = *Pinus contorta* var. *murrayana*; PIMO = *Pinus monticola*; and TSME = *Tsuga mertensiana*.

Species Code	Avg trees/ha (SD)	Range	Avg seedlings/ha (SD)	Range
ABMA	1.6 (3.4)	0-8	0	N/A
PIAL	103.6 (90.7)	12-276	61.7 (104.9)	0-264
PICOM	0.4 (1.2)	0-4	0	N/A
PIMO	1.6 (5.1)	0-16	0	N/A
TSME	488.8 (268.9)	20-876	679 (1064)	0-3456

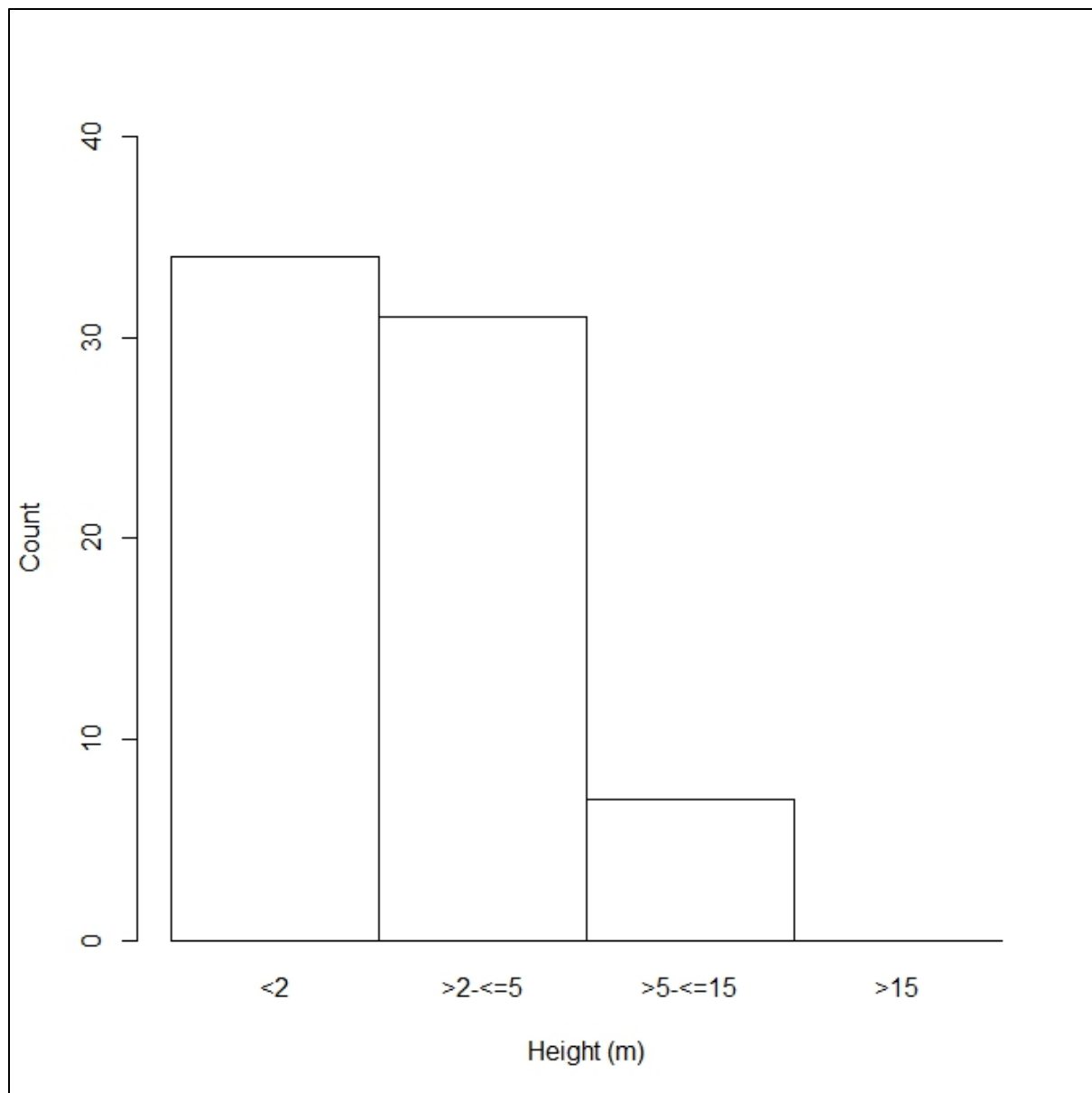


Figure 6. New trees at Lassen Volcanic NP tagged in 2016, by height class.

