A Novel Approach to Managing Fuelwood Harvest Using Bark Beetle Pheromones

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ABSTRACT: *A multiyear study of synthesized mountain pine beetle* (Dendroctonus ponderosae) *pheromones was conducted within lodgepole pine* (Pinus contorta) *stands on the Sawtooth National Recreation Area to demonstrate their potential use as a management tool for fuelwood harvest. The use of mountain pine beetle aggregant baits was shown to be highly effective in relocating beetles into designated bait blocks, dramatically increasing the amount of beetle-related tree mortality. Treatment of blocks with antiaggregant verbenone capsules appeared to provide little or no additional protection when compared with associated control blocks. Given defined objectives and appropriate stand and insect population conditions, pheromone baits can be used to improve management of fuelwood harvest and potentially improve stand health. West. J. Appl. For. 15(4):183–188.*

A 3 yr study within the Sawtooth National Recreational Area (SNRA) was conducted in which endemic beetle populations in lodgepole pine (*Pinus contorta*) stands were manipulated with the use of synthetic pheromones to accomplish specific management goals. Our primary objective was to move beetles out of currently infested stands into neighboring stands designated as fuelwood harvest areas. By grouping beetle mortality into desired harvest locations, close to existing roads and away from visually or environmentally sensitive areas, fuelwood management could be improved. If this initial objective was accomplished, we proposed utilizing the same techniques to enhance stand health by grouping beetle mortality within stands infected by dwarf mistletoe. Stand health could be improved if a significant proportion of infected overstory was killed by mountain pine beetle (*Dendroctonus ponderosae*) (MPB) and subsequently removed by fuelwood harvesters.

Background

The mountain pine beetle plays an important role in the life history of lodgepole pine, representing the most significant mortality factor in lodgepole pine ecosystems (Wellner 1978). Mountain pine beetle has typically been viewed as a destructive agent, responsible for the death and loss of millions of board feet of timber annually. As a naturally occurring agent within the forest, however, mountain pine beetle is linked to the long term health of lodgepole pine ecosystems. During endemic conditions, mountain pine beetle behaves as a thinning agent within a stand, reducing basal area by killing select trees, thereby relieving competition for light, water, and nutrients. During outbreaks, the mountain pine beetle can kill a large proportion of lodgepole pine within a few years (Amman and Baker 1972, Klein 1978, Safranyik 1989). These dead trees provide combustible fuel for fire, which in turn produces mineral soil for the establishment of new lodgepole pine forests (Peterman 1978). Since mountain pine beetle is such an important component in lodgepole pine ecosystems, management strategies developed in conjunction with the beetle's ecological effects are both prudent and necessary.

The typical 1 yr life cycle of the mountain pine beetle is spent predominantly under the bark, feeding within the phloem layer of the host. In the late summer, at the culmination of brood development, new adults emerge from the attacked tree and migrate to new host trees. Up to 80% of new adults will emerge during a single week, optimizing the beetle's ability to mass attack and overwhelm a lodgepole pine's natural defenses (Amman 1978, Rasmussen 1974). Female beetles select a suitable target tree based in part on a tree's health and diameter (Hopping and Beall 1948, Cole and Amman 1969, Roe and Amman 1970). Once established, the female beetle releases a complex array of chemical pheromones used to attract a mate as well as other mountain pine beetles in the area. As the number of beetles infesting an individual tree increases, attacks begin to shift to neighboring trees. This behavior is believed to be in response to the presence and proportion of aggregative and antiaggregative pheromones

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being released by attacking beetles (Amman 1978, Amman and Cole 1983, Bentz et al. 1996).

Once a female has bored through the outer bark into the phloem layer, she and her mate begin construction of a vertical egg gallery. Eggs are laid in individual niches within the phloem along both sides of the gallery. Eggs soon hatch, and larvae develop through four instars while feeding on phloem perpendicular to the parent gallery. Larvae typically overwinter as third or fourth instar and resume development with the onset of spring. Larvae complete development in June, pupate, and transform into callow adults from late June to mid-July (Amman 1978). The host tree is eventually killed by the girdling action of larval feeding galleries.

