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Incidence and severity of limber pine dwarf mistletoe (*Arceuthobium cyanocarpum*) on whitebark pine (*Pinus albicaulis*) at Newberry Crater

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Abstract

Incidence and severity of limber pine dwarf mistletoe (*Arceuthobium cyanocarpum*) on whitebark pine (*Pinus albicaulis*) at Newberry Crater

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Whitebark pine (*Pinus albicaulis* Engelm.) populations throughout much of the species' native distribution are threatened due to a number of factors. Many investigations have focused on threats posed by white pine blister rust, mountain pine beetle, high severity fire or fire exclusion, competition from other conifers and a warming climate. Dwarf mistletoes (*Arceuthobium* species) are parasitic plants known to occur on whitebark pine, but few reports document details of infestations observed in this ecologically important host. Limber pine dwarf mistletoe (*A*. *cyanocarpum* (A. Nelson ex Rydberg) Coulter & Nelson) is known to occur on whitebark pine at multiple locations in central Oregon, northern California, and other parts of the western U.S. where it can be locally damaging. One location in central Oregon where *A*. *cyanocarpum* has been reported on whitebark pine is Newberry Crater in Newberry National Volcanic Monument and the Deschutes National Forest. Whitebark pine mortality due to mountain pine beetle (*Dendroctonus ponderosae* Hopkins) has occurred in the same area. The primary objectives of this study were to determine incidence and severity of limber pine dwarf mistletoe on whitebark pine following mountain pine beetle activity in the area, and to estimate the extent of the mistletoe infestation. A survey was conducted where 43 fixed-radius plots were established along a grid across ~1,075 acres. Dwarf mistletoe was detected on whitebark pine in 84% of plots. Dwarf mistletoe was common on trees ≥ 1" dbh (mean incidence of 57%) and incidence was significantly ($p < 0.0001$) greater in this size class compared to incidence of mistletoe on seedlings (mean of 15%). Severity of dwarf mistletoe based on Hawksworth's Six-Class Dwarf Mistletoe Rating System was also significantly ($p < 0.0001$) greater on trees ≥ 1" dbh (mean of 2.3) than on seedlings (mean of 0.5). Incidence of topkill due to mistletoe in all whitebark pine trees ≥ 1" dbh was 15%, and significantly ($p = 0.007$) lower in seedlings (mean of 7%). Mean percent mortality (standing dead) in trees ≥ 1" dbh due to mistletoe was 5% (up to 40% in some plots) and none was detected in seedlings. Both dwarf mistletoe and mountain pine beetle are influencing stand structure. Mountain pine beetle had killed trees with a significantly ($p = 0.009$) larger dbh (mean of 10") than trees that were killed by dwarf mistletoe (mean of 2.9"). Following mortality of large-diameter whitebark pine due to mountain pine beetle, dwarf mistletoe is a threat to the remaining smaller-diameter whitebark pine saplings and trees here. White pine blister rust was only observed in two of 43 plots; dwarf mistletoe is currently more damaging at this location. The extent of this limber pine dwarf mistletoe infestation on whitebark pine is greater than 1,000 acres, but the total area infested is beyond the area surveyed. Management to reduce the adverse effects of dwarf mistletoe on whitebark pine could be evaluated. Additional dwarf mistletoe surveys are needed in central Oregon and elsewhere to evaluate effects of this disturbance agent along with other interacting threats to whitebark pine.

Introduction

Whitebark pine (*Pinus albicaulis* Engelm.) plays many significant ecological roles in subalpine forests of western North America (Tomback et al. 2001). However, it is now declared Endangered in Canada under the Species at Risk Act (Canada Species at Risk Public Registry 2012) and is currently a candidate species for protection under the Federal Endangered Species Act in the U.S. (U.S. Fish and Wildlife Service 2011). White pine blister rust (caused by the invasive fungus *Cronartium ribicola* J.C. Fisch.), mountain pine beetle (*Dendroctonus ponderosae* Hopkins), fire exclusion, competition from other vegetation and a warming climate are contributing to declining whitebark pine populations in many parts of its native distribution (Keane et al. 2012; Tomback et al. 2001). While less common range-wide in whitebark pine, dwarf mistletoes (*Arceuthobium* species) have been reported parasitizing whitebark pine in parts of the western U.S., including central Oregon (Hawksworth and Wiens 1996). Witches' brooms, reduced vigor and reproductive potential, as well as mortality in five needle pines (Genus *Pinus*, subgenus *Strobus*) can result from severe dwarf mistletoe infections (Hawksworth and Wiens 1996; Taylor and Mathiasen 1999). Nonetheless, there are relatively few reports (e.g., Knutson and Tinnin 1981; Mathiasen and Hawksworth 1988; Murray and Rasmussen 2000) documenting the incidence, severity or extent of any dwarf mistletoe on whitebark pine where it has been observed.