White Pine Blister Rust Infection

We documented white pine blister rust infection in whitebark pine trees, as well as other causes of mortality, in monitoring plots from the 2016 season at CRLA and LAVO.

Crater Lake National Park

In CRLA, the proportion of live whitebark pine per plot infected by white pine blister rust ranged from 0% to 100%, and the average rate of infection among all PIAL was 13% (Figure 7, Table 4). Of the 159 live trees assessed, 21 showed signs of infection: 19 inactive, two active. Infected whitebark pine trees/ha is shown in Table 4. We observed six recently dead PIAL trees, and two had inactive blister rust infection in 2013. Of the 79 PIAL that had inactive cankers in 2013 and were still alive in

2016, 17 still had observable inactive cankers in 2016, and one had active cankers. The remaining 61 PIAL did not meet our criteria being classified as either inactive or active. Of the seven PIAL that had active cankers in 2013, none still had active cankers, or observable inactive cankers, and one tree could not be found. We could identify, with confidence, the cause of death for three of the six recently dead whitebark pine trees in CRLA; all three died from blister rust.

Table 4. Summary statistics of whitebark pine (*Pinus albicaulis*) for Crater Lake NP plots 2013 and 2016 (n=10). Standard deviations in parenthesis.

Parameter	2013 CRLA	Range	2016 CRLA	Range
Blister Rust Infection (% trees/plot)	55 (39)	0-100	23 (34)	0-100
Blister Rust Infected Trees (# trees/ha)	36 (37)	0-108	8 (14)	0-44
Active Cankers Present (# trees/ha)	3.2 (6.2)	0-20	0.8 (2.5)	0-8
Inactive Cankers Present (# trees/ha)	32.8 (35)	0-108	7.6 (13.7)	0-44
Seedlings (seedlings/ha)	49 (119)	0-370	99 (182)	0-493
Mistletoe Infection (# trees/ha)	0 (--)	--	0 (--)	--
Beetle Infestation (# trees/ha)	0.8 (1.7)	0-4	0 (--)	--
Female Cones Presence (# trees/ha)	9.2 (14.2)	0-44	10 (13.5)	0-36

Lassen Volcanic National Park

In LAVO, the proportion of live whitebark pine per plot infected by blister rust ranged from 0% to 67%, and the average rate of infection among all PIAL was 4.6% (Figure 8, Table 5). Of the 259 live trees assessed, 12 showed signs of infection, including three active types, 10 inactive types, and one tree had both types. Infected whitebark pine trees/ha is shown in Table 5. Of the 50 live whitebark pine that had inactive cankers in 2013, six live PIAL still had visible inactive cankers in 2016. The remaining 44 PIAL did not meet our criteria being classified as either inactive or active. One of the three trees with active cankers in 2013 still had active cankers in 2016, and one showed signs of inactive cankers. We could identify cause of death for two of the three recently dead whitebark pine; both died from blister rust.

Table 5. Summary statistics of whitebark pine (*Pinus albicaulis*) for Lassen Volcanic NP plots 2013 and 2016 (n=10). Standard deviations in parenthesis.

Parameter	2013 LAVO	Range	2016 LAVO	Range
Blister Rust Infection (% trees/plot)	21 (15)	0-44	11 (20)	0-66
Blister Rust Infected Trees (# trees/ha)	22 (20)	0-52	5 (6)	0-20
Active Cankers Present (# trees/ha)	1.6 (3.9)	0-12	1.2 (2.7)	0-8
Inactive Cankers Present (# trees/ha)	21.2 (18.8)	0-44	4 (5)	0-16
Seedlings (seedlings/ha)	20.8 (39.5)	0-128	61.7 (104.9)	0-264
Mistletoe Infection (# trees/ha)	0 (--)	--	0 (--)	--
Beetle Infestation (# trees/ha)	0.8 (1.7)	0-4	0.4 (1.3)	0-4
Female Cones Presence (# trees/ha)	26 (38.8)	0-124	47.6 (65.9)	0-200

