Whitebark Pine (*Pinus albicaulis*) Mortality Monitoring in the Inyo National Forest – 2012 Report

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Widespread whitebark pine mortality along the slopes of the June Mountain ski area, Inyo National Forest.

Summary

Recent climate modeling projections and aerial-based tree mortality surveys have identified whitebark pine (*Pinus albicaulis*) populations in the southern Sierra Nevada as vulnerable to changes in climate and mountain pine beetle (MPB) outbreaks. We monitored whitebark pine populations in areas of recent (post–2005) and severe MPB-induced mortality to evaluate patterns of tree mortality, regeneration, and size class structure in whitebark pine stands of the Inyo National Forest in the southern Sierra Nevada. Our monitoring sites focused on whitebark pine dominated stands and included June Mountain, White Wing Mountain, and Rock Creek–Hilton Creek (collectively 'Rock Creek'). We also monitored nearby undisturbed 'control' sites lacking evidence of recent MPB related mortality at June Mountain and Rock Creek. We established a total of 66 plots (each 0.05 ha) and recorded site attributes, tree attributes and health, vegetation and ground cover, and tree regeneration. Our results indicate significant changes in stand structure, including the loss of basal area, tree densities, and canopy cover of whitebark pine in MPB-impacted stands. MPB-related mortality was greatest in larger diameter (>20 cm dbh) whitebark pine trees, but whitebark pine mortality was not contingent on the number of trees per cluster. In mortality plots from all sites, there was a shift in the size class distribution of whitebark pine to smaller diameter classes (<15 cm dbh) relative to control plots,

resulting in declines in mean tree diameter (all species), maximum tree diameter (whitebark pine), and the number of tree size classes following MPB attack (i.e., reduced structural diversity). Severity of MPB attack was positively related to the mean diameter of whitebark pine trees within stands, suggesting that stands containing larger whitebark pine were more susceptible to MPB attack. Whitebark pine regeneration was greater in MPB-impacted plots than control plots at June Mountain and White Wing Mountain, but there was no such difference at Rock Creek. Density of young (<3 year) whitebark pine seedling clusters was positively associated with percentage dead canopy cover and severity of MPB-attack, suggesting increased whitebark pine regeneration in response to stand impacts by MPB. All three sites showed a relatively stable production of whitebark pine regeneration at least within the past 50 years, with a pulse of new seedlings in the past 2–4 years in MPB-impacted stands. Our results show whitebark pine stands are heavily impacted by MPB outbreaks and suggest low resistance but potentially high resilience to initial attack. Long-term monitoring will be required to track future patterns of mortality, stand structure, and regeneration in whitebark pine populations of the southern Sierra Nevada.

Project Objectives

- Monitor patterns of mortality, regeneration, and recruitment in whitebark pine (*Pinus albicaulis*) populations experiencing mountain pine beetle outbreaks in the Inyo National Forest of the southern Sierra Nevada.
- Evaluate both status-and-trend monitoring of mountain pine beetle impacted stands and effectiveness monitoring of whitebark pine restoration treatments at June Mountain ski area.
- Use monitoring data from this project to contribute to improving future mountain pine beetle risk models in whitebark pine stands.
- Contribute to the development of a long-term monitoring plan and restoration and climate adaptation strategies for vulnerable whitebark pine populations on the Inyo National Forest.

Background

Recent climate modeling projections have identified whitebark pine populations in the southern Sierra Nevada as vulnerable to future changes in climate and climate-related stressors, such as introduced diseases and mountain pine beetle (MPB) outbreaks (Warwell et al. 2007, Anderson et al. 2012, Schwartz and Thorne *in prep*.) These projections are supported by recent (post-2005) observations of MPB outbreaks in several whitebark pine populations of the region (Millar et al. 2012). Taken in combination, these results signal an imperative need for monitoring whitebark pine populations in the southern Sierra Nevada, especially in areas of recent beetle-related mortality. Despite these recent observations, whitebark pine populations in the southern Sierra Nevada are one of the least studied in its entire geographic range, resulting in a significant information gap. Additionally, MPB-related mortality in the southern Sierra Nevada has taken place in the absence of the exotic white pine blister rust (WPBR), which is pervasive throughout much of the geographic range of whitebark pine, including northern California (Maloney 2011). The absence of WPBR in our study area provides us with a unique opportunity to study the effects of MPB not confounded by WPBR or other introduced pathogens. Results of this study have important implications for whitebark pine in the Sierra Nevada and potentially throughout its geographic range (Maloney 2011, Keane et al. 2012).

There is a critical need for monitoring whitebark pine populations in the southern Sierra Nevada, which represents the southernmost extent of the species' range (McCaughey and Schmidt 2001). Aerial and ground surveys since 2006 by Forest Health Monitoring (FHM) and Forest Health Protection (FHP) have identified unprecedented tree mortality levels with some sites experiencing a loss of up to 95% of all trees >5 inches dbh (B. Bulaon, unpublished data). Annual aerial reports show that mortality has not yet subsided, but rather is moving through the geographic range of whitebark pine in the region (Heath et al. 2012). The Inyo National Forest is especially concerned with the loss of a keystone species, but also safety hazards that have resulted due to the magnitude of tree mortality in popular recreation sites (USDA Forest Service 2012). This project will provide necessary information to understand patterns of MPB host selection, the extent and severity of MPB outbreaks in whitebark pine ecosystems, and the aftermath and progression of vegetation development post-outbreak. Monitoring data and summaries are critical for the development of regional whitebark pine restoration and climate adaptive strategies (e.g., Keane et al. 2012). This will be accomplished in close coordination with Southern Sierra Ecoregional Vulnerability Assessment, which is focused on modeling future changes in vegetation such as whitebark pine populations in response to climate and climate-related processes (Nydick and Sydoriak 2011a,b).

Whitebark pine is one of several five-needled pines with very limited ranges in high elevation forests of the western United States (Arno and Hoff 1990, McCaughey and Schmidt 2001). In California, whitebark pine occurs as isolated populations of trees occurring along mountaintop ridges and plateaus, enduring extreme weather conditions and environments (Griffin and Critchfield 1972). Whitebark pine is vital to the sustainability of high elevation ecosystems, providing ground stabilization for snowpack, overstory cover for delicate subalpine vegetation, and wildlife habitat and forage (Tomback et al. 2001). Monitoring vegetation and ecological changes after significant disturbances will provide crucial information of whitebark pine survival and persistence (Keane et al. 2012), which may also be applied to other high-elevation white pines in the southern Sierra Nevada (e.g., limber pine, *P. flexilis*; foxtail pine, *P. balfouriana*).

With this project, FHP, R5 Ecology, and the Inyo National Forest will assess: (1) status-and-trend monitoring of high-mortality and adjacent low-mortality (control) stands in the area, and (2) effectiveness monitoring of stands scheduled for restoration treatments (both pre- and post-treatment monitoring on June Mountain). Additional resources will be required to adequately monitor this growing problem both locally at June Mountain and across the region. Long-term monitoring of whitebark pine stands in response to MPB and other stressors (white pine blister rust) will be required to develop ecological restoration and climate adaptation strategies for vulnerable whitebark pine populations.

Approach/Methods:

We initiated monitoring of the ecological condition of whitebark pine populations on the Inyo National Forest using a 100-m grid-based monitoring design developed collaboratively by the Southern Sierra Forest Health and Protection and Region 5 Ecology Programs (based on the Greater Yellowstone Ecosystem Whitebark Pine Monitoring Working Group Protocol; GYEWPWG 2007). We selected whitebark pine stands (≥50% whitebark pine in overstory) that have experienced recent (post-2005) tree mortality related to MPB for long-term monitoring. Our sites included June Mountain and White Wing Mountain (northern sites), and Rock Creek and Hilton Creek (southern sites; hereafter referred to collectively as 'Rock Creek'). Northern sites were located on pumice-based soils, whereas southern sites were located on granitic substrates. We also monitored undisturbed 'control' sites lacking evidence of recent MPB related mortality on June Mountain and Rock Creek, to evaluate potential associations with recent beetle outbreaks. All whitebark pine-dominated stands on White Wing Mountain were heavily impacted by recent MPB activity, so the nearest control sites on similar substrates were located approximately 2 km to the northwest at June Mountain. Recorded variables primarily included:

- Site attributes – slope, aspect, elevation, substrate, vegetation type, and topographic position;
- Tree attributes and health – density of live and dead stems and tree clusters, severity and timing of MPB attack, crown condition, cone abundance, evidence of diseases and dwarf mistletoe;
- Vegetation and ground cover – overstory and understory vegetation cover, litter and woody debris cover, mineral soil and rock cover, and live and dead basal area;
- Stand size class structure;
- Tree regeneration – density and age structure of seedlings and saplings, insects and diseases.

Monitoring will focus on whitebark pine but will include data collection for coexisting species (e.g., lodgepole pine, *P. contorta*; red fir, *Abies magnifica*).

Whitebark pine mortality in monitoring plot located at White Wing Mountain, Inyo National Forest.

Results

Stand and tree variables

We sampled a total of 66 plots (each 0.05 ha or ~0.12 acres in size), including 29 plots in the upper Rock Creek drainage near Hilton Lakes (24 high mortality plots, 5 control/low mortality plots), 27 plots in June Mountain (21 high mortality, 6 control/low mortality), and 10 plots at White Wing Mountain (all high mortality; Figure 1). Total sample area including tree attributes and regeneration was 3.3 ha (8.2 acres). All plots were dominated by whitebark pine, with 93.3% of the total basal area (live and dead stems) attributed to whitebark pine (94% in Rock Creek, 93% at June Mountain, and 92% at White Wing Mountain). The exceptions included 1 plot at Rock Creek, 2 plots at June Mountain, and 3 plots at White Wing Mountain which were dominated by a relatively even mixture of whitebark pine and lodgepole pine; one plot at White

Wing was dominated by whitebark pine and red fir. We located most mortality plots (82%) on north- and west-facing aspects, and none were located on south-facing aspects (Figure 2). We located control plots predominantly (91%) on south- and east-facing aspects due to the lack of available low-mortality whitebark pine stands on north- and west-facing aspects.

In high mortality plots, MPB attack typically occurred less than 4 years prior to monitoring and was most recent at Rock Creek followed by June Mountain and White Wing Mountain (Figure 3). Tree mortality in high mortality sites at Rock Creek and June Mountain was considerable, resulting in 85–90% loss in basal area (Figures 4, 5), 47–60% loss in whitebark pine tree densities (all stems ≥0.1 cm dbh; Figures 6, 7), and 71–80% loss in canopy cover (Figures 8, 9). Remaining live basal area and tree densities were substantially higher in control than mortality sites. Basal area was noticeably lower in high mortality plots at Rock Creek, and whitebark pine densities were substantially greater in control plots at June Mountain.

Severity of MPB attack on whitebark pine, using a composite metric based on frequency of trees attacked and number of attacks per tree, was consistently greater in high mortality than control sites with generally greater mortality with age since MPB attack (Figure 10). Mortality of whitebark pine trees across all sites was contingent on diameter class ($\chi^2 = 783.3$, df = 4, $P < 0.001$ for all size classes), with greater mortality in the larger size classes (>20 cm; 7.9 inches) and lower mortality in the smaller size classes (<10 cm; 3.9 inches) than expected (Figure 11). We observed a similar diameter-dependent mortality pattern for lodgepole pine across all size classes ($\chi^2 = 77.6$, df = 4, $P < 0.001$ for all size classes; Figure 12). Mean diameter (all species; $F_{1, 33} = 8.508$, $P < 0.001$), maximum diameter (whitebark pine only; $F_{1, 33} = 7.588$, $P < 0.001$), and the total number of diameter classes (all tree species in 5 cm increments; $F_{2, 31} = 16.577$, $P < 0.001$) in whitebark pine stands were reduced following mountain pine beetle attack at June Mountain and White Wing Mountain (Figures 13–15). In mortality plots from all sites, there was a shift in the size class distribution of whitebark pine to smaller diameter classes (<15 cm dbh) relative to control plots (Appendix A, Figures 23–27). As a consequence, there was also an increase in the relative contribution of live lodgepole pine and red fir to whitebark pine stands especially at Rock Creek and White Wing Mountain (Appendix A, Figures 28–30).

The number of live and dead whitebark pine trees was relatively similar across a range of cluster sizes (Figure 16; tree 'cluster' includes those whitebark pine stems within 1 m of nearby stems). This general trend indicates that whitebark pine tree mortality may not be dependent on the number of similarly-sized stems in close proximity. The severity of MPB attack on whitebark pine (live and dead trees included) was positively related to mean tree diameter at June Mountain and White Wing Mountain (Overall model: $F_{2, 31} = 19.732$, $R^2 = 0.532$, $P < 0.001$; Mean dbh: $\beta = 0.67$, $P < 0.001$; Figure 17).