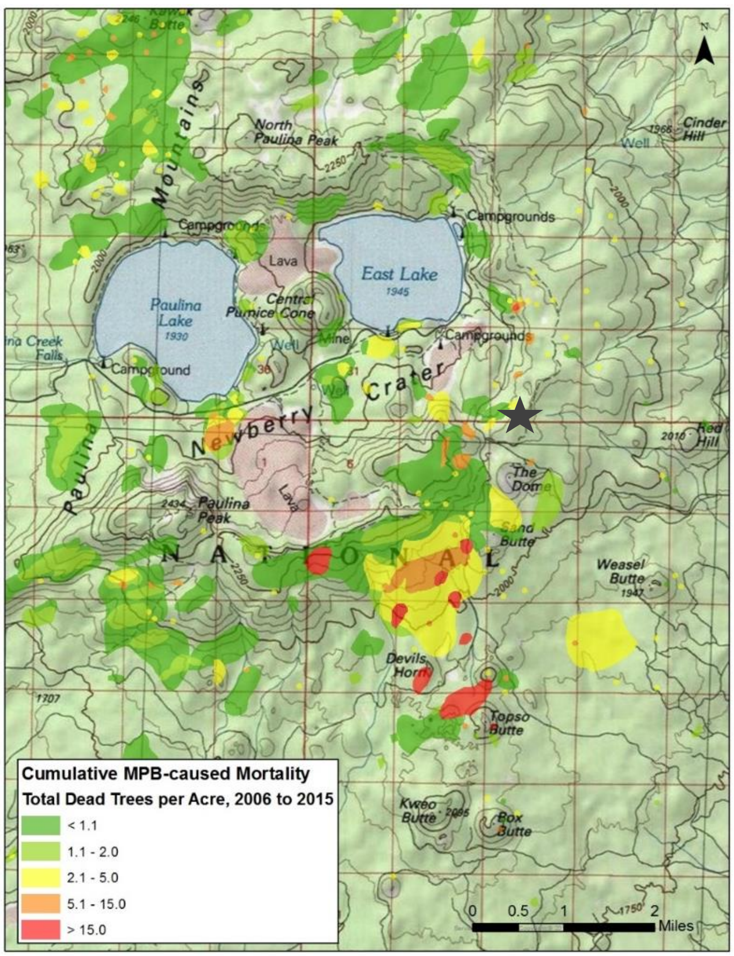
Whitebark pine is a principal host of limber pine dwarf mistletoe (*Arceuthobium cyanocarpum* (A. Nelson ex Rydberg) Coulter & Nelson) (Hawksworth and Wiens 1996; Taylor and Mathiasen 1999). Along with additional morphological characteristics, limber pine dwarf mistletoe can be differentiated from other species such as *A*. *americanum* Nutt ex Engelmann and *A*. *tsugense* (Rosendahl) G.N. Jones subsp. *mertensianae* Hawksw & Nickrent based on its densely clustered, shorter aerial shoots with flabellate (fan-shaped) branching and yellow-green color (Hawksworth et al. 2002; Kenaley et al. 2016; Reif et al. 2015). Additional principal hosts of limber pine dwarf mistletoe include limber pine (Pinus flexillis E. James) as the common name implies, Rocky Mountain bristlecone pine (*P*. *aristata* Engelm.) and Great Basin bristlecone pine (*P*. *longaeva* D.K. Bailey) (Hawksworth et al. 2002; Taylor and Mathiasen 1999). Secondary or occasional hosts include western white pine (*P. monticola* Douglas ex D. Don), mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.), and foxtail pine (*P. balfouriana* Balf.) (Hawksworth et al. 2002; Mathiasen and Daugherty 2001). Additional hosts have been reported rarely, such as sugar pine (*P. lambertiana* Douglas), but further evaluations are needed for these hosts (Mathiasen and Daugherty 2010). This parasitic plant spreads primarily by seeds shot via hydrostatic pressure to nearby hosts, and if a seed lands on a suitable branch or stem, directly infects its host through branches or the main stem (Hawksworth and Wiens 1996). Taylor and Mathiasen (1999, pg 1) noted, "Because of its widespread occurrence on limber and whitebark pines, and the high level of mortality it causes, limber pine dwarf mistletoe is considered to be one of the most important diseases of high-elevation 5-needle pines in the West."

Arceuthobium cyanocarpum has been reported damaging whitebark pine in the northwestern U.S. on the north slope of Mount Shasta in northern California (Angwin 2011; Mathiasen and Hawksworth 1988), on Wizard Island and along parts of the Rim in Crater Lake National Park (Jules et al. 2016; Reif et al. 2015; Wittmer 2007), just east of Middle Sister on the Deschutes National Forest (Mathiasen 2002), and near Tam McArthur Rim on the Deschutes National Forest (Knutson and Tinnin 1981). Limber pine dwarf mistletoe was also documented on whitebark pine near Newberry Crater in central Oregon, but limited information has been reported about this infestation (Shoal and Aubry 2006; Reif et al. 2015). The main objectives of this study were to: i) determine incidence and severity of limber pine dwarf mistletoe on whitebark pine post-mountain pine beetle activity at Newberry Crater; and ii) estimate the spatial extent of this infestation.

