Distribution of Bark Beetle Attacks After Whitebark Pine Restoration Treatments: A Case Study

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ABSTRACT: *Whitebark pine (*Pinus albicaulis *Engelm.), an important component of high elevation ecosystems in the western United States and Canada, is declining due to fire exclusion, white pine blister rust (*Cronartium ribicola *J.C. Fisch.), and mountain pine beetle (*Dendroctonus ponderosae *Hopkins). This study was conducted to evaluate the effects of whitebark pine restoration treatments on the distribution of bark beetle attacks. At a site in Idaho, silvicultural treatments were implemented in summer 1998 and 1999, with prescribed burning implemented in Oct. 1999. Permanent plots (400m^2) were established during summer 1999 within each treatment and monitored for 4 years. Within plots, tree characteristics were measured and a bark beetle survey was conducted. Bark beetle attacks remained low throughout the study; however, there was an increase in bark beetle attacks in 2000 after the prescribed burning. By years 3 and 4, there were virtually no successful attacks. Although bark beetles were not a serious concern at the site assessed in this study, our results indicate that managers should consider and monitor the bark beetle component of these ecosystems when implementing restoration treatments. If baseline bark beetle populations are high at the time of implementation, our results indicate that increases in beetle activity would be expected in some treatments, perhaps requiring mitigation. West. J. Appl. For. 20(2):110–116.*

Key Words: *Pinus albicaulis*, *Dendroctonus, Pityogenes,* forest restoration.

Whitebark pine (*Pinus albicaulis* Engelm.) is a hardy tree component of high-elevation ecosystems throughout the Northern Rocky Mountains. Whitebark pine's large, wingless seeds provide an excellent food source for wildlife such as birds, squirrels, and bears (Arno and Hoff 1989, Mattson et al. 1992). Whitebark pine and Clark's Nutcracker (*Nucifraga columbiana* Wilson), a bird in the jay family, have evolved a mutualistic relationship wherein the tree provides a food source for the bird and the bird disperses the whitebark pine's seeds through buried seed caches; unrecovered seed caches form the basis for most whitebark pine regeneration (Tomback 1982). Whitebark pine also contributes to snowpack retention, aesthetics, erosion prevention, summer wildlife range, and higher water yields (Pfister et al. 1977, Arno and Hoff 1989, Kendall and Arno 1990).

Whitebark pine is declining, primarily due to three factors: fire exclusion, white pine blister rust (caused by the exotic pathogen *Cronartium ribicola* J.C. Fisch), and mountain pine beetle (*Dendroctonus ponderosae* Hopkins) (Kendall and Arno 1990). Whitebark pine regeneration and survival has decreased due to fire exclusion, which has allowed the more shade-tolerant subalpine fir (*Abies lasiocarpa* Nutt.) and Engelmann spruce (*Picea engelmannii* Parry) to out-compete the more shade-intolerant whitebark pine. Subalpine fir has increased in abundance in many whitebark pine stands after a century of fire exclusion creating dense stand conditions not conducive to whitebark pine regeneration. With reduced regeneration, little natural selection for resistance to *C. ribicola* can occur.

Mountain pine beetle typically affects whitebark pine stands by killing scattered individuals or groups of large trees. However, epidemics of mountain pine beetle causing extensive mortality also have been documented (Ciesla and Furniss 1975, Kegley et al. 2001, J. Adams and D.L. Six, unpublished data).

Insects of Whitebark Pine

Whitebark pine ecosystems are characterized by extreme environmental conditions, including low winter temperatures and short growing seasons (Pfister et al. 1977). However, even under these harsh conditions, whitebark pine is a

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suitable host for both primary and secondary bark beetles (Coleoptera: Scolytidae). Primary beetles are aggressive (attack and kill trees). Secondary beetles range from non-aggressive to moderately aggressive, colonizing recently dead trees or killing weakened or stressed trees. The most damaging bark beetle occurring in whitebark pine is mountain pine beetle. This beetle colonizes and develops in the bole of trees over 20 cm in diameter. Mountain pine beetle's populations are capable of developing into outbreaks, causing widespread mortality in whitebark pine (Bartos and Gibson 1990, Ciesla and Furniss 1975). Other bark beetles that have been recorded in whitebark pine are considered secondaries. The secondary beetles usually infest small branches or twigs, and the occasional seedling or sapling. *Pityogenes fossifrons* (LeConte), occasionally recorded in whitebark pine, is usually considered a secondary beetle; however, it has been reported to act as a primary beetle in western white pine (*Pinus monticola* Dougl. ex D. Don) reproduction (Furniss and Carolin 1977).