The percentage of whitebark pine trees (both live and dead) producing cones was greatest in control sites, with a lower proportion of trees producing cones at June Mountain compared to Rock Creek and White Wing Mountain (Figure 18). Whitebark pine cone production index (based on the percentage of trees producing cones and the abundance of cones produced per tree) was virtually identical to the percentage of whitebark pine trees producing cones, indicating greater cone production within control than mortality plots.

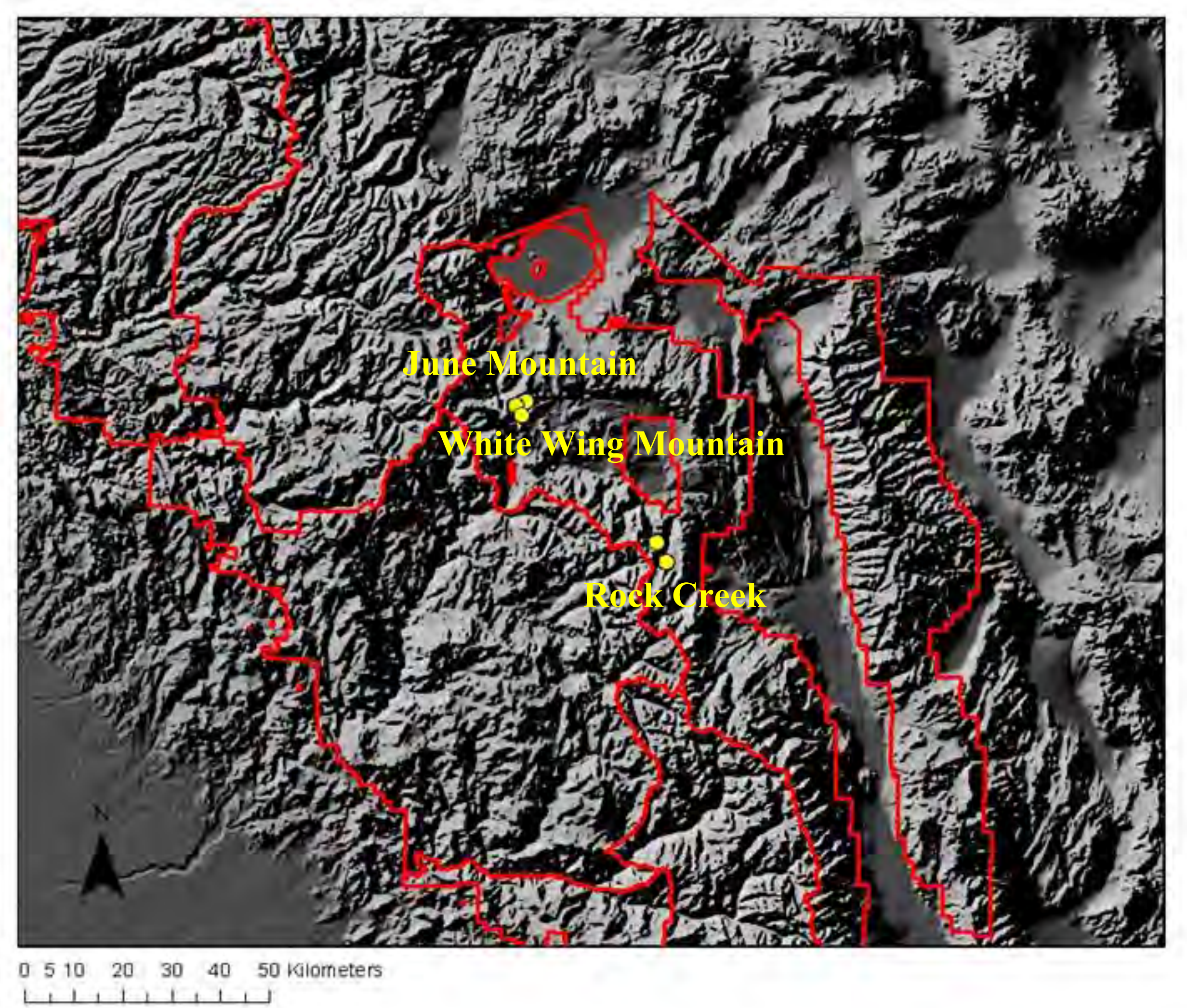

Figure 1. Map of monitoring plots on the Inyo National Forest. Plot locations include: (1) June Mountain (northern site), (2) White Wing Mountain (north-central site), and (3) Rock Creek/Hilton Creek (southern site). National Forest boundaries are outlined in red.

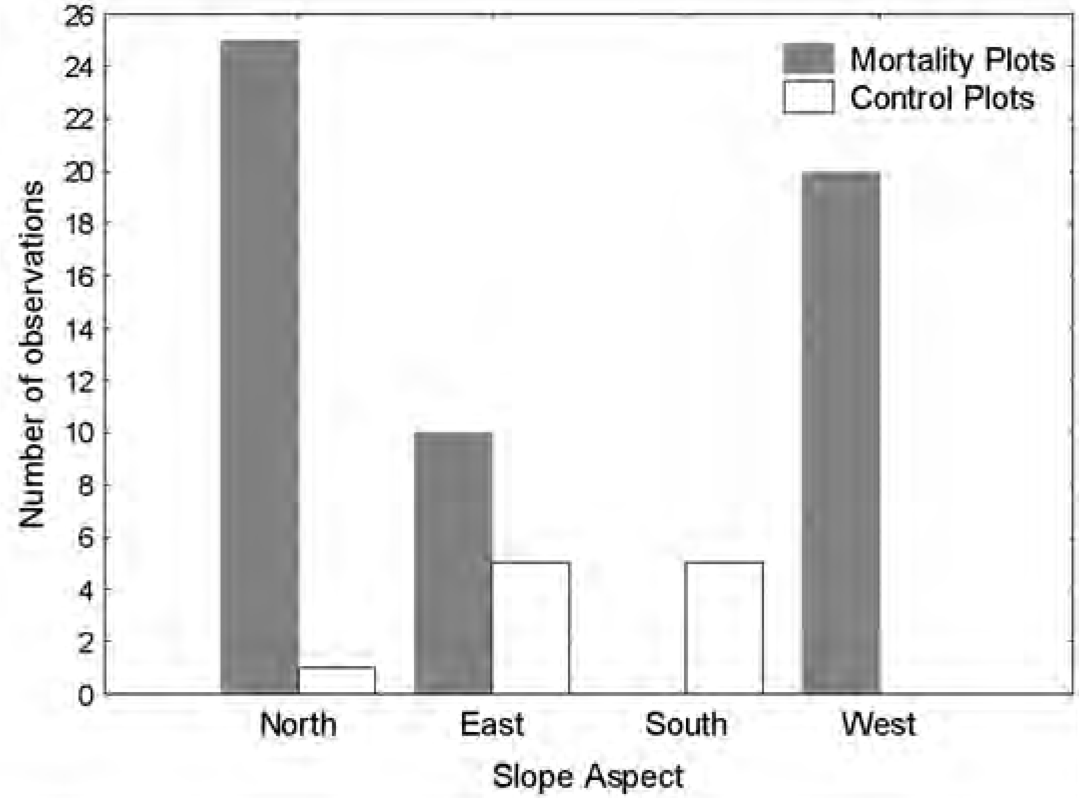

Figure 2. Slope aspect of mortality and control whitebark pine plots on the Inyo National Forest.

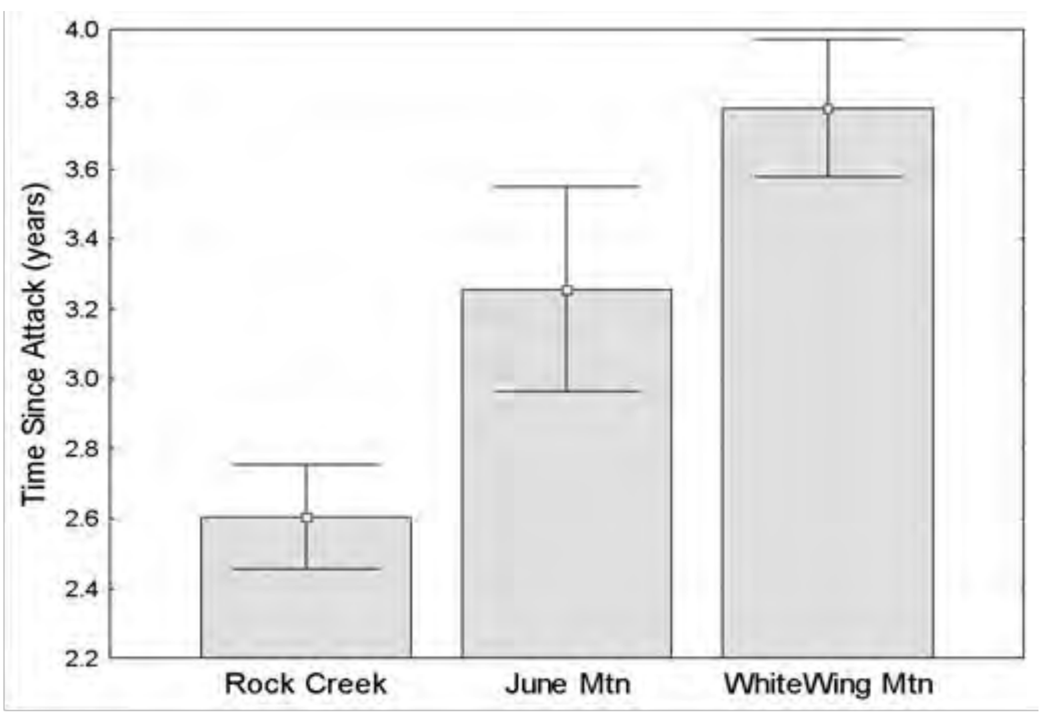

Figure 3. Mean (±95% Confidence Interval; CI) time since mountain pine beetle attack of whitebark pine stands at three whitebark pine monitoring sites on the Inyo National Forest.

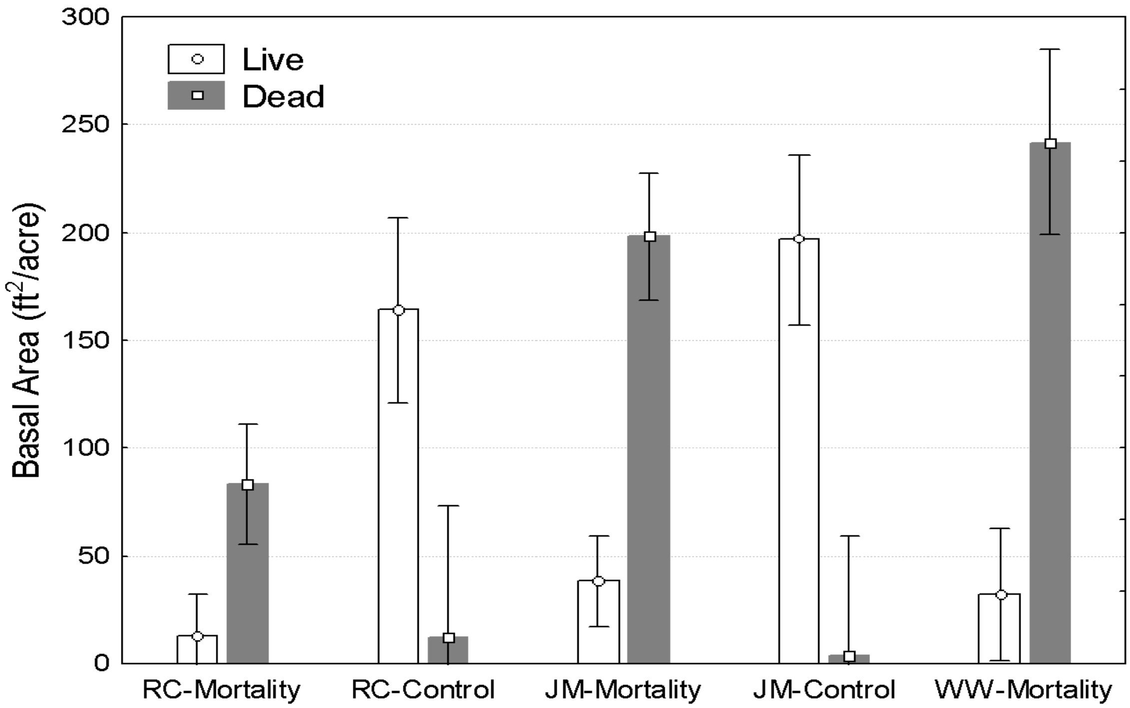

Figure 4. Mean (±95% CI) basal area of whitebark pine stands at three subalpine stands on the Inyo National Forest. Approximately 93% of mean basal area across sites consisted on whitebark pine.