Methods

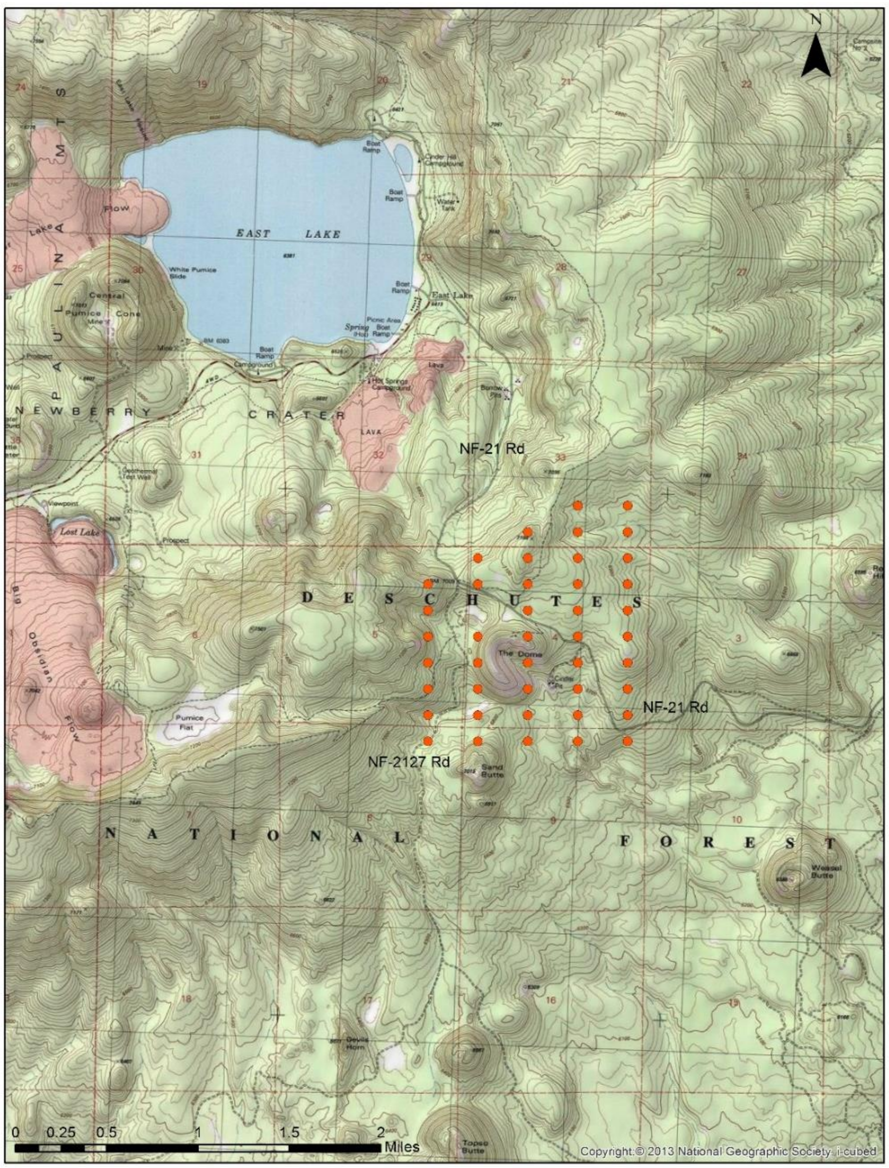
The area surveyed for *A. cyanocarpum* on whitebark pine is surrounding the Dome on the southeast slope of Newberry Crater in Newberry National Volcanic Monument and the Deschutes National Forest. The area is within the Whitebark Pine Conservation Area 505 and Whitebark Pine Seed Zone 5 for the U.S. Forest Service's Pacific Northwest Region (Aubry et al. 2008). The elevational range is approximately 6,400 - 7,400 ft with varying aspects. Poorly developed, excessively drained pumice and cinder soils exist here after volcanic activity in Newberry Volcano (Simpson 2007). Mean annual precipitation is around 34" with relatively short growing seasons (Simpson 2007). Dry whitebark pine – lodgepole pine (*Pinus contorta* Douglas subsp. murrayana)/pinemat manzanita (*Arctostaphylos nevadensis* A. Gray) plant associations are dominant with a few instances of mountain hemlock and ponderosa pine also occurring in the area surveyed (Simpson 2007). Based on lidar-derived data acquired in 2011, mean basal area was 21 ft^2/ac (range 0 - 138) for trees ≥ 5" diameter at breast height (4.5 ft; dbh) and the number of trees per acre (TPA) were highly variable (ranged no trees to over 1,200). There are no records of past fires dating back to the early 1900's near the area surveyed. However, charcoal and fire scars were observed at a few locations in the study area. Based on forest health aerial detection surveys and information by Shoal and Aubry (2006), mortality of larger whitebark pine and lodgepole pine in the overstory has been ongoing at Newberry Crater due to mountain pine beetle (Figure 1).