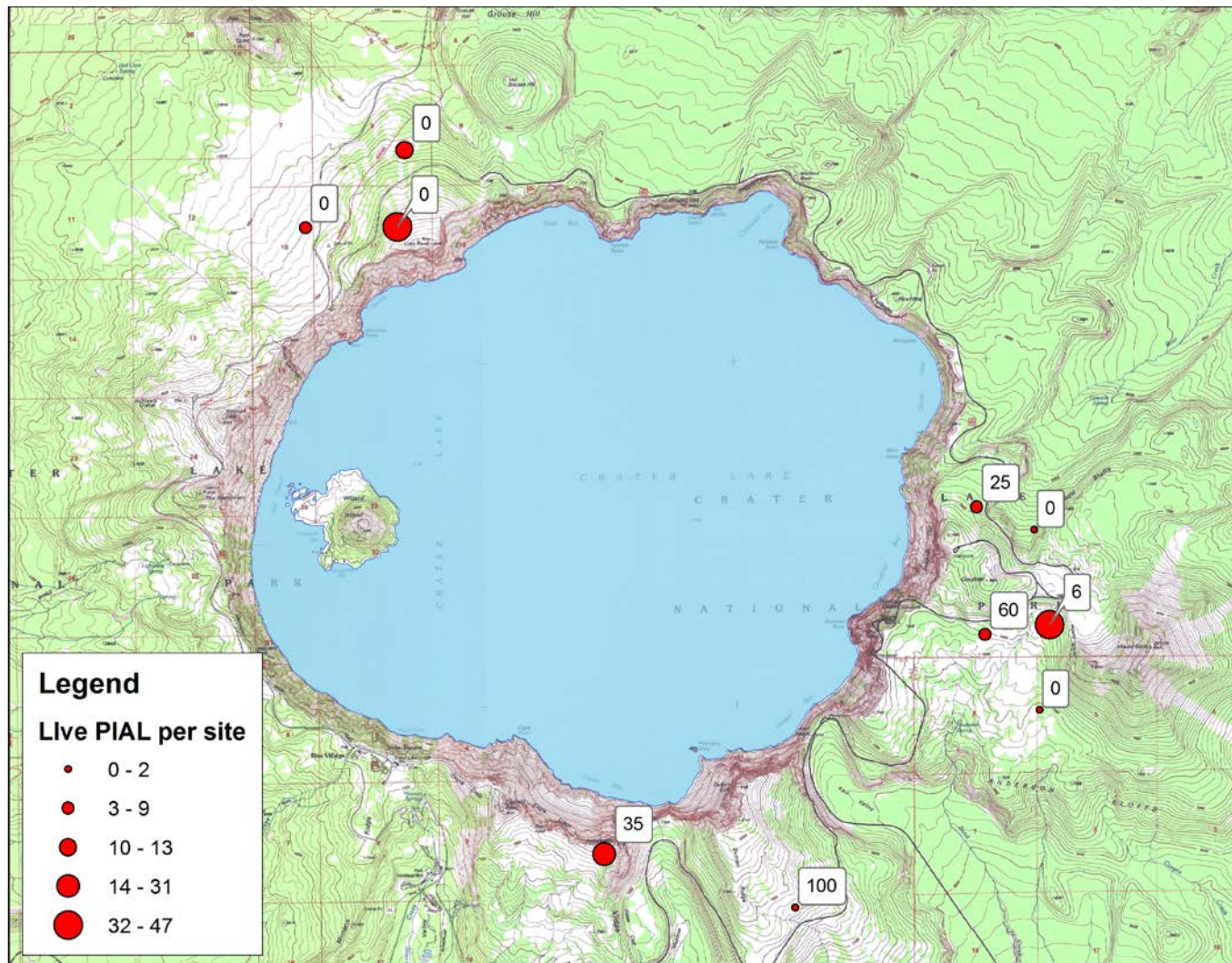


Figure 7. Crater Lake NP whitebark pine sites from 2016. Dot size is proportional to the number of live whitebark pine (PIAL) at each site. Labels indicate percentage of whitebark pine infected at each site.