Several species of bark beetles can pose serious threats to forest stands after cutting or burning (Furniss and Carolin 1977). Populations of the pine engraver (*Ips pini* Say) and red turpentine beetle (*Dendroctonus valens* LeConte) may increase in slash, logs, and stumps after harvesting (Furniss and Carolin 1977). These increased populations have the potential to then attack and kill residual trees nearby. Large amounts of downed woody debris are generated in whitebark pine restoration efforts, although some is eventually burned in prescribed fires. However, slash that is not burned, or is burned after beetles have had an opportunity to breed, develop, and emerge, may serve as ideal centers for increasing beetle populations (Furniss and Carolin 1977). Furthermore, cutting may stress residual trees by changing the microclimate and increasing wind speed and insolation. Cutting operations may result in additional stress when open wounds on residual tree boles result from falling trees or mechanical equipment (Aho et al. 1983). In addition, fire can stress trees, predisposing them to bark beetle attack (McCullough et al. 1998). Stressed trees, whether the stress is due to fire or increased exposure in recently opened stands, are more susceptible to successful attack by aggressive bark beetles such as mountain pine beetle and secondary bark beetles such as the pine engraver or the red turpentine beetle (Miller and Keen 1960, Mitchell et al. 1983).

Whitebark pine is a noncommercial tree species that, with few exceptions, has not been subjected to regular management activities or research until recent years (Gibson 1943, Keane and Arno 1993, 1996). Therefore, neither the efficacy of restoration treatments in restoring whitebark pine, nor the effects of restoration treatments on bark beetle population levels can yet be accurately predicted. The objective of this study was to assess the effect of whitebark pine restoration treatments on the distribution of bark beetle attacks, the relationship between successful bark beetle attacks and time after treatment, and the relationship between fire severity and bark beetle attack rates.

Materials and Methods

Study Location

This study was conducted at the Beaver Ridge whitebark pine restoration treatment area. Beaver Ridge is located approximately 65 miles southwest of Missoula, MT, on the Powell Area, Lochsa District, Clearwater National Forest, ID. The restoration area encompasses about 240 ha (600 ac), ranging in elevation from 1,966 m (6,450 ft) to 2,246 m (7,370 ft). The average slope at the site is 17° on primarily south aspects. The site supports a mixed-species forest composed of whitebark and lodgepole pines, subalpine fir, and Engelmann spruce.

Lodgepole pine was the most abundant tree at the study site, followed by subalpine fir, whitebark pine, and Engelmann spruce (Table 1). Engelmann spruce, although few in number, tended to be the tallest and largest trees (Table 1). Whitebark pine was the shortest and smallest in diameter (Table 1). *A. lasiocarpa / Luzula hitcockii / Vaccinium scoparium* was the primary habitat type on the study plots, with the *Menziesia ferruginea* phase of this habitat type encountered on moister plots near drainages. Moister sites were also more likely to support Engelmann spruce. Soil types present at Beaver Ridge include both Typic and Andic Cryochrepts (Wilson et al. 1983). These soils typically have an ash cap, which helps maintain site productivity. The potential for soil surface erosion is high, and the area is designated as noncommercial forestland (Wilson et al. 1983).

Restoration Treatments

Restoration treatments implemented at Beaver Ridge in late 1998 and during the summer of 1999 included slashing and Nutcracker opening treatments, and the establishment of a control unit. In Oct. 1999, prescribed burning was conducted within select slashing and Nutcracker opening treatments units, while other units receiving these treatments were left unburned.

Slashing

This treatment involved removal of over- and understory trees that shaded interspersed whitebark pine. Species of trees felled in slashing treatments consisted primarily of subalpine fir and Engelmann spruce, with lesser amounts of lodgepole pine. Slashing was conducted to improve growing conditions for whitebark pine by removing competition and creating conditions more conducive to seed caching by Nutcrackers (Tomback et al. 1995). Felled trees were left on the forest floor. In areas treated by slashing that also received prescribed burning, felled trees provided a more continuous fuel bed.

Table 1. Summary statistics for measured trees at Beaver Ridge, ID in 2000 arranged by species.