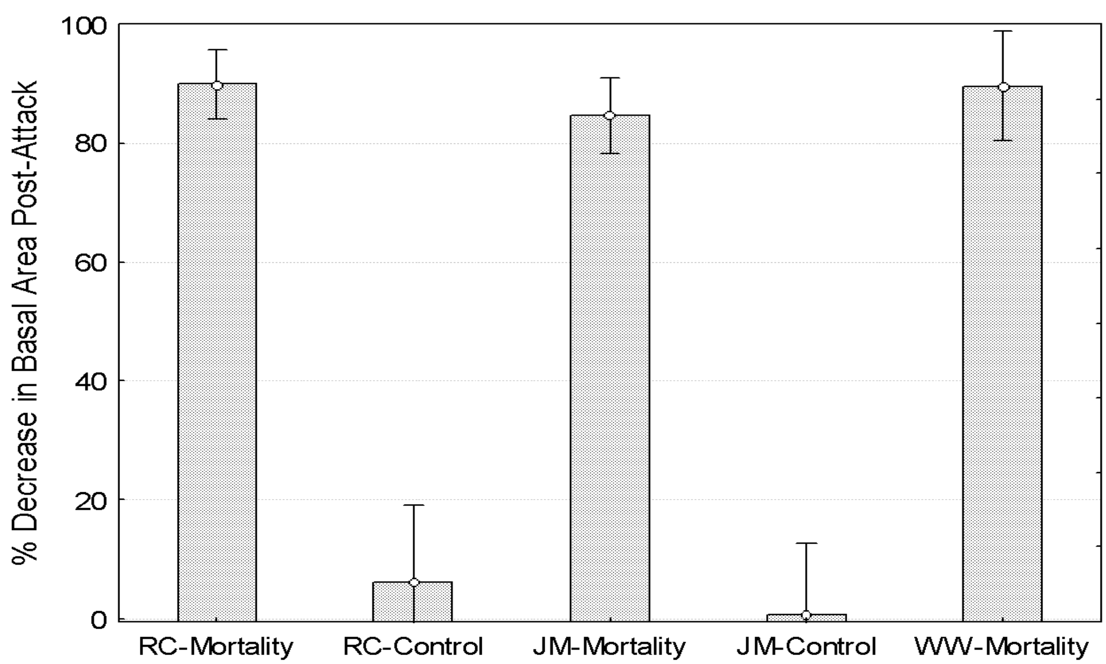

Figure 5. Mean (±95% CI) percent decrease in basal area of whitebark pine stands following mountain pine beetle attack at three subalpine stands on the Inyo National Forest.

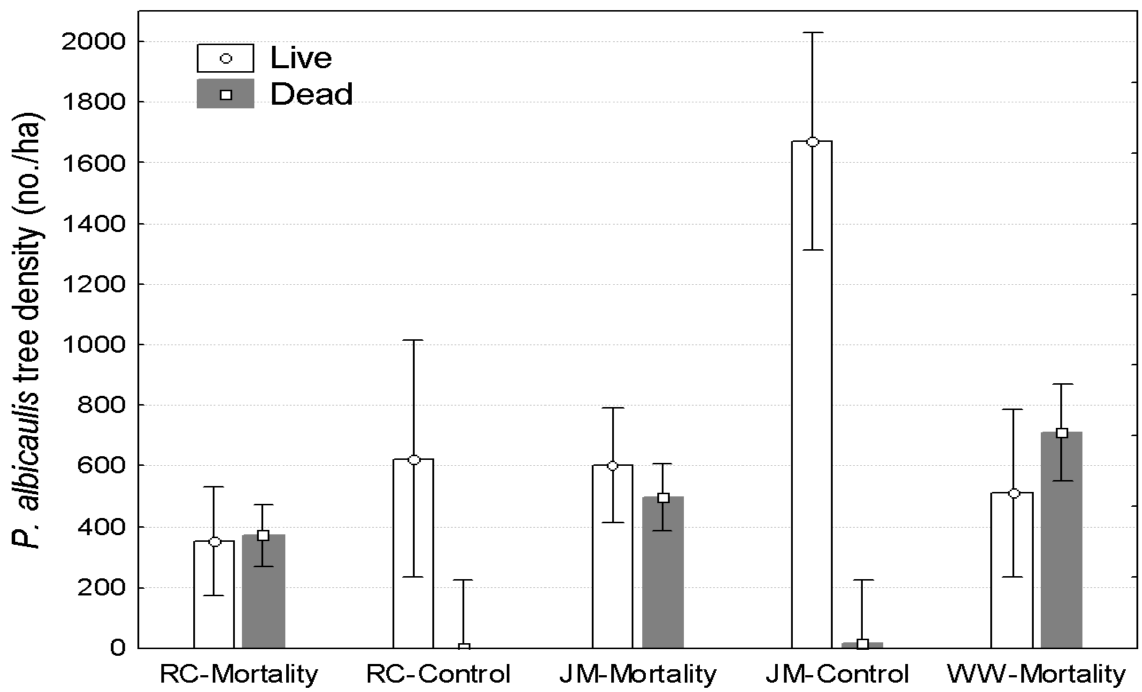

Figure 6. Mean (±95% CI) whitebark pine tree densities in subalpine stands of the Inyo National Forest. Density estimates include all stems ≥ 0.1 cm dbh.

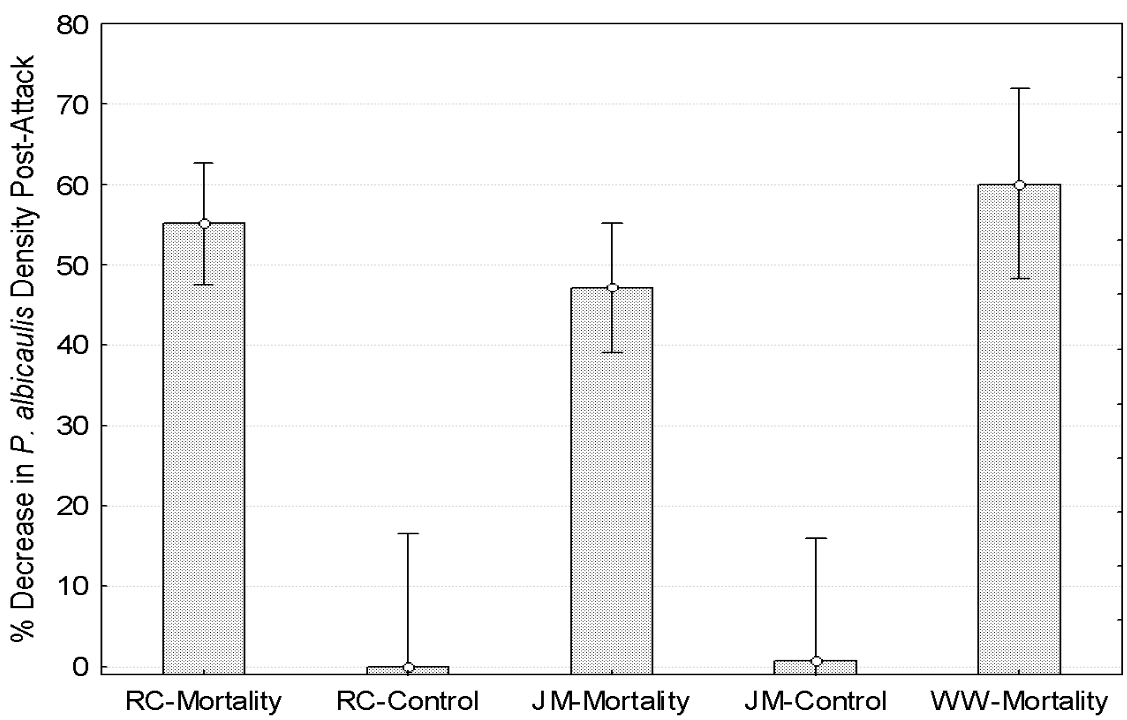

Figure 7. Mean (±95% CI) percent decrease in whitebark pine tree densities (all stems ≥ 0.1 cm dbh) following mountain pine beetle attack in subalpine pine stands of the Inyo National Forest.

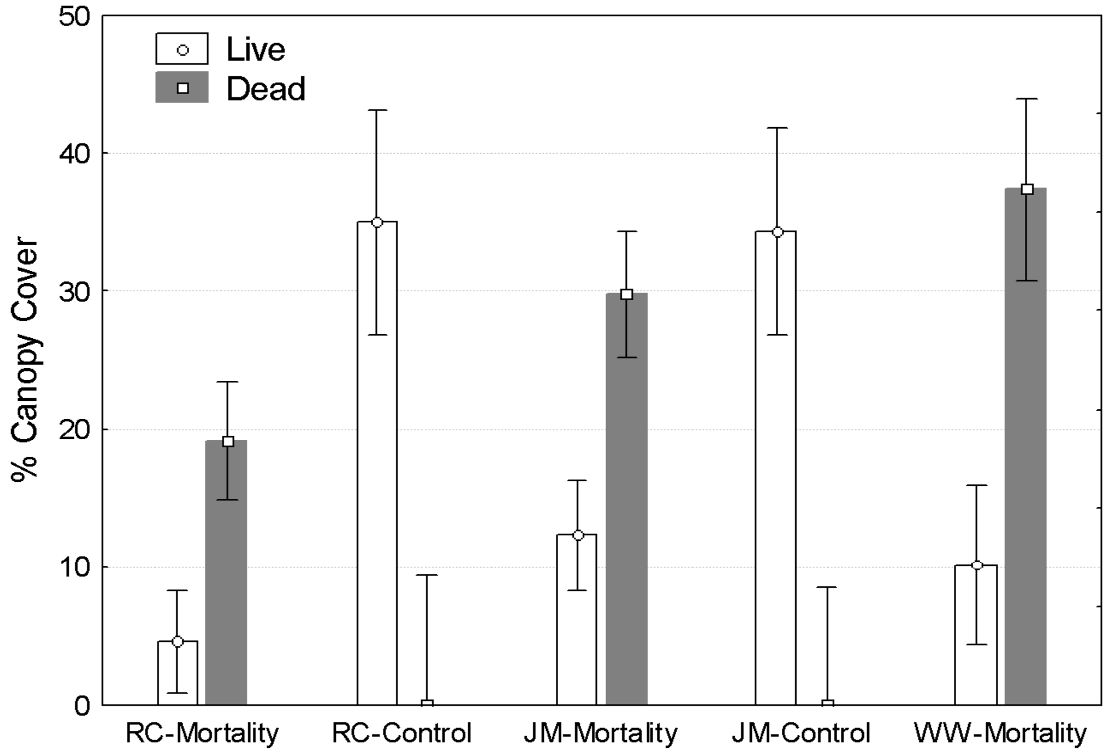

Figure 8. Mean (±95% CI) canopy cover of whitebark pine stands at three subalpine sites on the Inyo National Forest.

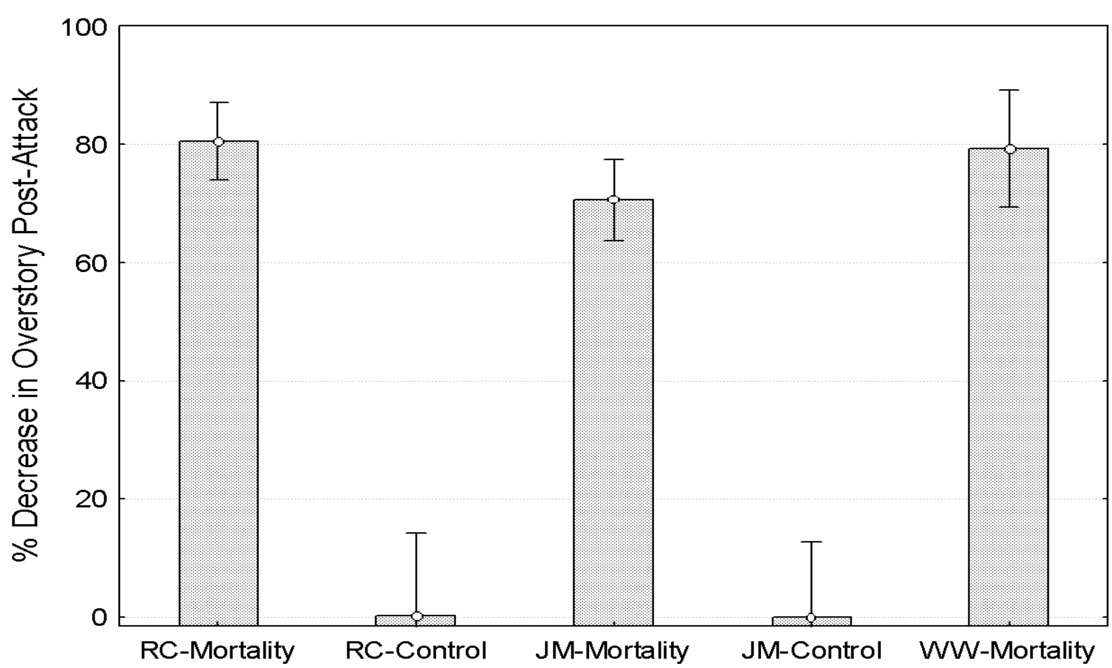

Figure 9. Mean (±95% CI) percent decrease in canopy cover following mountain pine beetle attack at whitebark pine stands on the Inyo National Forest.