Figure 1. Map showing cumulative mortality in lodgepole and whitebark pines attributed to mountain pine beetle (MPB) detected during forest health aerial surveys from 2006-2015.



A grid of fixed-radius plots was used to estimate the extent of this dwarf mistletoe infestation where *A. cyanocarpum* was known to occur on whitebark pine. A total of 43 fixed-radius plots (1/20th acre) were established in 2015 and 2016 along a 756 x 1,444 ft grid across ~1,075 acres (Figure 2). Diameter at breast height was measured for all whitebark pine trees ≥ 1" dbh in 1/20th acre plots (26.33 ft radius) and all whitebark pine seedlings ≥ 6" tall, but < 1" dbh, were recorded in nested 1/100th acre plots (11.77 ft radius). Incidence of dwarf mistletoe and mistletoe bole infections were recorded on all whitebark pines. Severity of dwarf mistletoe infections was rated using Hawksworth's (1977) Six-Class Dwarf Mistletoe Rating System (DMR). Incidence of white pine blister rust was also recorded. Incidence of topkill in live whitebark pine due to dwarf mistletoe, white pine blister rust, or other causes was recorded as well as the cause of death (for standing dead). If dead trees had evidence of severe dwarf mistletoe infections based on aerial shoots or basal cups of mistletoe plants on branch and bole swellings, dwarf mistletoe was recorded as the cause. If evidence of bark beetles (e.g., mountain pine beetle galleries) was present, bark beetles were recorded as the cause.

Figure 2. Map showing plot locations (orange points) for dwarf mistletoe survey on whitebark pine around the Dome.

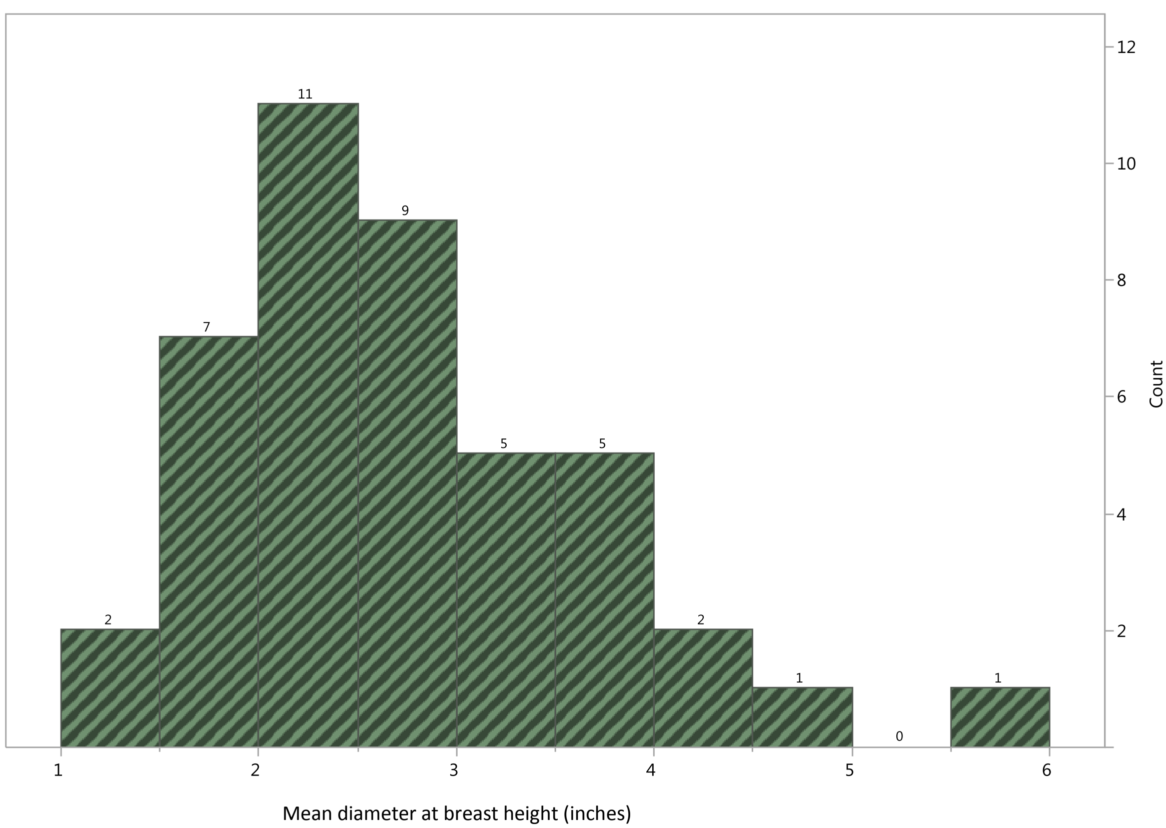


Data analyses were performed using the JMP software vers. 13.1 (2016, SAS Institute, Inc., Cary, NC). Means were calculated by plot and data were summarized for whitebark pine trees (≥ 1” dbh) vs. seedlings. Ranks of plot means were compared using Wilcoxon rank-sum tests to determine whether there were differences ($\alpha = 0.05$) in incidence and severity of dwarf mistletoe between the two size classes. Kruskal-Wallis tests were used to compare more than two groups (dbh of trees by mortality agent), and if a significant difference ($\alpha = 0.05$) was found, pairwise comparisons were then completed using the Steel-Dwass method ($\alpha = 0.05$).