Synthesized mountain pine beetle pheromones, both aggregating and antiaggregating, have been demonstrated to manipulate emerging beetle populations (see Borden et al. 1983, Borden et al. 1986, Amman et al. 1989, Gibson et al. 1991, Ross and Daterman 1997). Mountain pine beetle tree baits use attraction semiochemicals to group and concentrate infestations of beetles at designated locations. A single bait attached to a susceptible lodgepole pine will attract mountain pine beetle to attack the baited and surrounding trees. In field trials, verbenone inhibited the response of mountain pine beetle to traps baited with attractants (Borden et al. 1987, Amman et al. 1989, Lindgren et al. 1989). Treating trees with verbenone alone does not make the trees any less attractive than an unbaited tree, however, although mass-attacked trees are reduced (Shore et al. 1991). It is believed that antiaggregation semiochemicals inhibit response to the mass attack signal, discouraging or repelling attacks by mountain pine beetle.

Next to the mountain pine beetle, dwarf mistletoe (*Arceuthobium americanum*) is the most serious threat to the health of lodgepole pine stands in the Intermountain West (Hawksworth and Johnson 1989). Once established within the overstory of a lodgepole pine stand, inoculum from infected trees rains down and infects lodgepole pine regeneration, perpetuating infection within a stand. Historically, fire has acted as the primary cleansing agent of stands infected by dwarf mistletoe (Hawksworth 1975). Aggravated by past cutting and fire protection practices, dwarf mistletoe has become increasingly abundant within lodgepole pine stands of the Intermountain Region (Hoffman 1978). Mistletoe infection results in a significant reduction of tree growth, branch and stem deformity, loss of vigor, premature death, and eventual stand replacement by more shade-tolerant tree species. Managed control of dwarf mistletoe infected stands involves the removal of all infected overstory, followed by the removal of infected understory trees (Hawksworth and Johnson 1989).

Stands of lodgepole pine within the Sawtooth Valley have experienced periodic outbreaks of mountain pine beetle, as well heavy occurrences of dwarf mistletoe infections (Hoffman and Hobbs 1985, Wadleigh et al. 1991). Located in south-central Idaho, the Sawtooth Valley is managed by the USDA Forest Service as part of the Sawtooth National Recreation Area (SNRA). The Salmon River flows through this high elevation valley, bordered to the west by the Sawtooth Mountains and to the east by the White Cloud Mountains. The Sawtooth Valley is characterized by valley bottoms of irrigated and nonirrigated pasture land, moraine foothills dominated by lodgepole pine, and steep mountain hillsides of Douglas-fir, spruce, and subalpine fir. The headwater of the Salmon River is located at the south end of the valley, providing critical spawning habitat for several species of salmon. While this area is managed by the Forest Service primarily for its extraordinary scenic and recreational values, other resources managed within the valley include wildlife, livestock grazing, fisheries, timber, and mining.

Due in part to fire exclusion over the past several decades, fire-regenerated lodgepole pine stands within the Sawtooth Valley now vary in age from 100 to 300 yr old (the last large fires to occur within the Sawtooth Valley were between 100 and 300 yr ago) (Anonymous 1993). Stands of lodgepole pine have become overmature and have begun to be replaced by more shade-tolerant conifer species. Stands of mature lodgepole pine become increasingly susceptible to insect and disease agents, especially mountain pine beetle and dwarf mistletoe. Since mature lodgepole pine (older than 80 yr and greater than 9 in. in diameter) are highly vulnerable to mountain pine beetle attack (Hopping and Beall 1948, Amman 1978), most stands in the Sawtooth Valley are now susceptible to large-scale beetle infestations. The last major epidemic of mountain pine beetle occurred in the 1980s and was concentrated primarily near the headwaters of the Salmon River.

Beetle populations fluctuated radically during the 3 yr of our study. Building populations of mountain pine beetle suddenly collapsed in 1994, the last year of our study. According to USDA Forest Pest Management aerial surveys of the SNRA, lodgepole pine mortality attributed to mountain pine beetle increased from 2,491 trees in 1992 to 9,011 in 1993. Mortality then plummeted to only 534 trees in 1994. This dramatic decrease in mortality has been correlated with below average summer temperatures during the summer of 1993 (Logan and Bentz 1999, Ross and Daterman 1997), when July average temperatures were the coolest of record between 1895–1997 (NOAA, NCDC Regional Summary Data, Idaho Region 8).