	DBH (cm)		Height (m)	
Species (*n*)	Mean	s.e.	Mean	s.e.
Whitebark pine (173)	14.03	0.786	6.63	0.303
Lodgepole pine (355)	24.43	0.654	12.62	0.315
Subalpine fir (284)	20.12	0.338	11.19	0.184
Engelmann spruce (27)	35.97	2.87	15.68	0.911

Nutcracker Openings

These treatments consisted of small artificial openings, between 0.4 and 1.2 ha (1 and 3 ac) in size, designed to encourage seed caching by the Clark's Nutcracker. Within each opening, all trees except whitebark pine (primarily sapling size) were felled. In some nutcracker openings, the slash was piled, burned or both, while in others it was left in place.

Prescribed Burning

Prescribed burning treatments were applied in late Oct. 1999 to select nutcracker opening and slashing units. Within the burned units, fire coverage was not complete, resulting in a matrix of varying fire severity. The summer after implementation of the burns, each tree on the study plots (described below) within the burn units was ranked for fire severity using the method of Ryan and Noste (1977). According to this method, each tree was placed into one of nine categories based on postburn estimations of flame length and depth of ground char. Estimations of flame length were based on crown scorch height and mortality size classes (average size of nearest dead trees). Resulting classes ranged from 1–5, with five denoting the greatest flame length class. Depth of ground char was evaluated using visual cues of consumption by fuel size class; resulting classes ranged from unburned to deep (each receiving a letter corresponding to the char class: U = unburned, L = light, M = moderate, H = heavy). Flame length and char class were then combined to form 16 separate categories of total fire severity for each individual tree (for example, a tree with a flame length rating of 3 and a char class of L would fall into the 3L category). Ryan and Noste (1977) provide descriptions of each fire severity category.

Permanent Plots

Permanent 400 m^2 (0.1 ac) circular plots, hereafter referred to as "study plots," were established in summer 1999 to assess whether restoration treatments affected the distribution of bark beetle attacks. Fifteen plots were established in each of seven planned treatment areas on a systematic grid, resulting in 105 plots located 78 m (198 ft) apart. A buffer zone of 52 m (132 ft) was established along either side of the road that ran through the treatment area to avoid possible road effects such as dust. Plot centers were marked with 3-ft rebar stakes and metal tags to allow for relocation of plots from year to year. For this analysis, 23 plots were removed due to lack of 2002 data.

Breakpoint diameters (the diameter below which no smaller trees were measured) used were 12.70 cm (5 in) for subalpine fir and Engelmann spruce, 7.60 cm (3 in) for lodgepole pine and 5.08 cm (2 in) for whitebark pine. Trees below the breakpoint diameter were not included because they were considered too small to host bark beetles. Species, dbh (1.37 m), total height, and incidence of disease or physical damage were recorded for each tree. Physical damage included dead/broken tops, forks, animal browsing, recent mortality, or other defining features.

Bark Beetle Surveys

Bark beetles were surveyed in the study plots during late Aug. and early Sept. 1999, then again in Sept. 2002 (trees attacked in the intervening years were backdated using visual evidence of tree mortality and beetle attacks). In each plot, trees at or above that tree species' break diameter were examined for signs of bark beetle attack. Attacks were confirmed as successful or unsuccessful and beetle species determined by peeling back the bark at the entrance hole and observing the galleries. Insects present in the galleries were collected for later identification in the laboratory. Attacks were recorded for each tree as presence (successful beetle attack) or absence (unsuccessful or no beetle attack).

Population levels of the pine engraver and red turpentine beetle were estimated in downed logs and stumps in the Nutcracker opening and slashing treatment areas prior to prescribed burning. Pine engraver was present in both stumps and logs while red turpentine beetle was present only in stumps. A 20% subsample was used in each study plot using a nested plot design. Total area of each circular nested plot was 135.6 m^2. Only lodgepole pine was surveyed, as subalpine fir and Engelmann spruce are not hosts for these beetles and there was no whitebark pine slash. The number of pine engraver attacks in a 10 cm wide strip extending around the log at the midpoint of the log or log portion falling within the nested subplot was counted and midpoint diameter recorded for each log. Stumps were assessed for pine engraver in the same manner, except diameter and beetle attack counts were taken at a height of 0.3 m (1 ft). All red turpentine beetle attacks were recorded regardless of position on the stump.

Results

Insects

Lodgepole Pine, Subalpine Fir, and Engelmann Spruce

Several secondary beetle species were collected from lodgepole pine in the plots. These included red turpentine beetle, *Pityogenes knechteli* (Swaine), *P. carinulatus* (LeConte), two *Pityopthorus* species, *Ips mexicanus* (Hopkins), pine engraver, and *I. latidens* (LeConte). *Pissodes* sp. (a weevil) was also collected out of a stump in a nutcracker opening. Mountain pine beetle attacks were not observed on lodgepole pine. Beetles collected from subalpine fir included western balsam bark beetle (*Dryocetes confuses* Swaine), fir engraver (*Scolytus ventralis* LeConte), two *Pityopthorus* species, and a bark beetle predator (*Tenebrionidae* spp.). The only insect occurring in Engelmann spruce was the spruce beetle (*Dendroctonus rufipennis* Kirby).