Results

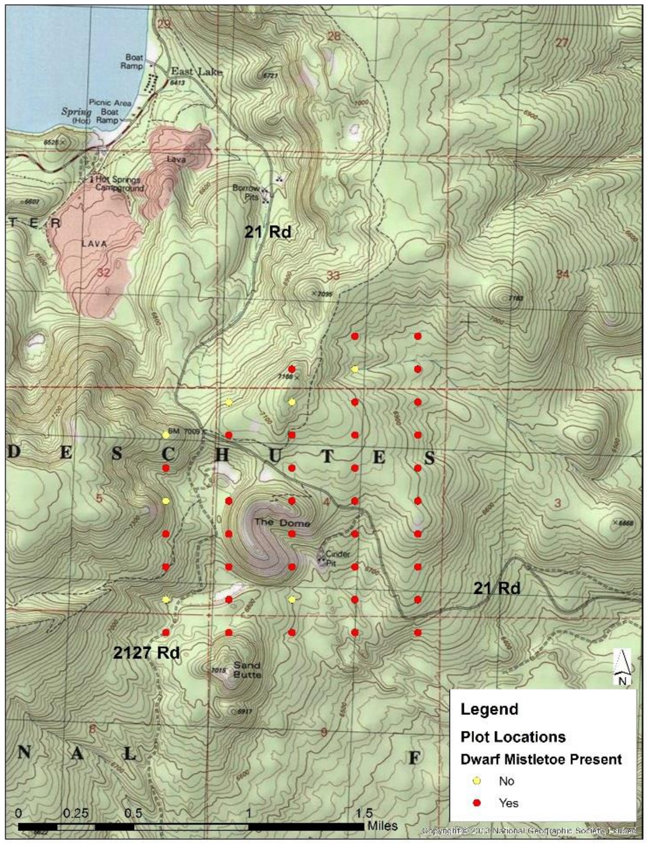
Few live, large whitebark pine are now present in this area and only 2% (one of 43) of plots had a mean dbh ≥ 5.0” for live whitebark pine trees ≥ 1” dbh (Figure 3). Lodgepole pine co-occurred with whitebark pine throughout the area surveyed; mountain hemlock and ponderosa pine also were present in several plots. Overall mean dbh of whitebark pine trees was 2.8 ± 0.1” SE (range 1.4 - 6.0) and the mean basal area of whitebark pine trees was 12 ± 2 SE ft^2/ac (range 1 - 71). Mean number of live trees per acre was 224 ± 26 SE (range 40 - 820). Abundance of whitebark pine seedlings varied (range 0 - 4,000 per acre), but seedlings were often common with a mean number of live seedlings per acre of 867 ± 131 SE.

Figure 3. Distribution of mean plot diameters at breast height for live whitebark pine trees ≥ 1” dbh.



Dwarf mistletoe occurred on whitebark pine in 84% (36 of 43) of plots and the extent of this infestation was beyond the area surveyed (Figure 4).

Figure 4. Map showing plots with dwarf mistletoe present on whitebark pine around the Dome.



Incidence of dwarf mistletoe was high in whitebark pine trees ≥ 1” dbh and significantly lower ($p < 0.0001$) in seedlings (Table 1). Branch and bole swellings as well as “bottle brush” and chlorotic crowns were common symptoms associated with mistletoe infections (Figure 5). Within all live infected whitebark pine, incidence of bole infections was very high in both size classes. In trees ≥ 1” dbh, DMR was significantly higher ($p < 0.0001$) compared to DMR in seedlings. There was no difference ($p > 0.49$) in DMR among crown thirds within either size classes. Both percent topkill (Figure 5) and mortality due to dwarf mistletoe were significantly greater ($p < 0.007$) in trees ≥ 1” dbh than in seedlings (Table 1).

Table 1. Summary statistics for incidence and severity of dwarf mistletoe (DM) on whitebark pine based on plot means.

Size class	Mean incidence (%)[1]	Mean incidence of bole infections (%)[1,2]	Mean DMR[1]	Mean incidence of topkill due to DM (%)[1,3]	Mean % mortality due to DM[1,4]
Saplings and trees ≥ 1" dbh	57 (0-100)a	59 (0-100)a	2.3 (0-6)a	15 (0-78)a	5 (0-40)a
Seedlings < 1" dbh & ≥ 6" tall	15 (0-100)b	73 (0-100)a	0.5 (0-6)b	7 (0-100)b	0 (0)b

[1]Means and ranges in parantheses shown but Wilcoxon rank-sum tests were used for comparisons of ranks between size classes. Different letters denote significant differences ($\alpha = 0.05$) between size classes within a column.
[2]Within the live whitebark pines infected with DM, the percentage with bole infections.
[3]For all live whitebark pines, the percentage with topkill due to DM.
[4]Percentage of whitebark pine that were still standing and killed by DM.