Many residents of the Sawtooth Valley and other surrounding communities rely on fuelwood for heat during the winter months. The SNRA administers about 600 firewood permits each year, resulting in the harvest of between 1500–1800 cords/yr of dead lodgepole pine. Subepidemic levels of mountain pine beetle have provided a ready and available source of this fuelwood. However, because mortality occurs randomly throughout the forest and because current programs allow fuelwood gathering in designated "hunt and peck" areas as shown on fuelwood permit maps, fuelwood harvesters often venture off designated roads to access dead trees. In some cases, these "pioneered" wood roads become permanent and cause resource damage. In addition to visual and vegetative degradation, some unauthorized roads cross streams and meadows, increasing the need for management strategies that protect fragile resources while continuing to manage fuelwood.

Methods

With the assistance of SNRA managers, we located several stands of lodgepole pine suitable for our research, and each year from 1992 through 1994, new sets of pheromone blocks were established. Criteria for selection included: suitability for fuelwood harvest; appropriate stand structure of large, mature lodgepole pine (average diameter of 12 in. and greater); the presence of current mountain pine beetle activity within the stand; access to the area by existing dirt roads; and in the last year of the study, stands with an overstory of lodgepole pine infected with dwarf mistletoe.

The objective in 1992 and 1993 was to determine if pheromones might be used in a "push/pull" strategy to move (push) mountain pine beetle from one area and congregate (pull) them into another area where the infested trees could be readily harvested. During these 2 yr, a complete block design was used with 18 total replicates. Each replicate consisted of three 1 ac blocks located a minimum of 2 chains apart (1 chain = 66 ft). To push the beetles out of an area, one block received 40 antiaggregative verbenone bubble-caps (Phero Tech Inc. 7572 Progress Way, Delta, BC, Canada V4G 1E9) evenly spaced throughout the block (see Amman et al. 1989). To pull the beetles, one block received five attractant tree baits (attractant tree baits composed of trans-verbenol, exo-brevicomin, and myrcene; Phero Tech Inc.), one bait located at the center of the block and four baits near each corner. One surveyed block became a control plot, receiving no treatment. Since we wanted to test the effectiveness of a push/pull strategy, blocks with the largest number of current mountain pine beetle infested trees were assigned randomly to either control or "push" verbenone blocks. Attractant "pull" blocks were assigned to blocks with the fewest current attack trees.

Baits and verbenone capsules were stapled to the north side of appropriate host trees at a height of six ft. Efforts were made to ensure that all blocks within a replicate were similar in aspect as well as stand structure. We treated and surveyed eight replicates in 1992 and 10 in 1993.

In 1994 we modified our design using results from the previous 2 yr to include the new objective of mistletoe control. In 1992 and 1993, no significant benefit was demonstrated by the use of verbenone in "push" blocks (no apparent reduction in current attacks between verbenone blocks and control blocks). We therefore discontinued the use of verbenone in 1994. Each resulting replicate consisted of a baited attractant block and an associated control block. Also, to determine if mistletoe control could be incorporated, 1994 replicates were located in sites with a mature overstory heavily to moderately infected with dwarf mistletoe. An additional 14 replicates were surveyed, each with a 1 ac baited "pull" block and an associated 1 ac control plot.

In each year, replicates were surveyed during the summer, immediately prior to emergence of the current year's mountain pine beetle brood. In late summer, immediately prior to brood flight, pheromone tree baits and antiaggregative verbenone capsules were placed within their assigned blocks. Following brood flight of mountain pine beetle, each replicate was revisited, and all trees over 5 in. in diameter were surveyed. Each sampled tree was tallied and ranked according to species, diameter class, and infestation status (green tree, previous year attack, current mass attack, strip or partial attack, and other mortality factors).

The status of attack was determined by the condition of tree foliage and the presence and condition of mountain pine beetle brood under the bark. A tree under attack by current adult beetles will still have green foliage; however, the bole of the tree will have numerous, fresh pitch tubes where attacking parents have bored into the phloem. The base of the tree will be covered with boring dust, or frass, excavated by beetles established under the bark. When the bark is peeled, live parents within vertical galleries will be obvious. Along the gallery, small pearly white eggs will be present; or at right angles to the parent gallery, first or second instar larvae will be evident within horizontal galleries. A tree attacked the previous year will have faded foliage, ranging from yellow to light red. Pitch tubes on the bole of the tree will appear old and dry. Under the bark, light brown to black callow adults may be present if the survey is conducted previous to brood flight (prior to late summer). A tree attacked 2 yr previously will still retain most of its foliage, but the foliage will be red and dry. Exit holes are obvious on the exterior of the bark, which when peeled will reveal abandoned beetle galleries. Trees attacked previous to 2 yr progressively lose foliage and fine twig material.