Whitebark Pine

The two bark beetle species collected most frequently from whitebark pine were the primary beetle, mountain pine beetle, and the secondary beetle, *Pityopthorus fossifrons. P. fossifrons* occurred in small sapling-sized trees in Nutcracker openings and was rarely observed elsewhere, while mountain pine beetle occurred solely in larger, mature trees growing in more closed conditions.

Two beetles typically associated with timber harvesting and fire, pine engraver and red turpentine beetle, were observed in living whitebark pine at Beaver Ridge. Both beetles were also present in lodgepole pine slash (stumps and downed logs) from restoration treatments. The average number of pine engraver entrance holes found in lodgepole pine logs and stumps was 0.169 attacks per 10 cm^2 strip. Red turpentine beetle attacks in lodgepole pine stumps averaged 0.012 attacks per stump.

Tree Diseases, Damages, and Interactions

Diseases observed in whitebark pine included white pine blister rust and dwarf mistletoe (*Arceuthobium* spp.). Overall incidence of white pine blister rust infection on the study plots was 78%. The limited number of successful mountain pine beetle attacks on whitebark pine precluded analysis of whether the beetles were attacking infected trees more frequently than uninfected trees.

Distribution of Bark Beetle Attacks

During 1999 (prior to prescribed burning), most successful beetle attacks took place in the nutcracker opening treatments. The season after the prescribed fire (2000), successful attacks increased in both the burned nutcracker opening treatments and the slashing/burn treatment (Figure 1). Lodgepole pine was the most frequently attacked tree species (Table 2), primarily by red turpentine beetles. No discernible trends in attacks by treatment were apparent in 2001 and 2002.

Frequency of Attacks

Based on general field observations at the site during Fall 1998, successful bark beetle attacks appeared to have increased in 1999, immediately following the implementation of cutting treatments. After the prescribed burning in late Oct. 1999, there was a large increase in successful attacks the following year, primarily due to red turpentine beetle attacks on lodgepole pine (Figure 1, Table 2). Subsequent years exhibited a dramatic decline in successful attacks.

Fire Severity

Figure 2 presents the mean proportion of successful attacks occurring during the three postburn years as related to fire severity category. Successful bark beetle attacks were significantly positively correlated with fire severity, probably due to the higher proportion of attacks in the light ground char category (Two-tailed Pearson's correlation 0.149, significant at 0.01).

Discussion

The distribution of trees at Beaver Ridge is suggestive of the fire history of the area. Much of the area burned in 1910 in a stand replacement event (R.E. Keane, USFS Fire Sciences Lab, Missoula, MT, personal communication, August, 1999). However, the presence of large spruce indicated that perhaps the wettest sites did not burn in the fire, leaving a somewhat patchy distribution of remnant older trees in and around the moist drainages. Stand replacement fires are conducive to both lodgepole pine and whitebark pine regeneration.

Two bark beetle species appear to be of concern when implementing whitebark pine restoration treatments. Mountain pine beetle appeared to prefer whitebark pine to lodgepole pine at the Beaver Ridge site, although the reason for this was not immediately clear. Mountain pine beetle typically prefers larger diameter trees (>10–12 cm) due to their thicker phloem layer, which creates better reproductive conditions (Cole and Amman 1980). At Beaver Ridge, mountain pine beetle attacks were found only in whitebark pine,