Figure 5a-c. Limber pine dwarf mistletoe plants and branch swelling (a), chlorotic crowns and "bottle brush" symptoms (b-c) on whitebark pine associated with limber pine dwarf mistletoe infections.

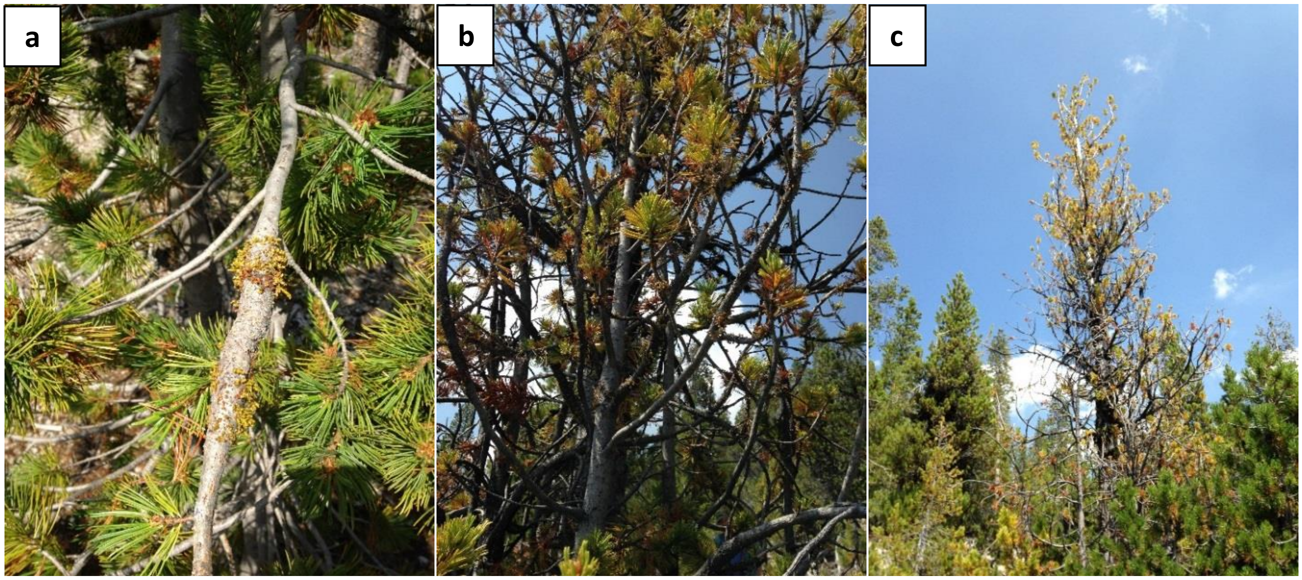
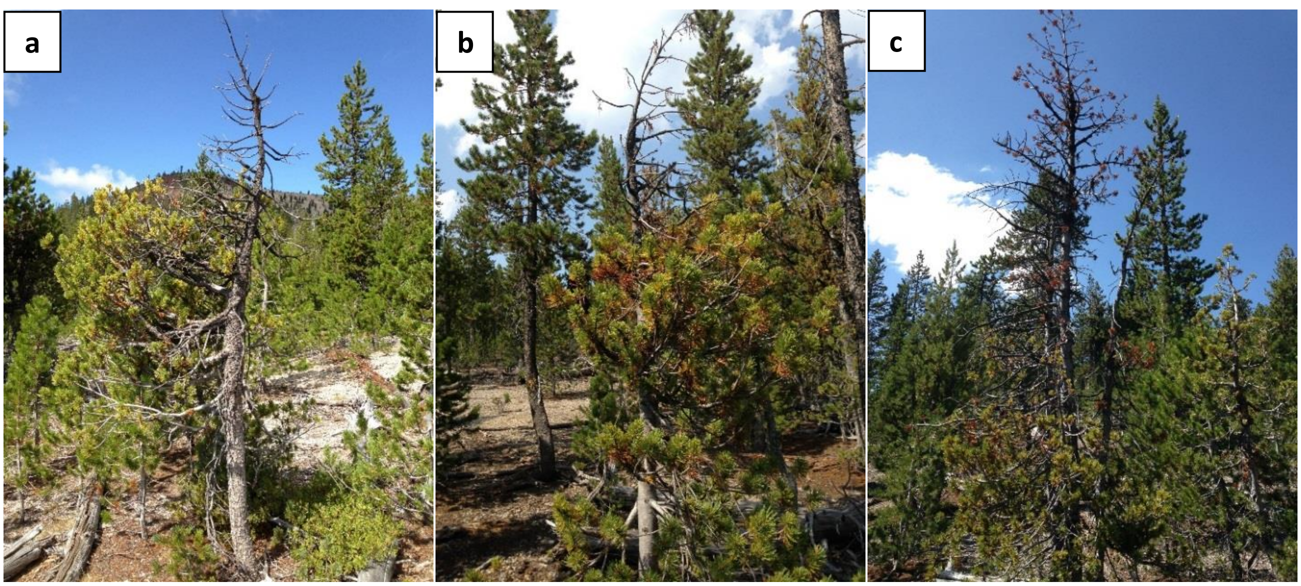
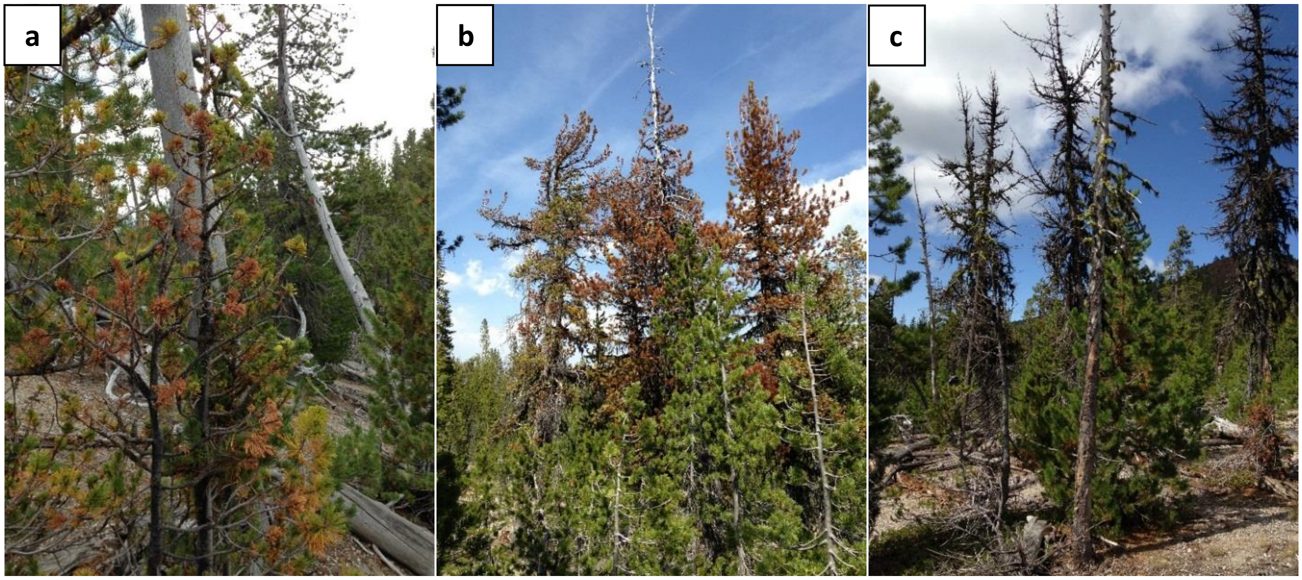