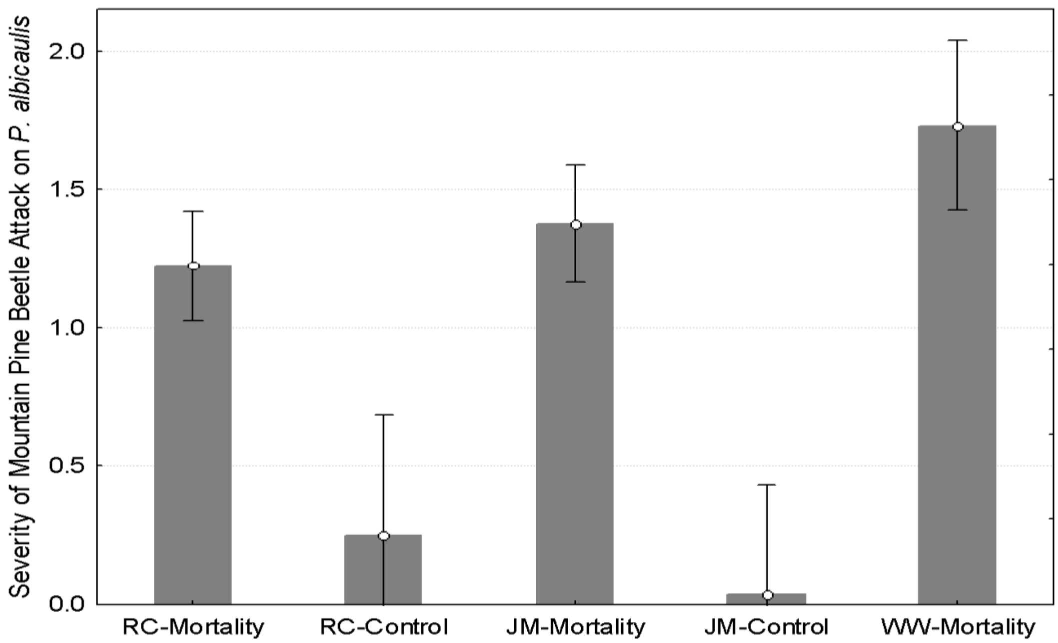

Figure 10. Mean (±95% CI) severity of mountain beetle attack on whitebark pine trees (scale range: 0 to 3). Values below 0.5 generally represent low or background severity, 0.5 to 1.0 moderate severity, and above 1.0 high severity.

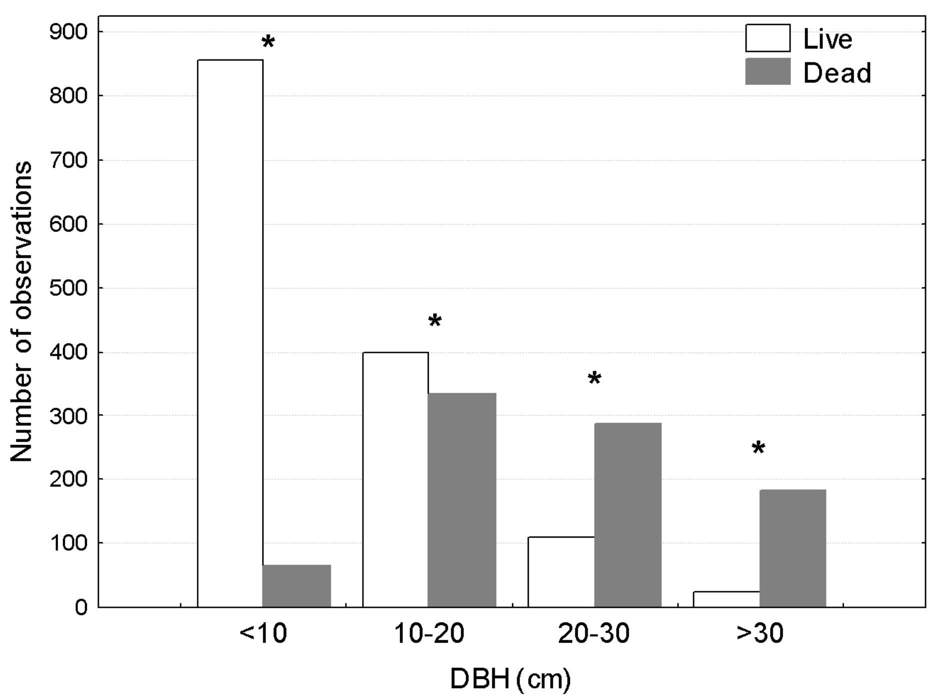

Figure 11. Frequency of live and dead whitebark pine trees by diameter class. A chi-square test was used in all significance testing (* indicates that the observed mortality in each size class is significantly greater or lower than the overall expected mortality for that class; $P < 0.001$). Data in figure is based on June Mountain and White Wing Mountain.

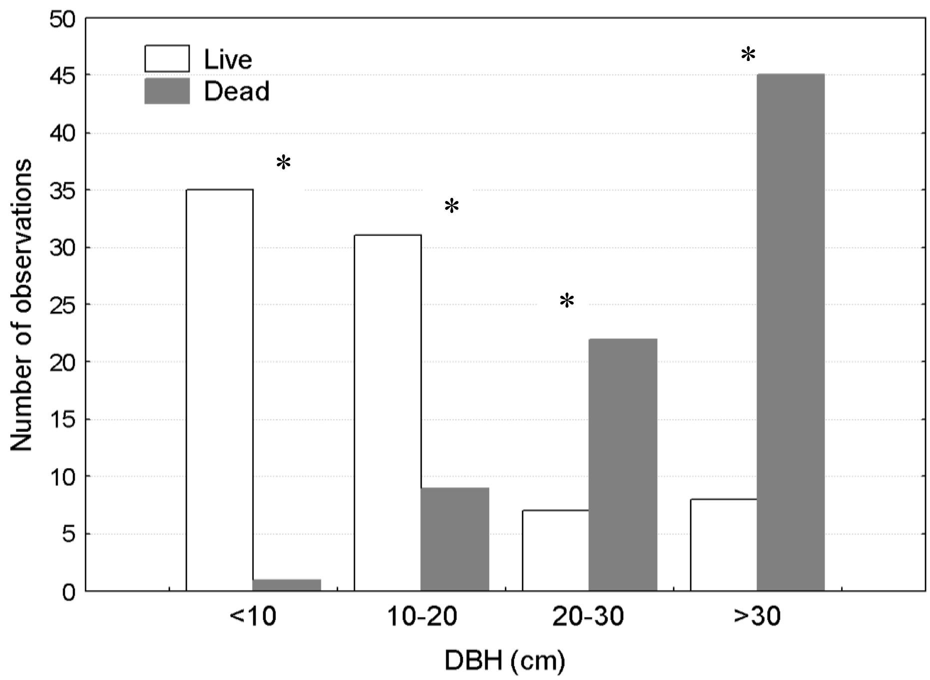

Figure 12. Frequency of live and dead lodgepole pine trees by diameter class. A chi-square test was used in all significance testing (* indicates that the observed mortality in each size class is significantly greater or lower than the overall expected mortality for that class; $P < 0.01$). Data in figure is based on June Mountain and White Wing Mountain.

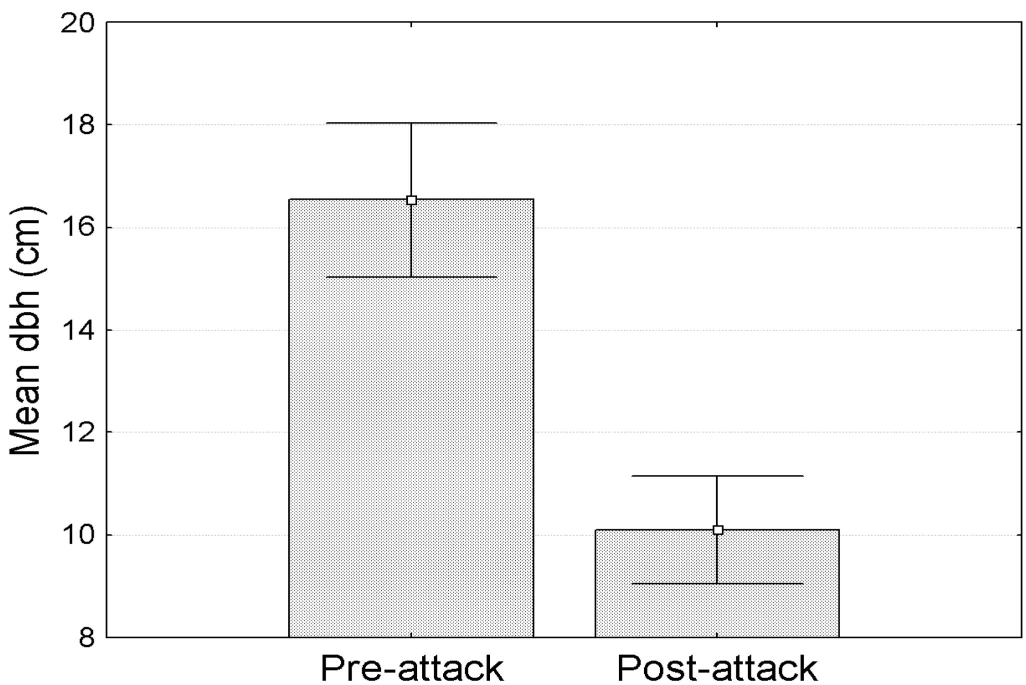

Figure 13. Mean (±95% CI) tree diameter of whitebark pine stands prior to and following mountain pine beetle attack on the Inyo National Forest.

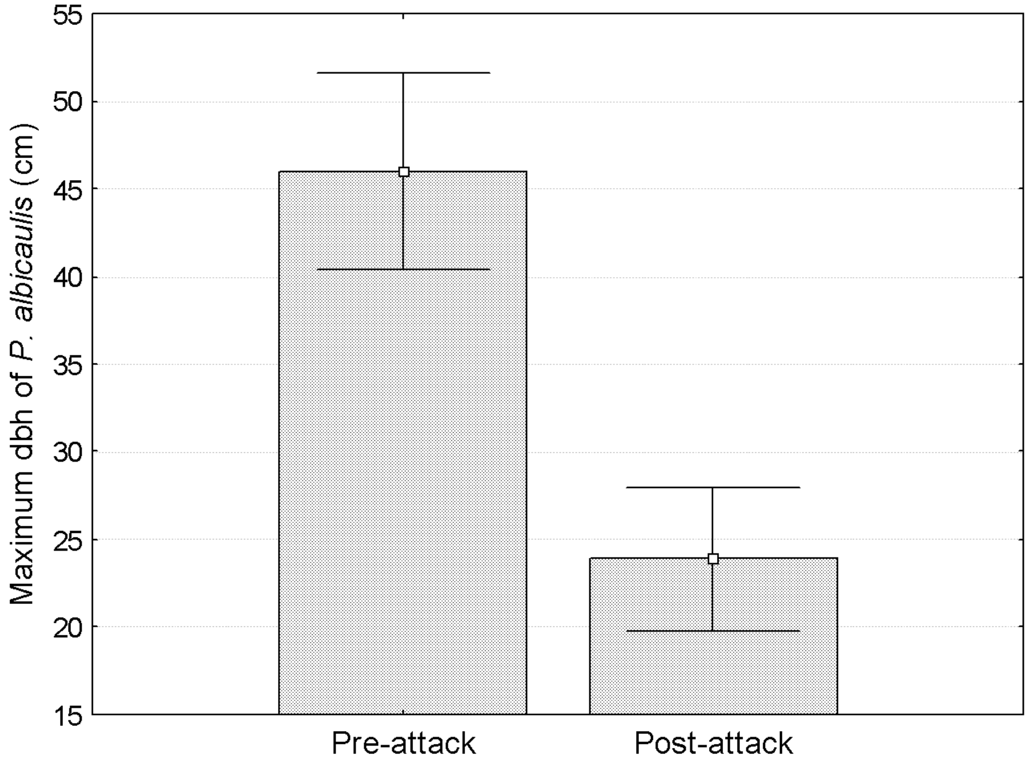

Figure 14. Maximum (±95% CI) tree diameter in whitebark pine stands prior to and following mountain pine beetle attack on the Inyo National Forest.