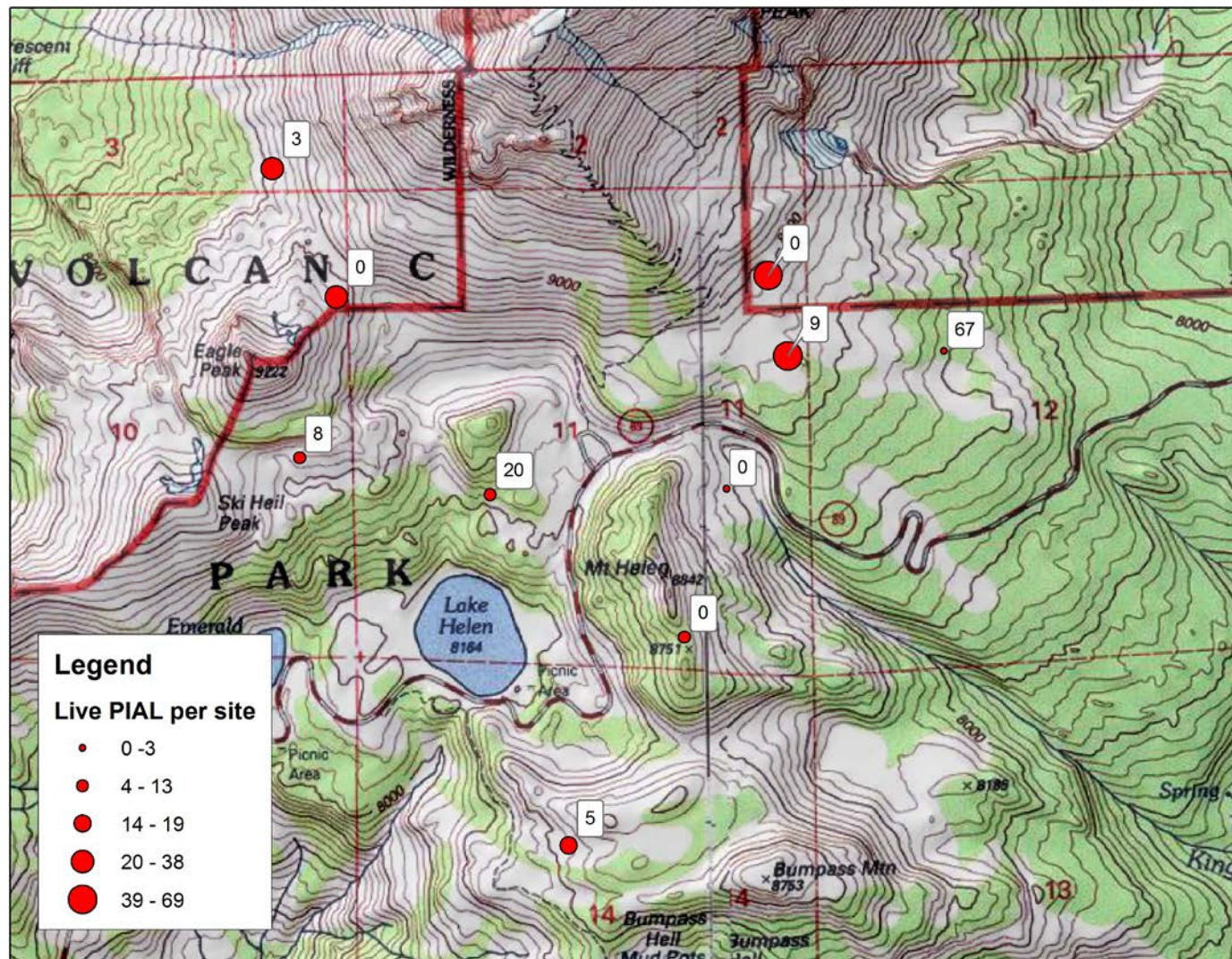


Figure 8. Lassen Volcanic NP whitebark pine sites from 2016. Dot size is proportional to the number of live whitebark pine (PIAL) at each site. Labels indicate percentage of whitebark pine infected at each site.

Overall Blister Rust Infection

Although mean blister rust infection percent by plot was lower in 2016 than 2013 for both parks sampled, these differences were not statistically significant. At CRLA, the average proportion of live infected trees per plot in 2016 (23%) was lower than that in 2013 (55%), but this difference was not statistically significant ($p=0.089$; Figure 9). At LAVO the average proportion of live infected trees per plot in 2016 (11%) was lower than that in 2013 (21%), but this difference was not statistically significant ($p=0.19$; Figure 9, Tables 4 and 5).

At CRLA and LAVO, respectively, 3.7% and 1.2% of the PIAL died between 2013 and 2016. We estimated the percentage of blister rust-attributed death at 50% for CRLA and 67% for LAVO. Determining the exact mechanism of tree death can be difficult, due to weathering or decay, but can sometimes be estimated when comparing the 2013 and 2016 data. Two trees at CRLA and one at LAVO had undetermined causes of death in 2016 but had inactive blister rust cankers in 2013, suggesting that the trees were killed by blister rust. If we attribute the cause of death to blister rust for trees that exhibited blister rust during a previous survey, blister rust-caused death could be as high as 83% at CRLA and 100% at LAVO.