Results

In 1992, blocks treated with aggregative baits had a total of 287 newly infested trees, for an average of 36 mass attacked trees/block. This compared to 80 total attacks determined to be from the previous year. The verbenone "push" blocks had 13 new mass attacks, down from 113 in 1991, for an average of 2/block. The control blocks had a total of 9 newly infested trees, down from 211 in 1991, for an average of 1/block (Figure 1 and Table 1). Comparing the live trees after treatment within each age class for baited blocks, larger age classes lost a greater proportion of trees than smaller age classes (Figure 2).

Results from 1993 were similar to those of 1992. A total of 166 new trees were mass attacked in the attractant bait

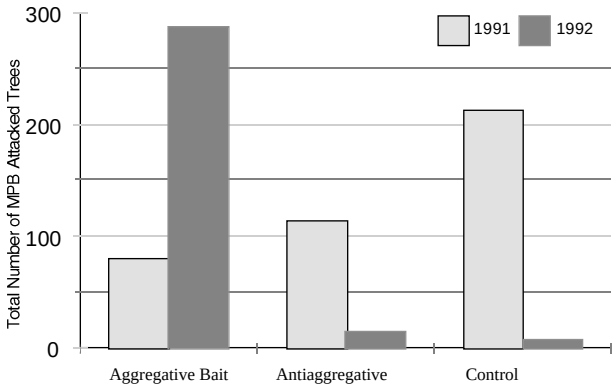

Figure 1. Total number of lodgepole pine trees 5 in. and larger dbh infested by MPB for each of three designs (aggregative bait, antiaggregative verbenone, and control plots) prior to treatments in 1991, and following treatments in 1992.

Table 1. Total number of infested trees for each treatment year (mean number/block).

	Current infestation	Previous year infestation
1992		
Aggregative bait	287 (35.9)	80 (10.0)
Antiaggregative verbenone	13 (1.6)	113 (14.1)
Control	9 (1.1)	211 (26.4)
1993		
Aggregative bait	166 (16.6)	19 (1.9)
Antiaggregative verbenone	2 (0.2)	200 (20.0)
Control	0	134 (13.4)
1994		
Aggregative bait	116 (8.3)	
Control	0	

blocks, up from a total of 19 in 1992, for an average of 17 trees/block. The verbenone blocks had 2 newly infested trees, down from 200 in 1992, for an average of 0.2/block. The control blocks had no new mass attacked trees, down from 134 in 1992 (Figure 3 and Table 1). Fewer current attacks occurred within the baited blocks than in 1992, resulting in a lower proportion of larger diameter mortality (Figure 4).

Analysis of data from 1992 and 1993 resulted in the discontinued use of verbenone treated antiaggregative blocks during the 1994 survey. There was no significant difference in the number of trees currently infested by mountain pine beetle in blocks treated with verbenone and associated control blocks (Table 2; $F = 15.91$; $df = 1, 33$; $P = 0.6079$ using the Kruskal-Wallis nonparametric rank of sums test).

In 1994, all replicates were located within dwarf mistletoe infected stands. Attractant "pull" blocks had a total of 116 mass attacked trees, for an average of 8.3/block. The control blocks had no mass attacked trees (Table 1). Analysis of beetle caused mortality data for each of the 3 yr, comparing baited aggregative treatments with their associated control blocks, revealed significant differences between these two treatments ($F = 274.43$; $df = 1, 60$; $P = 0.0001$ using the Kruskal-Wallis nonparametric rank of sums test).