Figure 6a-c. Witches' brooms and topkill (a-c) in whitebark pine caused by limber pine dwarf mistletoe.



Mean percent mortality due to all causes in trees ≥ 1" dbh was 7 ± 2% SE (range 0 - 56) and no mortality was observed in seedlings. Mean TPA for standing dead whitebark pine trees ≥ 1" dbh was 22 ± 7 SE (range 0 - 180). The primary cause of recent mortality in whitebark pine still standing was dwarf mistletoe (in 15 of 43 plots). Mountain pine beetle (in four of 43 plots; Figure 5) and unknown causes (in four of 43 plots), without evidence of a mortality agent, were also recorded as causes of mortality. Dead and down whitebark and lodgepole pines were observed. There was no evidence of root disease observed in any dead whitebark pine.

Figure 5a-c. Whitebark pine recently killed by limber pine dwarf mistletoe (a), mountain pine beetle (b), and trees in the overstory killed by mountain pine beetle and trees in the understory killed by dwarf mistletoe (c).



The dbh of dead whitebark pine trees ≥ 1" dbh was different ($p = 0.009$) depending on the cause of mortality. The dbh of trees killed by mountain pine beetle (mean 10.1 ± 2.6" SE, range 5.8 - 17.1) was significantly greater ($p = 0.0087$) than the dbh of trees killed by dwarf mistletoe (mean 2.9 ± 0.3" SE, range 1.4 – 5.8). However, no difference ($p = 0.10$) was found in the dbh of trees killed by mountain pine beetle and unknown causes (mean 3.5 ± 0.9" SE, range 1.4 - 5.8) and no difference ($p = 0.89$) occurred in the dbh of trees killed by dwarf mistletoe and unknown causes. No mortality due to white pine blister rust was detected and white pine blister rust was only recorded in two of 43 plots with one sapling in each plot having topkill caused by white pine blister rust. No white pine blister rust was observed in seedlings.