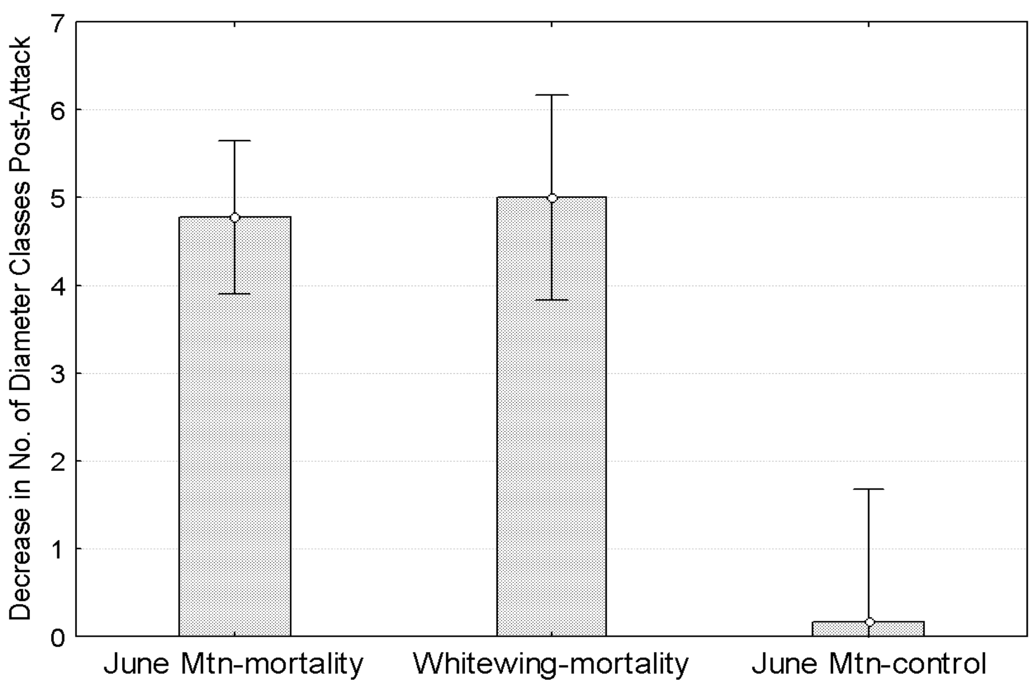

Figure 15. Mean (±95% CI) decrease in the number of tree diameter classes (5 cm increments) following mountain pine beetle attack in whitebark pine stands on the Inyo National Forest.

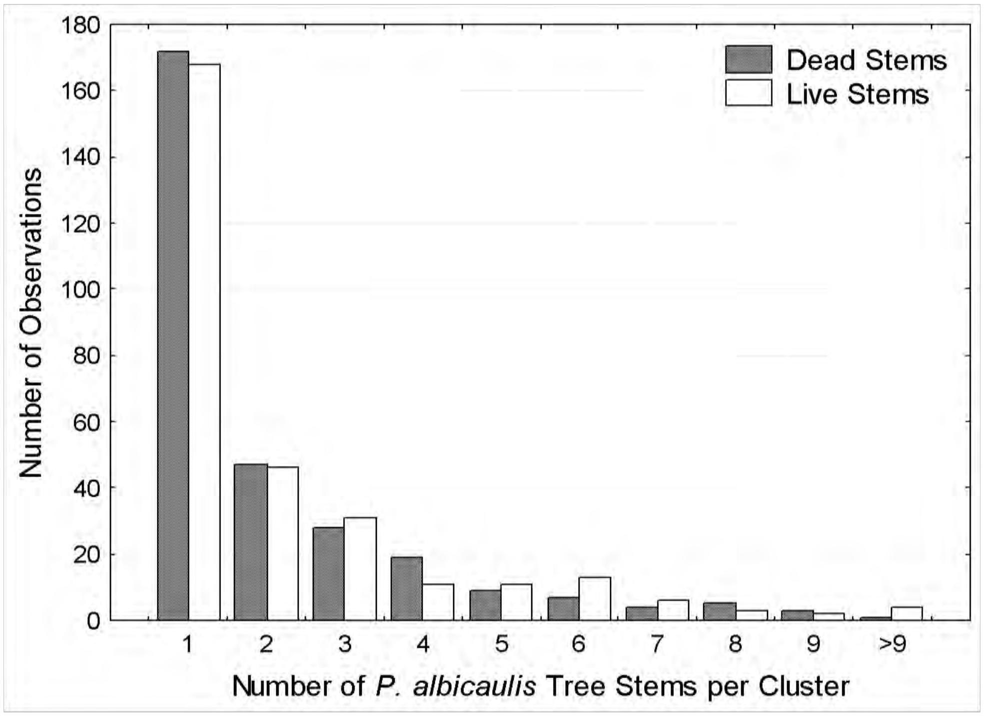

Figure 16. Number of live and dead whitebark pine tree stems per cluster (based on Rock Creek data only). Note the relatively even ratio of live-to-dead stems across the range of cluster sizes.

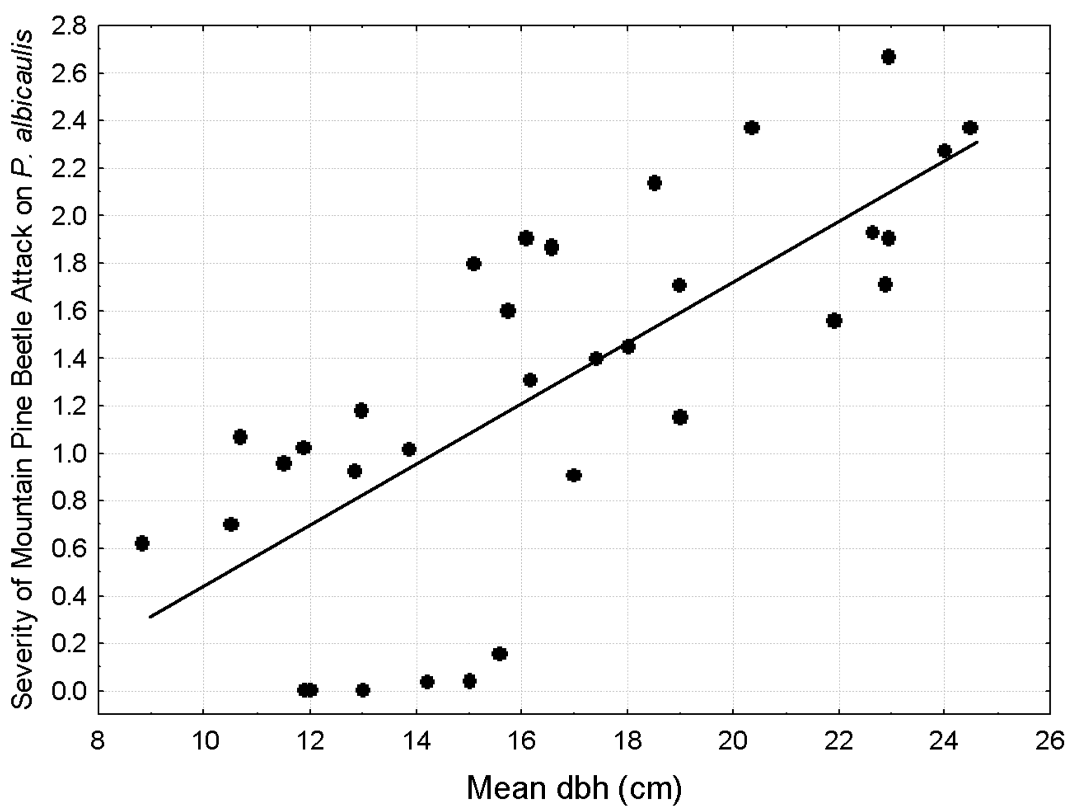

Figure 17. Relationship between mean tree diameter of whitebark pine stands and the severity of attack by mountain pine beetle. Data based on June Mountain and White Wing Mountain.

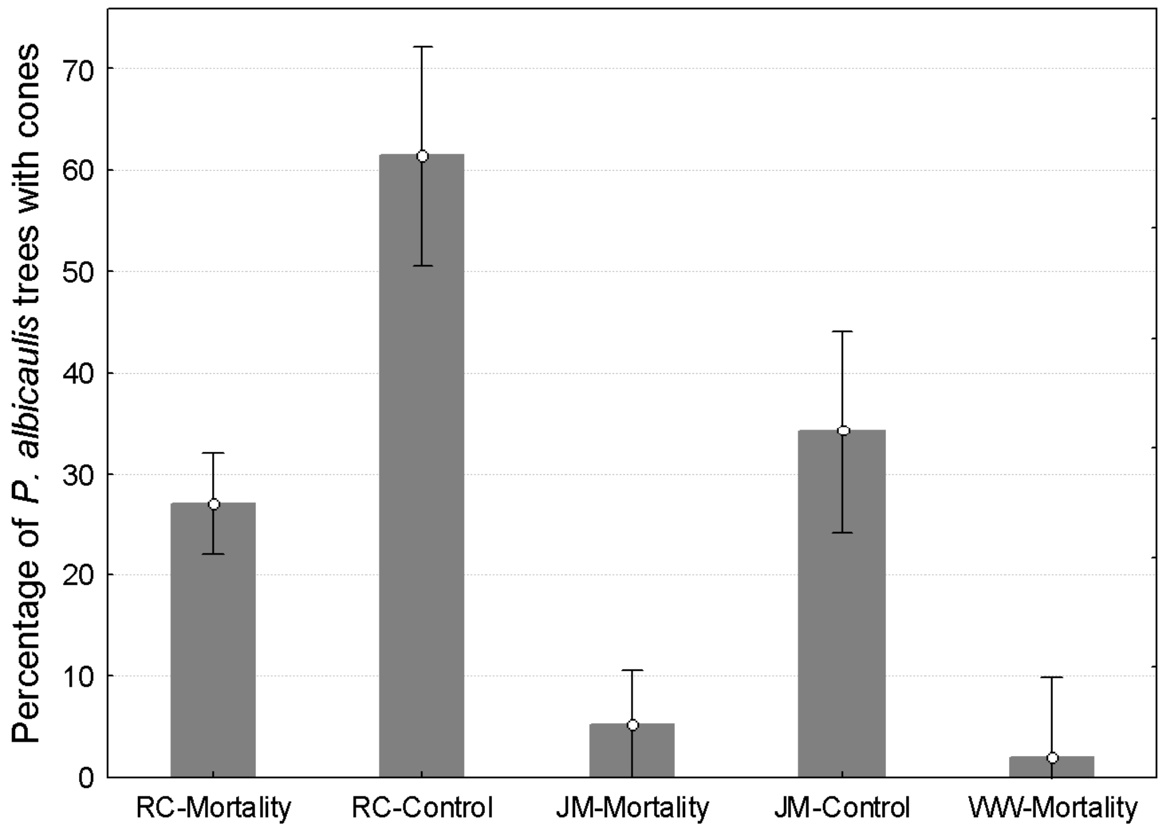

Figure 18. Mean (±95% CI) percentage of whitebark pine trees (live and dead) with cones in whitebark pine stands.

Whitebark pine mortality monitored in the Hilton Lakes area near Rock Creek, Inyo National Forest.

Tree regeneration

Density of whitebark pine regeneration was similar between high mortality and control sites at Rock Creek, but regeneration at June Mountain was greater in mortality than control sites (Figure 19). Whitebark pine regeneration at White Wing Mountain was intermediate between Rock Creek and June Mountain high mortality sites. Greater relative densities of whitebark pine regeneration at June Mountain and White Wing Mountain compared to Rock Creek may have resulted from the relatively longer period of tree mortality at this site, but these trends are speculative.