Beetles, Female Cones, and Mistletoe

Crater Lake National Park

No PIAL at Crater Lake showed signs of beetle infection (mountain pine beetle [MPB] or other). No PIAL had cause of death attributed to MPB. Female cones were observed at seven sites, with a site mean of 2.5 trees with cones. Mistletoe was not observed on any trees. Summary statistics showing infected trees/ha are shown in Table 4.

Lassen Volcanic National Park

Lassen Volcanic had one PIAL with beetle (MPB or other) activity. No PIAL had cause of death attributed to MBP. Female cones were observed at nine sites, with a site mean of 11.9 trees with cones. Mistletoe was not observed. Summary statistics showing infected trees/ha are shown in Table 5.

Overall Beetle Infestation

No trees at Crater Lake had signs of beetles in 2016 versus two trees in 2013. We observed one PIAL tree with beetle presence at Lassen in 2016, and two infested trees in 2013. No recently dead trees evaluated in 2016 had mortality attributed to beetles.

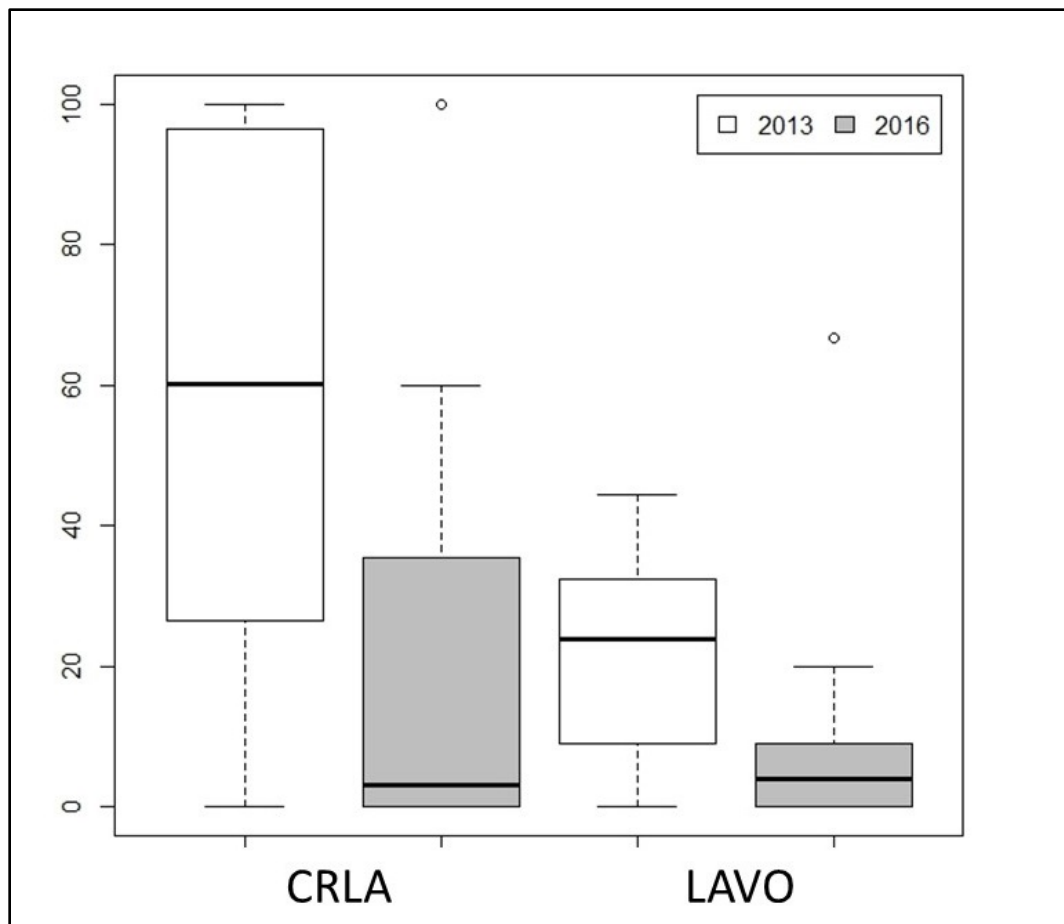


Figure 9. Blister rust infection plot percentages by park and year. The horizontal lines within boxes are mean values. Bottom and top of boxes show 25th (first quartile) and 75th (third quartile) percentiles, respectively. Whiskers show maximum and minimum, except when outliers are present. Outliers are shown as hollow dots, and are 1.5 times below the first quartile and 1.5 times above the third quartile. (Note that 1.5 times the interquartile range of the data is roughly 2 standard deviations, and the interquartile range is the difference in the response variable between the first and third quartiles.).