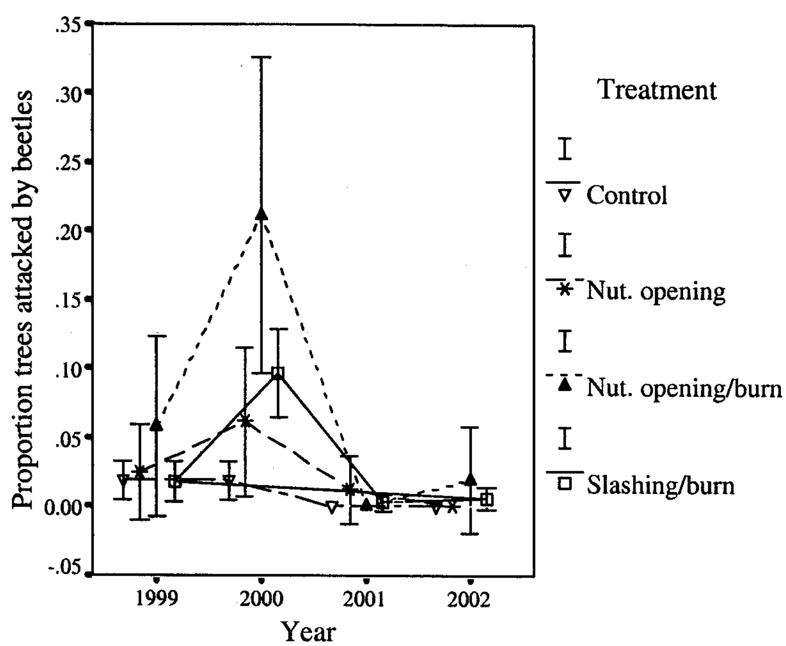

Figure 1. Mean proportion of trees attacked by bark beetles at Beaver Ridge, ID, by year and treatment type. See text for description of treatments. Error bars indicate 95% confidence intervals.

Table 2. Successful bark beetle attacks by year, by treatment and by species, Beaver Ridge, ID. Numbers in parentheses are percentages of total trees for that year.

Year	Control 373*	Nut. Opening 81*	Nut. Opening/burn 54*	Slashing/burn 331*	Total 839*	Whitebark 173*	Lodgepole pine 355*	Subalpine fir 284*	Engelmann spruce 27*
1999	7 (1.9)**	2 (2.5)	3 (5.5)	6 (1.8)	18 (2.1)	13 (7.5)	0 (0)	5 (1.8)	0 (0)
2000	7 (1.9)	5 (6.2)	11 (20.4)	32 (9.7)	55 (6.6)	15 (8.6)	36 (10.1)	4 (1.7)	0 (0)
2001	0 (0)	1 (1.2)	0 (0)	1 (0.3)	2 (0.2)	0 (0)	2 (0.5)	0 (0)	0 (0)
2002	0 (0)	0 (0)	1 (1.9)	2 (0.6)	3 (0.3)	0 (0)	2 (0.5)	0 (0)	1 (3.7)

*total number of measured trees in each treatment or species
**total number of successfully attacked trees followed by the percentage of total number of trees in category

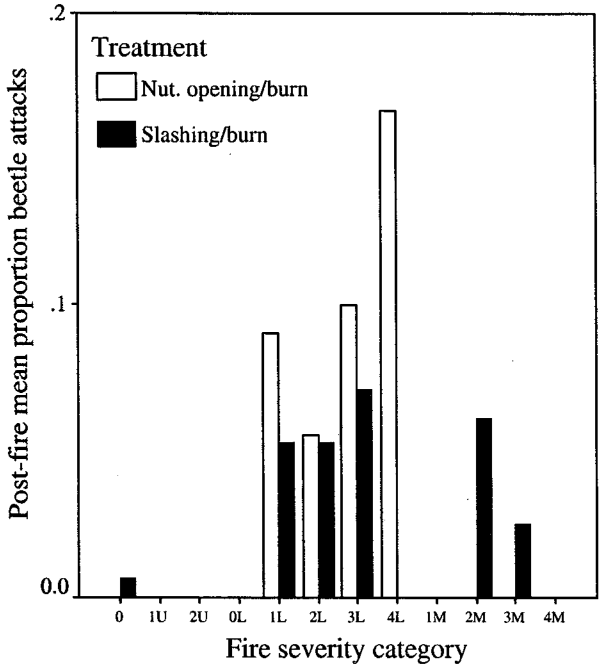

Figure 2. Mean proportion successful bark beetle attacks by tree and fire severity class in burned treatment areas. 0, no burn; 1–5, increasing flame length class. U, unburned; L, light ground char; M, medium ground char.

even though lodgepole pine had a larger mean diameter (Table 1). This preference for whitebark pine has also been noted at several other sites (Kegley 2001, D.L. Six unpublished data). Whitebark pine has been found to have thicker phloem than lodgepole pine of similar diameters (Baker et al. 1971, C. Austin and D.L. Six, unpublished data). At Beaver Ridge, the larger lodgepole pine may be equivalent to smaller diameter whitebark pine as a host in regard to phloem thickness indicating that some other factor, or factors, may account for differences in beetle preference between the two species. Factors influencing mountain pine beetle preference for whitebark pine may include differences between the two tree species in regard to host vigor or suitability (Mitchell et al. 1983), as well as microclimate (Amman and Logan 1998, Bartos and Amman 1989). Studies have found that localized endemic mountain pine beetle populations often prefer a particular host tree species even when other suitable host tree species are also present (Kulhavy et al.1984, Bartos and Schmitz 1998).