The age distribution of live whitebark pine regeneration (Figure 20) showed a pulse of first-year seedlings at Rock Creek (high mortality and control sites were pooled), where tree morality was primarily within the past 2 years prior to monitoring. In contrast, whitebark pine regeneration at June Mountain and White Wing Mountain displayed a 4-year pulse of recent regeneration, coincident with the relatively longer tree mortality observed at these sites (Figure 3). All three sites showed a relatively stable production of whitebark pine regeneration at least within the past 50 years (Figure 20). The proportion of live-to-dead whitebark pine seedlings or saplings at Rock Creek was contingent on the number of stems in each cluster (Figure 21); there was a greater proportion of live-to-dead stems in multiple clusters of two or more ($\chi^2 = 409.8$, $P <$ 0.001) and a lower proportion of live-to-dead stems in single stem clusters ($\chi^2 = 169.0$, $P <$ 0.001) than expected based on the overall ratios (data for June Mountain and White Wing Mountain were not included in this analysis). Thus, whitebark pine seedlings and saplings growing in multi-stem clusters appeared to have greater survivorship than single stems.

The density of whitebark pine regeneration clusters was positively associated with percentage dead overstory cover (Figure 22; $\beta = 0.428$, $R_{partial} = 0.398$, $P = 0.001$) and severity of MPB attack ($\beta = 0.260$, $R_{partial} = 0.295$, $P = 0.040$; Overall model: $F_{2, 63} = 19.797$, $R^2 = 0.366$; $P <$ 0.001), suggesting increased whitebark pine regeneration in response to stand impacts by MPB. Approximately 89.8% (±5.5% CI) of tree regeneration consisted of whitebark pine in all mortality and control plots across sites. The remainder of tree regeneration consisted of red fir (6.9 ± 4.9%), lodgepole pine (3.2 ± 1.9%), and other species, including mountain hemlock (*Tsuga mertensiana*) and Jeffrey pine (*P. jeffreyi*; both species totaled less than 0.01% of all regeneration).

Seed-Caching Wildlife

Based on single, unrepeated point counts, we observed a total of 27 Clark's nutcrackers (79%; *Nucifraga columbiana*), 5 Douglas' squirrels (15%; *Tamiasciurus douglasii*), and 2 lodgepole chipmunks (6%; *Neotamias speciosus*) within 9 plots at June Mountain (late-August 2012). Detection rates were 3 (Clark's nutcracker), 0.6 (Douglas' squirrel), and 0.2 (lodgepole chipmunk) individuals per plot. Other seed-caching or seed predator species that we observed during vegetation surveys (but not during point counts) included Steller's jay (*Cyanocitta stelleri*) and black bear (*Ursus americanus*).

Measuring whitebark pine saplings and seedlings in whitebark pine monitoring plots of the Inyo National Forest.

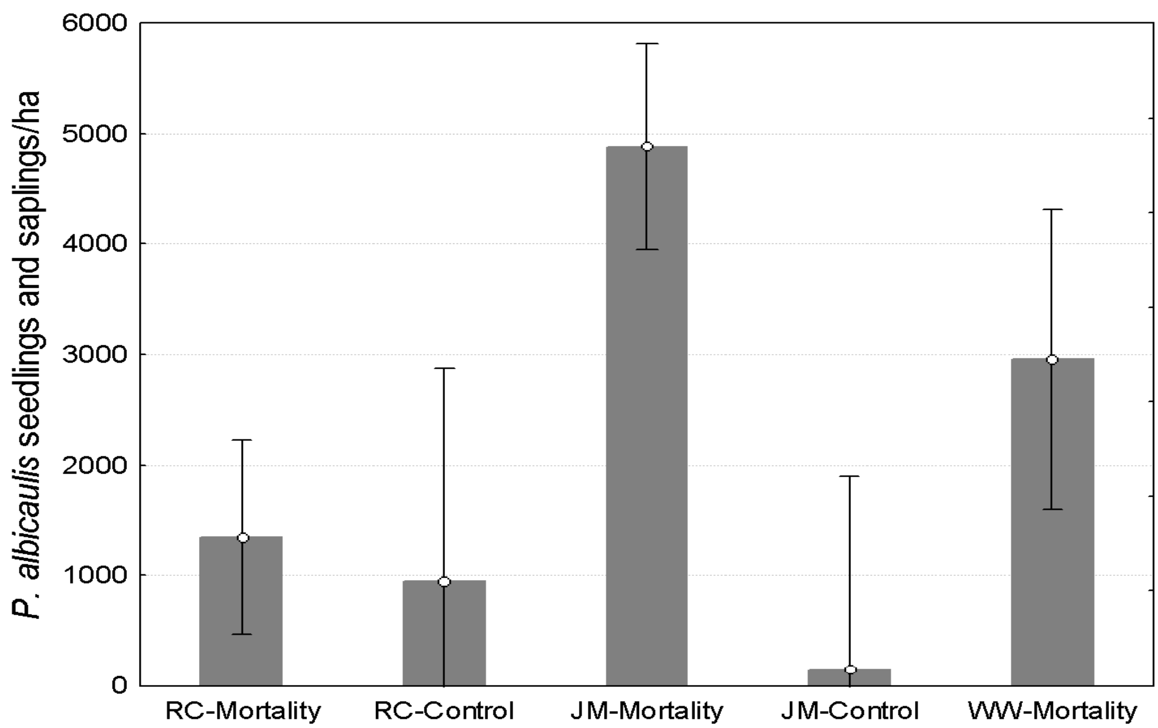

Figure 19. Mean (±95% CI) whitebark pine regeneration at three monitoring sites on the Inyo National Forest.

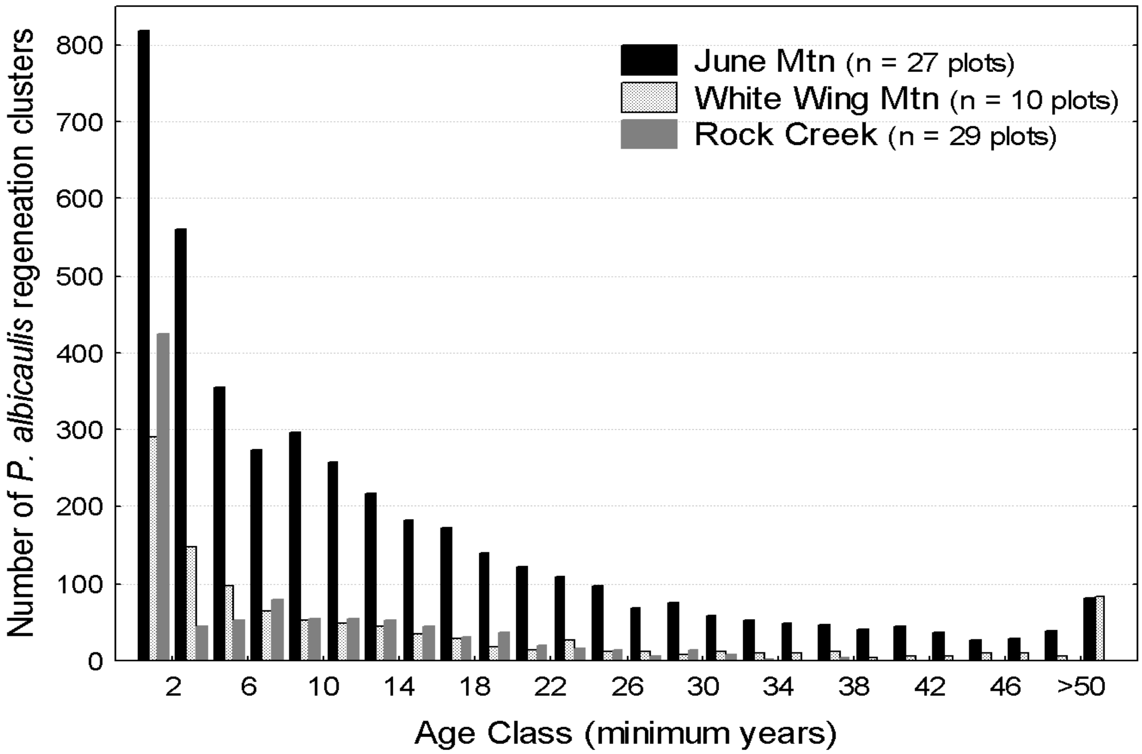

Figure 20. Age class distribution of whitebark pine regeneration at monitoring sites on the Inyo National Forest. High mortality and control sites are pooled for June Mountain and Rock Creek.

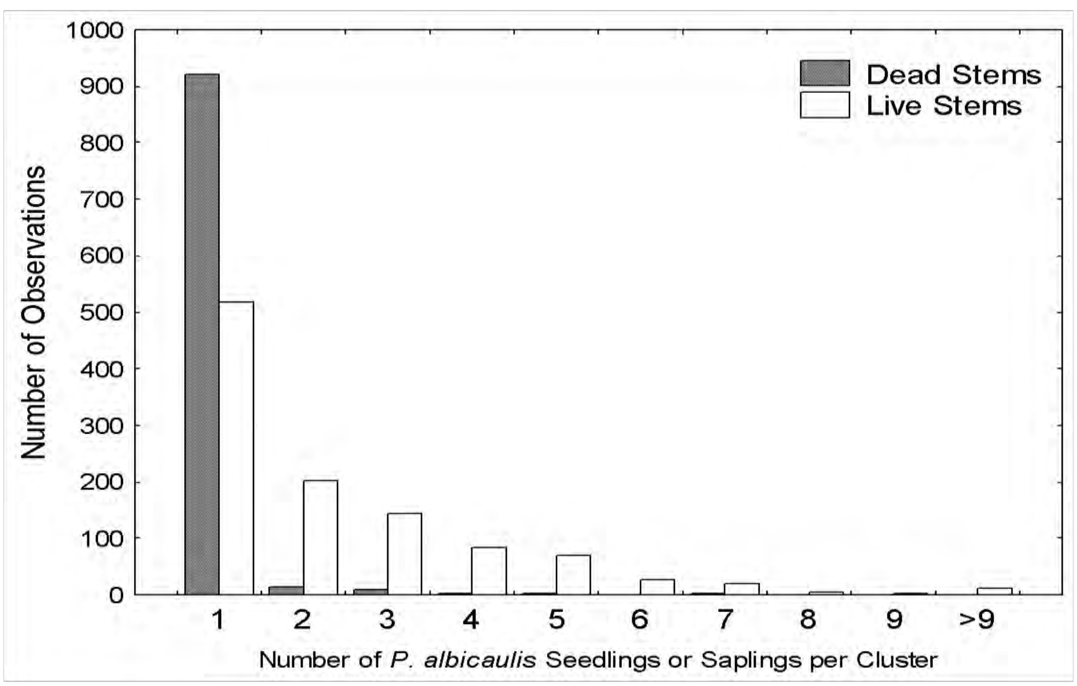

Figure 21. The number of live and dead whitebark pine seedlings or saplings per cluster. Note the relatively high proportion of dead-to-live stems as single individuals compared to clusters of two or more seedlings or saplings. Data based on Rock Creek plots only.