Discussion

The 2016 whitebark pine monitoring in CRLA and LAVO was successfully implemented as planned. We followed the protocol (McKinney et al. 2012) and revisited 20 plots established in 2013, including 10 from each park.

In both parks, average rate of blister rust infection in 2016 appeared lower than in 2013, but this difference was not statistically significant. Blister rust accounted for the majority of PIAL tree death in 2016. The severity of blister rust infection is influenced by many factors, and any discussion of the reasons for the lower infection rate in 2016 would be speculation. However, Jules et al. (in press) provides an initial evaluation on local blister rust dynamics. Through continued monitoring and trend analysis we aim to gain a better understanding of blister rust dynamics and infection through time.

Beetle presence in 2016 was very low: No PIAL trees at CRLA and one at LAVO. Possibly, the beetle outbreak that was responsible for a good portion of previous PIAL mortality (Jackson et al. 2015) could be on the decline. Beetle outbreaks are typically episodic, and a decline after a mass infestation event is expected, but the current situation with mountain pine beetle seems to be closely tied to climate (Logan et al. 2010) and may be more complex than historic outbreaks. Continued monitoring will aid us in evaluating the relationship between beetles, climate, and whitebark pine.

Although tagging of seedlings is not specifically a part of the McKinney et al. (2012) protocol, some seedlings had been tagged by the HSU field crew. At LAVO, all PIAL seedlings were tagged, but no TSME seedlings were tagged. At CRLA, both species of tree seedlings were tagged (TSME and PIAL), but not all seedlings. The six PIAL that were not tagged were also not observed in 2013, and we did not choose to tag these seedlings in 2016. When tags were observed, we recorded tag numbers in the database comment field. Other networks using the shared McKinney et al. (2012) protocol have expressed interest in tagging seedlings for the purposes of tracking individual growth and mortality. We will discuss this with other networks this winter and, likely, develop a shared SOP for tagging seedlings.

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Appendix A: Sampling schedule and revisit design for whitebark pine monitoring plots in CRLA and LAVO

Each “x” represents a site visit to the sampling panel. Plots within the six park panels were established during their first year of sampling (2012 – 2014).

Panel	Year								
	2012	2013	2014	2015	2016	2017	2018	2019	2020
CRLA 1 (n = 10)	x			x			x		
CRLA 2 (n = 10)		x			x			x	
CRLA 3 (n = 10)			x			x			x
LAVO 1 (n = 10)	x			x			x		
LAVO 2 (n = 10)		x			x			x	
LAVO 3 (n = 10)			x			x			x

Appendix B: Data recorded for each tree found within 50 × 50 m plots established in CRLA and LAVO.

Methods follow McKinney et al. (2012).

Parameter	Data Recorded
Species	Tree (nominal)
Diameter	Tree (cm)
Height	Tree (m)
Status	Tree (live or dead)
Crown kill	Each of three parts of a tree (%)
Active canker	Each of three parts of a tree (present/absent)
Inactive canker	Each of three parts of a tree (present/absent)
Rust infection	Tree (presence/absence of active or inactive canker)
Pine beetle	Tree (present/absent)
Dwarf mistletoe	Tree (present/absent)
Female cones	Tree (present/absent)
Seedlings	9 m ² plot; number of each of three size classes by species

Literature Cited – Appendix

McKinney, S. T., T. Rodhouse, L. Chow, A. Chung-MacCoubrey, G. Dicus, L. Garrett, K. Irvine, S. Mohren, D. Odion, D. Sarr, and L. A. Starcevich. 2012. Monitoring white pine (*Pinus albicaulis*, *P. balfouriana*, *P. flexilis*) community dynamics in the Pacific West Region: Klamath, Sierra Nevada, and Upper Columbia Basin Networks. Narrative version 1.0. Natural Resource Report NPS/PWR/NRR—2012/532. National Park Service, Fort Collins, Colorado.

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