In 1994, far fewer current attacks occurred in baited blocks than in either 1992 or 1993, resulting in a stand structure that remained relatively unchanged after treatment (Figure 5). While beetles appeared to have been moved out of control blocks and into baited blocks, not enough large

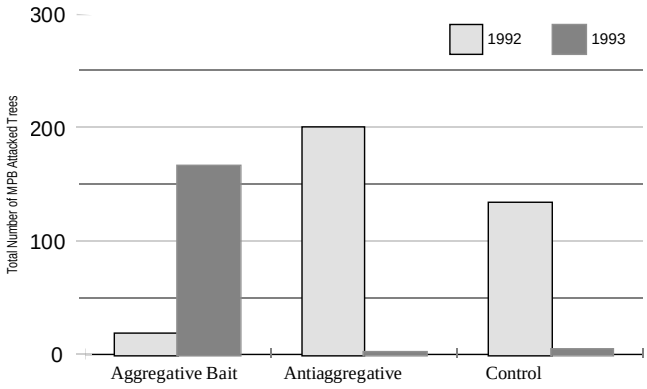

Figure 3. Total number of lodgepole pine trees 5 in. and larger dbh infested by MPB for each of three designs (aggregative bait, antiaggregative verbenone, and control plots) prior to treatments in 1992, and following treatments in 1993.

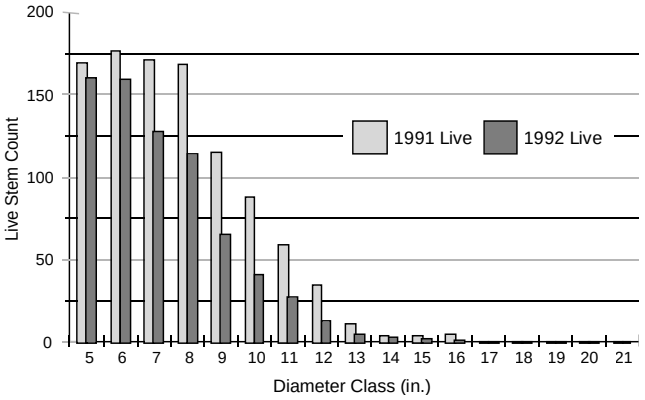

Figure 2. Green stem counts of lodgepole pine trees 5 in. and larger dbh by diameter class prior to aggregative bait treatment in 1991, and following treatment in 1992, demonstrating changes in stand structure due to MPB infestations.

overstory trees infected with dwarf mistletoe were removed to visibly reduce overstory inoculum and thereby improve stand health.

Discussion

We demonstrated the apparent effectiveness of attractant baits in moving mountain pine beetle into selected blocks. Each year, in every replicate, beetle attacks increased dramatically within the baited blocks, while simultaneously decreasing in associated control and verbenone treated blocks (Table 1). This suggests that we were successful in moving beetles out of designated study plots and surrounding areas and pulling them into the baited fuelwood harvest plots. During 1992 and 1993, there was little difference between current attacks in control and verbenone blocks (Table 1). Aggregative baits appeared to be more successful in pulling beetles into designated areas than antiaggregative verbenone was in pushing beetles out of a particular block. Past studies have demonstrated ambiguous or limited success in the use of verbenone to reduce mountain pine beetle attacks within stands of lodgepole pine (see Amman et al. 1989, Gibson et al. 1991, Shore et al. 1992, Safranyik et al. 1992). Our study indicated no apparent added protection associated with the use of verbenone capsules. Since verbenone appeared to have

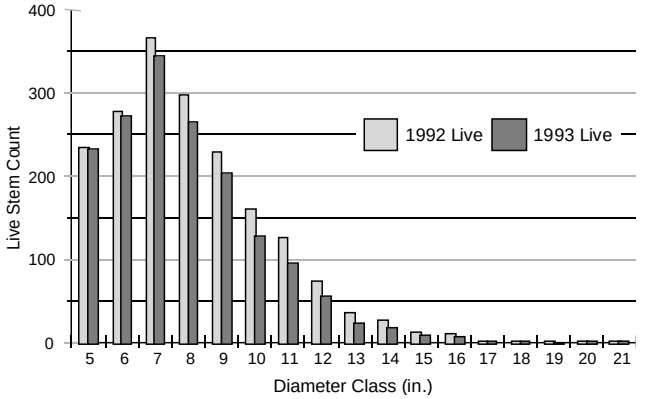

Figure 4. Green stem counts of lodgepole pine trees 5 in. and larger dbh by diameter class prior to aggregative bait treatment in 1992, and following treatment in 1993, demonstrating changes in stand structure due to MPB infestations.