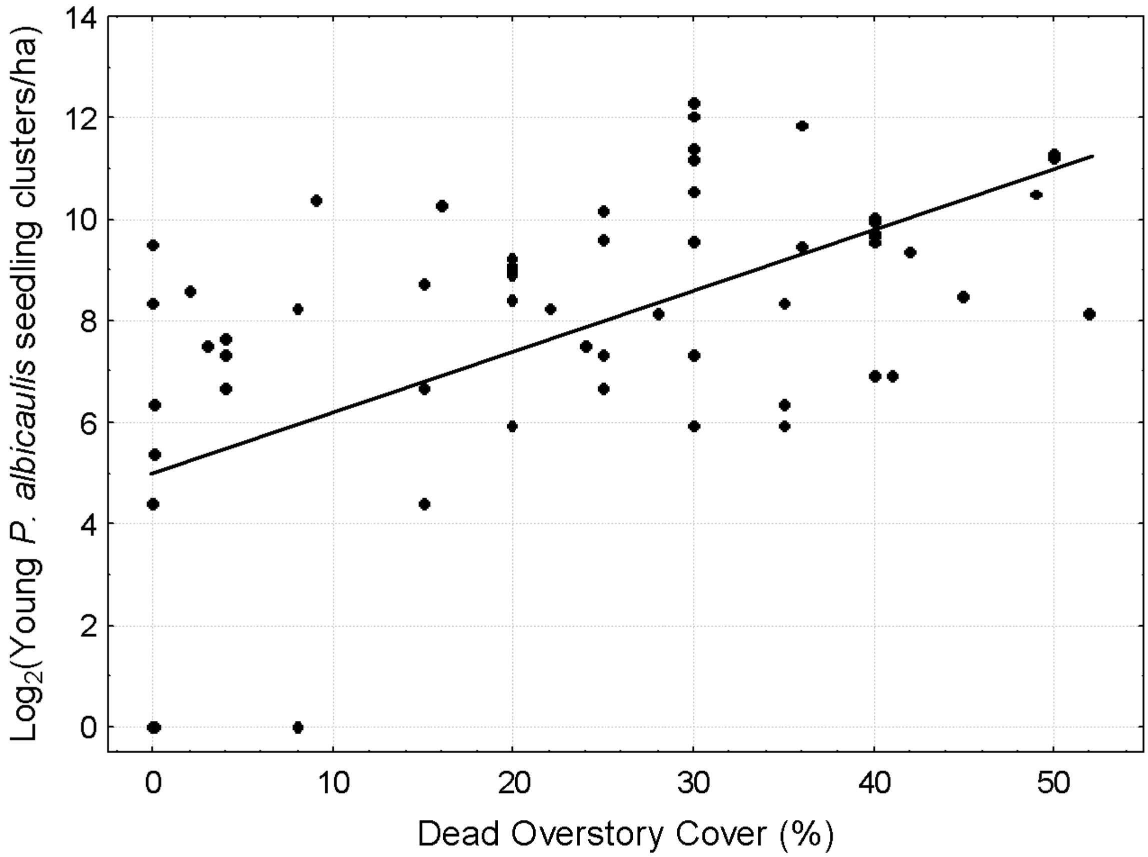

Figure 22. Relationship between percent dead overstory cover and density of young (<3 year) whitebark pine seedling clusters (log-transformed) in subalpine stands of the Inyo National Forest.

Whitebark pine monitoring plot location on White Wing Mountain, Inyo National Forest.

Future Monitoring

We anticipate continued whitebark pine mortality monitoring in the future. Our near-term objective is to complete the establishment of baseline subalpine monitoring plots at Rock Creek and additional suitable sites on the Inyo National Forest or neighboring Sierra Nevada national forests. With the establishment of baseline monitoring plot data, sampling at regular time intervals (e.g., every 2 to 5 years) will be required to track changes in whitebark pine tree mortality and regeneration with changing regional climate patterns and associated stressors (i.e., status and trend monitoring). We have established a total of 8 plots within future whitebark pine treatment areas (including removal of dead and infested trees and prescribed burning) for effectiveness monitoring of restoration treatments by the Inyo National Forest (USDA Forest Service 2012). We will continue to track these important changes using an integrated and collaborative monitoring strategy.

We will use monitoring data to contribute to the development of ecological restoration and climate adaptive strategies for regional whitebark pine populations. Adaptive strategies will be developed in close coordination with the Interagency Southern Sierra Nevada Ecoregional Vulnerability Assessment (Schwartz et al. *in prep*), Climate Vulnerability Assessment for the Sierra Nevada (USDA Forest Service *in prep*), NASA Ames Research Center (Anderson et al. 2012), and similar efforts focused on modeling projected changes in the distribution of whitebark pine populations in response to climate and climate-related processes.

Acknowledgements

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Cluster of dead whitebark pine trees in whitebark pine monitoring plot near Hilton Lakes in the Rock Creek area, Inyo National Forest.

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Appendix A. Additional Figures

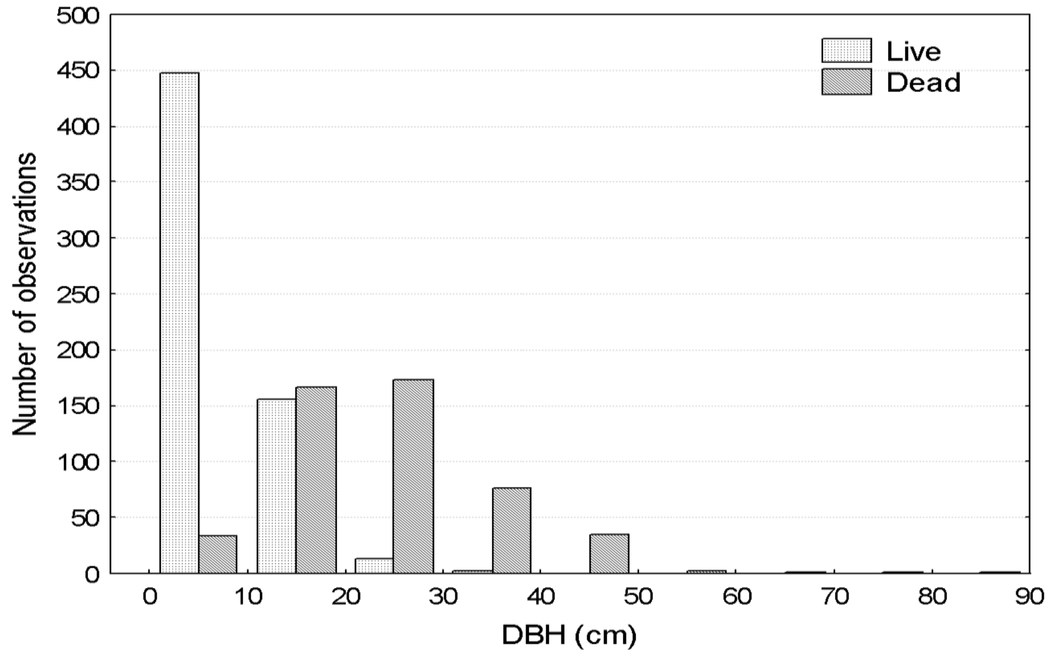

Figure 23. Size class distribution of live and dead whitebark pine trees in **mortality plots** at June Mountain.

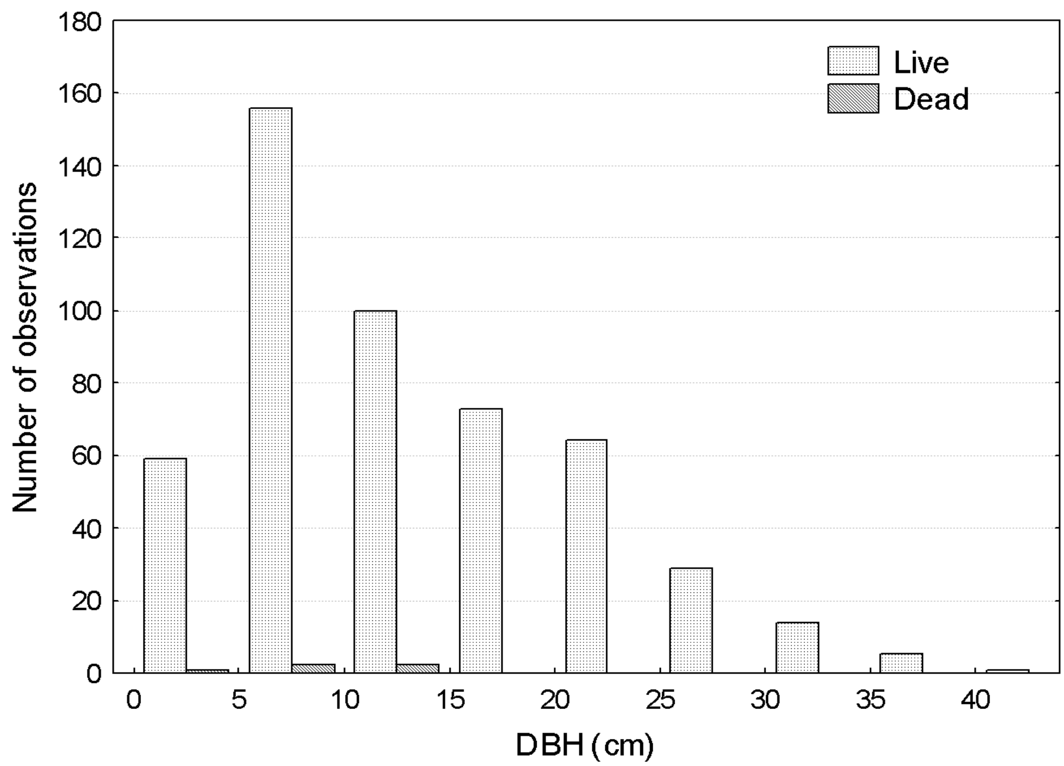

Figure 24. Size class distribution of live and dead whitebark pine trees in **control plots** at June Mountain.

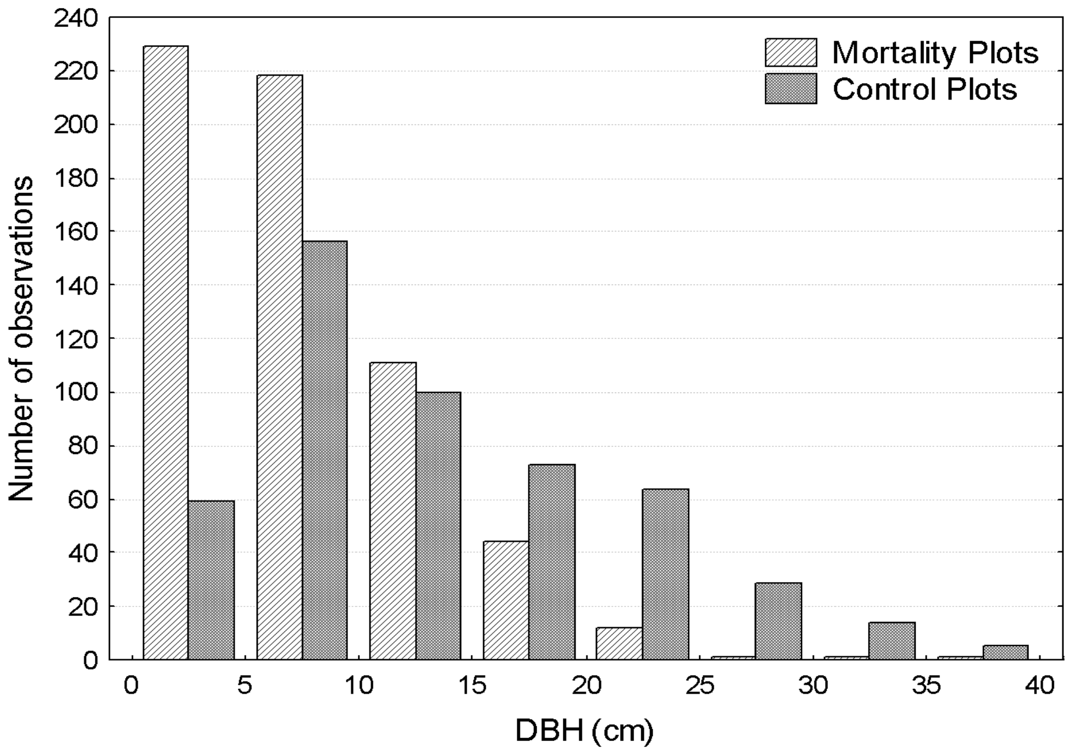

Figure 25. Size class distribution of **live** whitebark pine trees in mortality versus control plots at June Mountain.

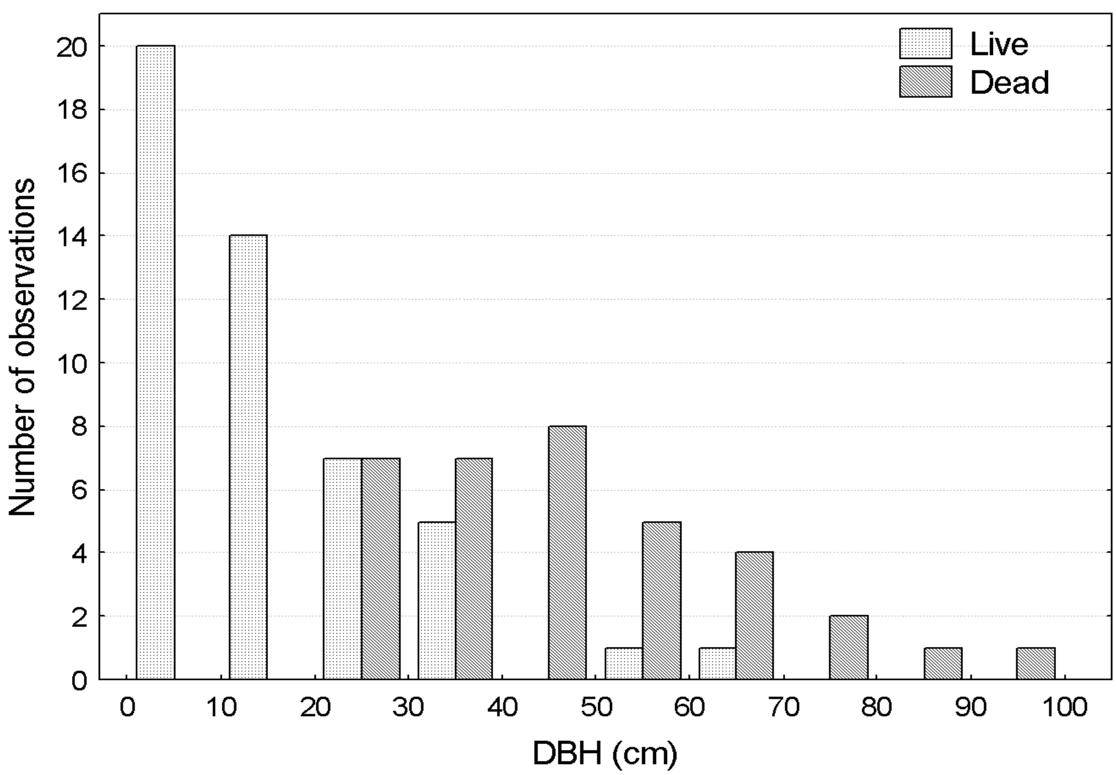

Figure 26. Size class distribution of live and dead **lodgepole pine** trees at June Mountain.