Discussion

Limited reports document details of the incidence, severity or extent of any dwarf mistletoe species on whitebark pine (e.g., Mathiasen and Hawksworth 1988). In *A Range-Wide Restoration Strategy for Whitebark Pine (Pinus albicaulis)* (Keane et al. 2012) and the *Whitebark Pine Restoration Strategy for the Pacific Northwest Region: 2009-2013* (Aubry et al. 2008), the need to assess and evaluate conditions in whitebark pine communities is expressed as a key component of restoration efforts. In central Oregon and other parts of the western U.S. where dwarf mistletoes may be locally damaging, additional surveys are needed to document the occurrence of *Arceuthobium* spp. on this candidate species for listing as Endangered in the U.S. (U.S. Fish and Wildlife Service 2011). Fire can alter the abundance and spatial pattern of dwarf mistletoe populations (Alexander and Hawksworth 1975; Shaw and Agne 2017). Relic *A. cyanocarpum* populations may occur on whitebark pine (Reif et al. 2015) in central Oregon where volcanic-derived sites lack fuel continuity and have experienced fire exclusion. Based on this survey, the extent of the *A. cyanocarpum* infestation in whitebark pine is over 1,000 acres but the total area infested at Newberry Crater is beyond the area surveyed.

Limber pine dwarf mistletoe was widespread (mean of 57% infected) on whitebark pine trees ≥ 1” dbh at Newberry Crater and is currently more damaging to this size class than to whitebark pine seedlings. One reason for a lower incidence and severity observed on seedlings is likely due to smaller trees being too-small of a target to intercept inoculum (Wicker and Shaw 1967). Snow loads, snow melt or rain in the spring could potentially cause mistletoe seeds to slide off of seedlings before branches are infected (Hawksworth and Wiens 1996). Trees ≥ 1” dbh with severe mistletoe infections were often present near seedlings in the understory, which will provide nearby sources of inoculum for overstory-to-understory spread and threatens advance regeneration. Some seedlings may have had latent infections without showing visible signs (aerial shoots or basal cups) of infection as well (Hawksworth and Wiens 1996).

Limber pine dwarf mistletoe and mountain pine beetle, both native disturbance agents, are having demographic effects on whitebark pine populations based on the different dbh of trees killed. Few large-diameter whitebark pines currently exist at Newberry Crater. Stand structure and successional dynamics are being affected by mountain pine beetle that has killed larger-diameter trees and dwarf mistletoe that has killed smaller-diameter trees (up to 40% in some plots) threatening the recruitment of trees reaching larger sizes (Figure 3). Only dead trees that were still standing were recorded so estimates of past mortality were not included, as some dead trees had fallen and were not recorded. In addition to tree mortality from dwarf mistletoe, significant levels of topkill (up to 78% in some plots) due to dwarf mistletoe were observed in live trees ≥ 1” dbh. Topkill in whitebark pine may affect future reproductive potential and increase mortality rates. Unlike in other regions (Tomback et al. 2001) or along the crest of the Cascades (Shoal and Aubry 2006), dwarf mistletoe poses a greater threat to whitebark pine than white pine blister rust at this particular location. Shoal and Aubry (2006) also reported a very low incidence of white pine blister rust near the area surveyed.

Whitebark pine may be at risk of successional replacement by lodgepole pine and other conifers, however additional data is needed on species composition. Further investigations are warranted to evaluate multiple interacting threats to whitebark pine that include dwarf mistletoe, particularly post-mountain pine beetle activity. Whether or not severely infected trees are at the same risk of being attacked or killed by mountain pine beetle as uninfected trees, under endemic beetle populations, could also be investigated. Potential effects of dwarf mistletoe and mountain pine beetle on fuel profiles and wildlife habitat in whitebark pine communities could be evaluated as well.

Keane et al. (2012) emphasized the importance of reducing pest and disturbance impacts on whitebark pine when considering restoration efforts. Restoration efforts should include knowledge of regeneration, stand structure and disturbance agents that affect different size/age classes. Trees can be killed by limber pine dwarf mistletoe, and severely infected trees can have unhealthy crowns (e.g., Figures 5-6), their hydraulic architecture is altered in the mainstem of trees with bole infections, and water and carbon relations may be disrupted (Meinzer et al. 2004). Damage from drought injury may be exacerbated in whitebark pine severely infected by dwarf mistletoe (Kolb et al. 2016). Also, decreased cone production may occur in severely infected trees compared to uninfected or lightly infected trees (Taylor and Mathiasen 1999). Adverse effects of dwarf mistletoe on whitebark pine may be reduced with treatments that include pruning infected branches (witches’ brooms), using prescribed fire in infested stands to reduce mistletoe levels and planting whitebark pine seedlings at least 30 ft (Taylor and Mathiasen 1999) from infected trees. The effects of pruning dwarf mistletoe brooms on host vigor has been evaluated in other conifers to prevent the obligate parasite from severely damaging its host (Maffei et al. 2016; Scharpf et al. 1987). Raising the crown in whitebark pines could also decrease ladder fuels and reduce the risk of trees being torched and killed by fire.

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