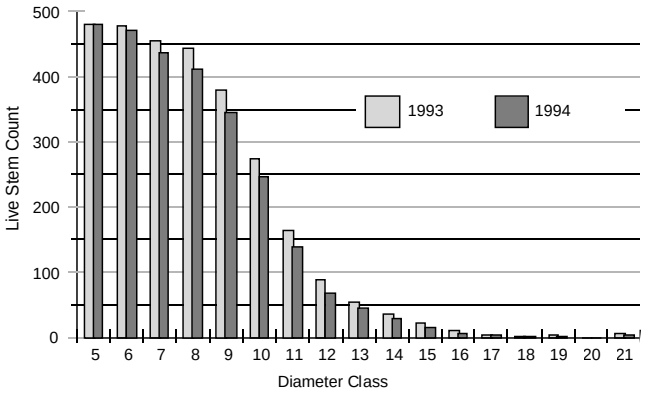

Figure 5. Green stem counts of lodgepole pine trees 5 in. and larger dbh by diameter class prior to aggregative bait treatment in 1993, and following treatment in 1994, demonstrating changes in stand structure due to MPB infestations.

little effect in our study, we felt justified in discontinuing its use during the 1994 experiment.

Although treatment blocks were not in the same area in each year, they were located within the same stands. The average number of current attacks/block decreased each year, with the fewest number of infested trees occurring in 1994 (Table 1). This coincides with the observation that beetle populations throughout the valley were in decline due to abnormally cool summer temperatures recorded in 1993. In 1994, we were hoping to remove a significant proportion of the dwarf mistletoe infected overstory trees, thereby reducing inoculum and initiating sanitation of infected lodgepole pine stands. While we successfully moved beetles into these baited plots, not enough overstory trees were attacked to significantly change the stand structure, hence sanitation of these stands was not successful (Figure 5). While Hawksworth and Johnson (1989) cite evidence that dwarf mistletoe infected trees are less susceptible to mountain pine beetle, other studies have found little correlation between dwarf mistletoe and beetle susceptibility in lodgepole pine (McGregor 1978, Hawksworth et al. 1983). To remove a greater proportion of overstory, we believe that either a greater number of beetles need to be present in the area at the time of treatment, or multiyear treatments may be necessary. Yearly placement of baits within a designated fuelwood harvest area may continue to remove dwarf mistletoe-infected overstory trees until stand density is reduced to levels considered undesirable for mountain pine beetle colonization (see Mitchell et al. 1983, Schmid et al. 1992, Schmid and Mata 1992). Managers would then have to remove remaining infected overstory and understory trees to complete local sanitization. These trees could either be sold commercially or as fuelwood.

Our results demonstrated several potential benefits for managers willing to use mountain pine beetle baits in the management of lodgepole pine stands. The primary benefit for managers within the SNRA was for placement and management of designated fuelwood harvest areas. By grouping mortality near existing roads, resource damage to unroaded areas can be decreased.

Overall stand health may also improve as pockets of mortality are removed within an area. The removal of large, overmature trees creates openings within a stand, thereby reducing competition for water, nutrients, and sunlight by remaining trees and improving individual tree and stand vigor. In addition, this management strategy may break up the age distributions within treated even-age stands of lodgepole pine, thereby creating a spatial mosaic of age and size classes within a stand. This strategy presumably increases stand health, creates improved visual dynamics, and may reduce future stand losses during epidemic outbreaks of mountain pine beetle (Peterman 1978, Roe and Amman 1970).

We believe further research may yet demonstrate an effective use for baits in the improvement of stand health within stands of overstory lodgepole pine infected with dwarf mistletoe. We would also like to conduct an experiment that would demonstrate whether local control of mountain pine beetle populations may be possible by using synthetic aggregative pheromones in harvestable stands adjacent to areas designated for protection. By removing infested trees within baited areas following infestation, but prior to brood emergence, a level of mountain pine beetle control may be demonstrated.

Attractant baits are effective at attracting mountain pine beetle to specific sites, and research has repeatedly demonstrated their effectiveness in localizing and concentrating mountain pine beetle attacks. The challenge remains to find better ways to use this tool effectively in conjunction with local management objectives, beetle population numbers, and forest stand conditions. Given the right circumstances, including road access, existing endemic levels of mountain pine beetle, and defined silvicultural objectives, we successfully demonstrated a strategy where local managers were able to manipulate populations of mountain pine beetle to improve management of fuelwood resources as well as potentially improve stand health. Ecosystem management demands that more creative strategies be developed to meet human needs while recognizing the role of "destructive" agents in the overall health of lodgepole pine forests.

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