The other beetle potentially of concern is *P. fossifrons*, which was found mostly in small-diameter whitebark pine in the Nutcracker opening treatments. In these treatments, *P. fossifrons* exhibited aggressive behavior not previously recorded in whitebark pine. This beetle is usually considered a secondary beetle, attacking only stressed or weakened trees. However, most sapling-sized trees infested by this beetle at Beaver Ridge were rated as exhibiting very low infection levels or were uninfected by white pine blister rust and had no other visible damage. However, removal of the overstory canopy radically altered the microclimate in these units, resulting in higher temperatures, increased wind flow, and changes in soil moisture. These factors may have created stress in the remaining understory trees increasing susceptibility to *P. fossifrons. P. fossifrons* may also prefer open, sunny sites; however, little is known about the behavior and preferences of this beetle.

At Beaver Ridge, the distribution and frequency of successful bark beetle attacks did not appear to be affected by implementation of restoration treatments in the long-term. A short-term increase in attacks following burning did occur, but this trend disappeared in the final two years of the study. Bradley and Tueller (2001) found a similar short-term increase following late-season prescribed fire in California, with a corresponding increase in attacks with increasing individual tree fire severity. The apparent correlation at Beaver Ridge between light ground char and bark beetle attacks may indicate a level of physiological damage by fire that weakens the tree but still maintains its suitability as a host (unlike heavily damaged trees that possess poor suitability for bark beetle brood development or trees with no damage that remain unstressed and defensive). Lodgepole pine slash within cut areas hosted populations of both the pine engraver and red turpentine beetle that were higher than in the surrounding matrix; however, this localized population build-up appeared to have less of an effect on increasing beetle attacks in the treatments than did individual tree fire severity rating.

Bark beetle populations at Beaver Ridge before implementation of restoration treatments were very low, with only a few trees successfully attacked in 1998 (D. Six and K. Waring, personal observation). The results of restoration treatments at this site might have been dramatically different if large or rapidly increasing bark beetle populations had been present, particularly given the prolonged drought conditions currently being experienced in the Northern Rocky Mountains. Mild winters and dry summers can create conditions in which beetle populations suffer little winter mortality and trees are water-stressed, potentially predisposing them to beetle attacks. Implementing restoration treatments under these climatic conditions and in the presence of higher beetle populations may result in high amounts of residual tree mortality. If restoration treatments are implemented when bark beetle populations are high, mitigating techniques should be developed to prevent loss of high value whitebark pine from bark beetle attack. High value trees are those that exhibit genetic resistance to white pine blister rust and may provide seed for regeneration (large, cone-bearing trees with little to no blister rust infection). Possible preventative techniques include the use of anti-aggregant pheromones and prophylactic treatments with pesticides. Verbenone is the anti-aggregant pheromone of mountain pine beetle and can protect stands of lodgepole pine from mountain pine beetle (Amman and Lindgren 1995), although results have been variable. Anti-aggregant pheromones are probably not an option for the pine engraver, as access to whitebark pine sites is usually restricted by weather and snow until after the first seasonal flight has occurred; however, potential host material (pine slash) could be removed from the restoration site or treated in such a manner as to render it unsuitable for beetle development. Another option may be the use of Carbaryl, an effective pesticide useful in protecting pines from mountain pine beetle for up to two seasons, and which has been used successfully in high elevation areas (Gibson and Bennett 1985, Haverty et al. 1998). In the future, these techniques could be tested for effectiveness in protecting whitebark pine at the same time restoration treatments are implemented.

Conclusions

Managers should be aware of the potential consequences of trying to reestablish historic conditions in whitebark pine ecosystems. Monitoring bark beetle populations and climatic conditions before, during, and after restoration treatments will help determine whether mitigation measures are needed and will help time their implementation. Research is needed on many aspects of whitebark pine ecosystems including interactions among the tree, white pine blister rust and bark beetles. Investigations of bark beetle host selection, coupled with investigations of white pine blister rust effects on tree physiology and phloem suitability would help answer many questions regarding the quality of whitebark pine as a host for bark beetles. Answers to such basic questions will ultimately be needed if we are to effectively manage mountain pine beetle in whitebark pine.

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