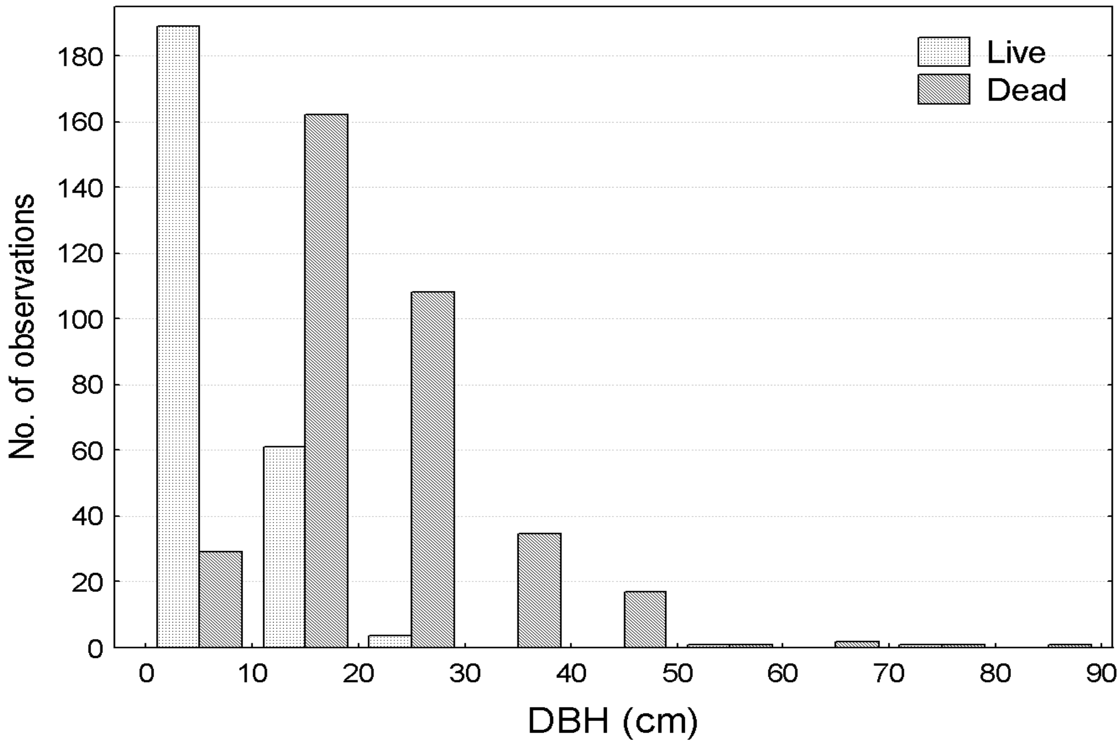

Figure 27. Size class distribution of live and dead whitebark pine trees at White Wing Mountain.

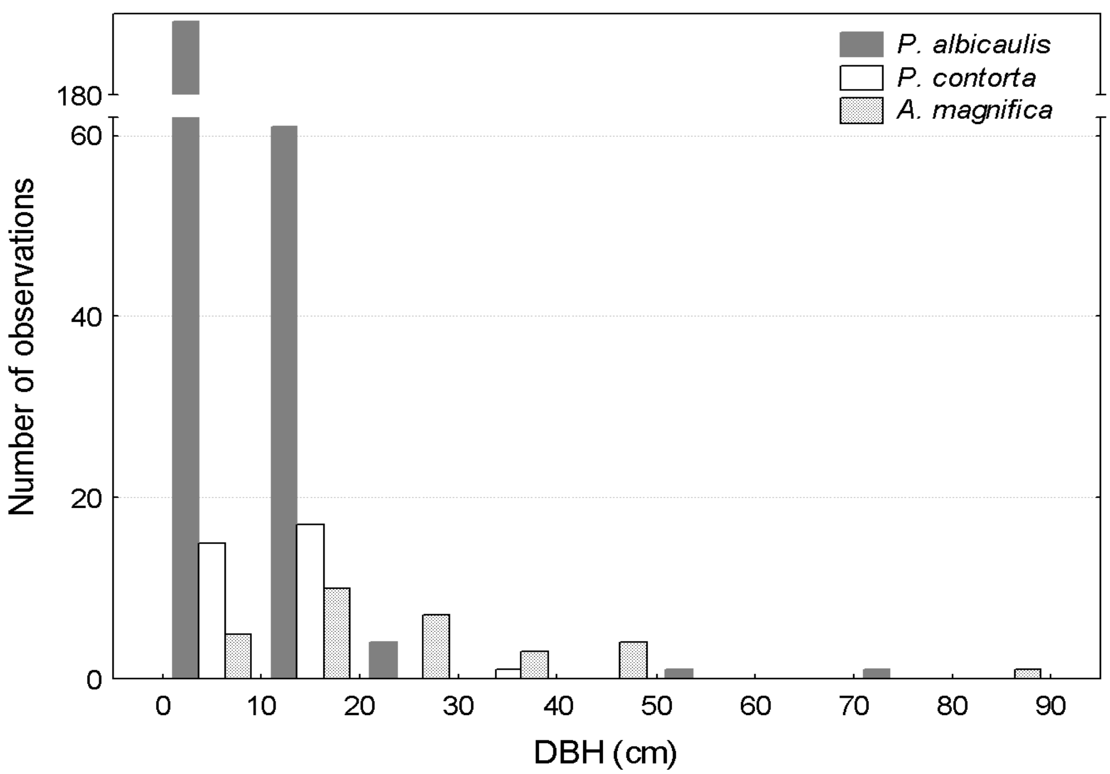

Figure 28. Size class distribution of all live tree species at White Wing Mountain.

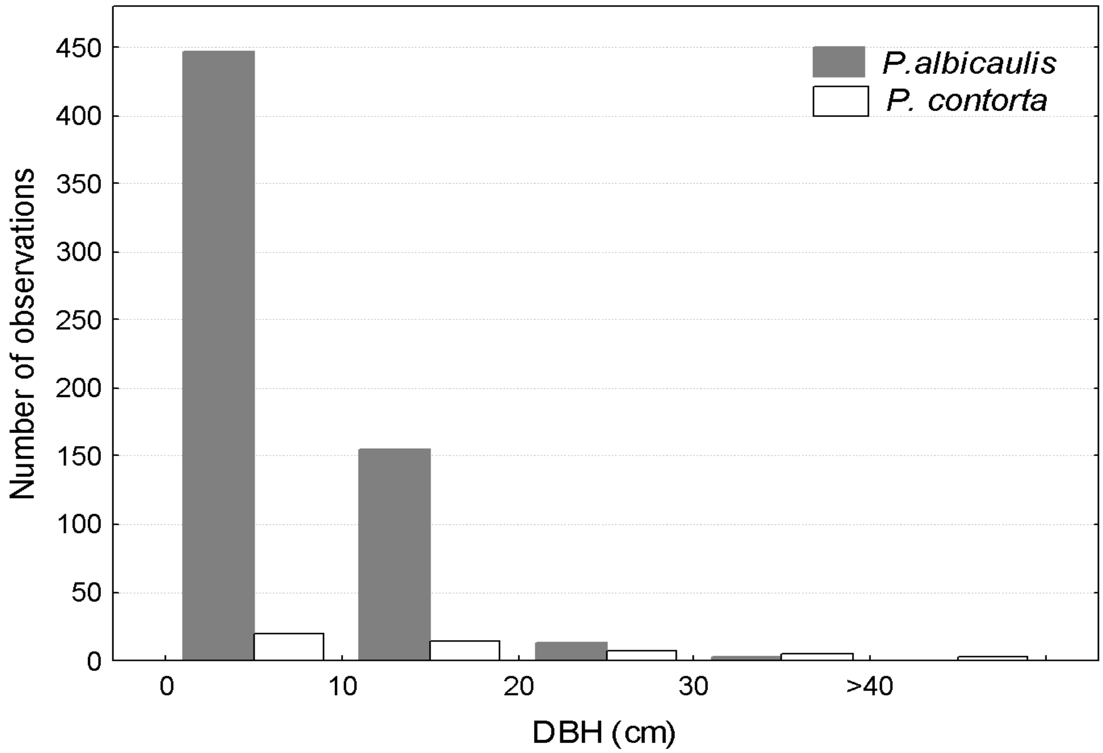

Figure 29. Size class distribution of all live tree species at June Mountain.

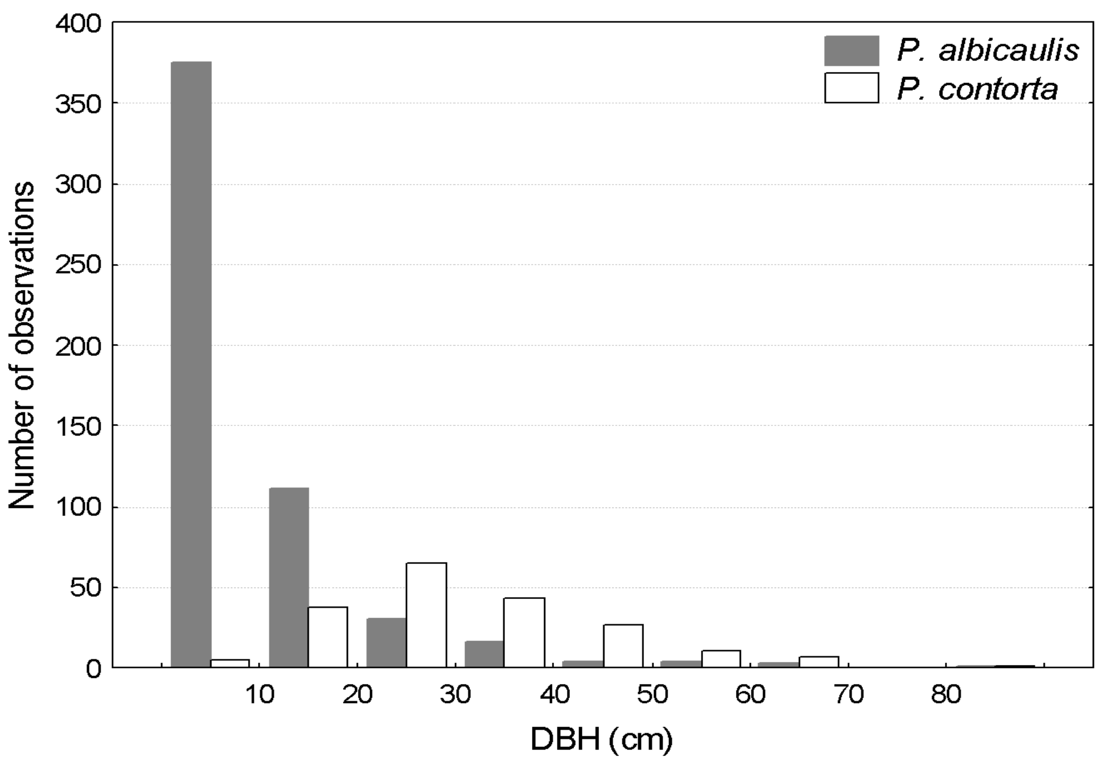

Figure 30. Size class distribution of all live tree species in mortality plots at Rock Creek.