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Using Pheromones to Protect Heat-Injured Lodgepole Pine From Mountain Pine Beetle Infestation

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Abstract—The bark beetle antiaggregative pheromones, verbenone and ipsdienol, were tested in protecting heat-injured lodgepole pine (*Pinus contorta* Dougl. ex Loud.) from mountain pine beetle (*Dendroctonus ponderosae* Hopkins) infestation in the Sawtooth National Recreation Area in central Idaho. Peat moss was placed around 70 percent of the basal circumference of lodgepole pines. When the peat moss was ignited, it simulated the smoldering of natural duff, generating temperatures that killed the cambium. The four treatments tested were uninjured tree, heat-injured tree, heat-injured tree treated with verbenone, and heat-injured tree treated with verbenone plus ipsdienol. Treatments were replicated 20 times. Mountain pine beetles were attracted into treatment blocks by placing mountain pine beetle tree baits on metal posts 3 to 5 meters from treated trees. Fisher's Exact Test showed that treatment and beetle infestation were not independent ($P < 0.015$). Check treatments contained more unattacked and mass-attacked trees, whereas pheromone treatments contained more unsuccessfully attacked trees. Ipsdienol did not increase verbenone's efficacy in protecting trees.

Keywords: *Dendroctonus ponderosae*, *Pinus contorta*, verbenone, ipsdienol

Trees injured by prescribed fires or wildfires may attract bark beetles (Fellin 1980; Furniss 1965; Miller and Keen 1960; Mitchell and Martin 1980). Mountain pine beetles (*Dendroctonus ponderosae* Hopkins) have been observed infesting fire-injured ponderosa (*Pinus ponderosa* Dougl. ex Laws) and lodgepole (*P. contorta* Dougl. ex Loud.) pines (Geiszler and others 1984; Rust 1933) but apparently do not prefer them (Blackman 1931; Hopkins 1905). Bark beetle antiaggregative pheromones offer promise of protecting injured trees from infestation.

Antiaggregative pheromones are chemicals produced and released by adult mountain pine beetles as they construct egg galleries. Increasing concentrations of these chemicals reduce a tree's attractiveness to other beetles, stopping additional beetles from attacking the tree and causing them to attack another tree. The overall effect of the antiaggregative pheromones is to prevent overcrowding and excessive competition among developing larvae (Lindgren and Borden 1989).

We decided to study beetle response to heat-injured trees treated with pheromones in the Sawtooth National Recreation Area, where the mountain pine beetle population currently is epidemic.

Several studies have been conducted to determine the feasibility of using bark beetle antiaggregative pheromones to protect trees from infestation. For the mountain pine beetle, these studies have centered around the use of verbenone, the species' principal antiaggregative pheromone (Borden and others 1987). In nature, verbenone is derived from three sources: female beetles, auto-oxidation of alpha-pinene, and microorganisms (primarily yeasts) growing in established egg galleries (Borden and others 1987). When synthetic verbenone was released near sticky screen traps (Ryker and Yandell 1983) and in funnel traps (Borden and others 1987; Schmitz and McGregor 1990) in the presence of the attractive synthetic mountain pine beetle lure, the number of beetles caught was greatly reduced.

These findings led to large-scale tests of verbenone to develop strategies to help reduce tree losses in high-value areas, such as riparian areas, campgrounds, administrative sites, and summer homes. These tests, which were designed to protect areas of lodgepole pine rather than individual trees, significantly reduced

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losses in verbenone-treated stands compared to untreated check stands (Amman and others 1989, 1991; Gibson and others 1991; Lindgren and others 1989). Although verbenone-treated lodgepole stands had significantly less mortality than check stands for 3 years, verbenone did not appear to be effective during the next 2 years (Rasmussen 1991). Verbenone bubble capsules did not significantly reduce beetle infestations in ponderosa pine stands (Bentz and others 1989; Gibson and others 1991; Lister and others 1990).

A test on individual lodgepole pine in British Columbia showed that verbenone-treated and check trees had similar beetle infestation. However, verbenone significantly reduced mountain pine beetle infestation of trees on which vials of the attractant pheromone, *exo*-brevicomin, were attached (Shore and others 1992).

In a second test in British Columbia, Safranyik and others (1992) tested two release rates of verbenone in lodgepole pine stands. They did not observe significant differences between the two release rates for the number of mountain pine beetles trapped, number of attacked trees, and number of attacking beetles. Although the averages were lower in the treated plots than in untreated plots, only the difference in the number of beetles trapped was statistically significant.

Another pheromone, ipsdienol, the principal aggregative pheromone of the pine engraver (*Ips pini* Say), was also found in small quantities in mountain pine beetles. In laboratory studies, ipsdienol reduced the attraction of mountain pine beetles to extracts of female frass, bark fragments chewed away when females construct egg galleries (Hunt and Borden 1988). In field trapping studies the number of mountain pine beetles caught was significantly reduced when ipsdienol was included in traps containing synthetic mountain pine beetle attractant pheromones (Hunt and Borden 1988). It was shown to have an inhibitory effect on mountain pine beetles (Hunt and Borden 1988). Although the results of tests to protect pine trees and stands with pheromones have been mixed, we decided to test the efficacy of verbenone and ipsdienol to protect individual heat-injured trees.

The objectives of our study were to determine: (1) if verbenone and ipsdienol can prevent infestation of heat-injured lodgepole pine, and (2) if mountain pine beetles are attracted to heat-injured lodgepole pine.

STUDY AREA

The 1992 study was conducted in Sawtooth Valley of the Sawtooth National Recreation Area where the mountain pine beetle population is epidemic. Large groups of trees have been killed. In some areas, particularly along Alturas Lake Creek, beetle populations are declining because of host depletion—they have killed most of the large-diameter lodgepole pine they need to produce the large broods that allow the infestation to continue (Cole and others 1976). Because of host depletion in the older portions of the infestation, study plots were selected on the periphery of the infestation. These areas had been infested for only 1 or 2 years, presumably by beetles that migrated out of the main infestation. Plots were located in three drainages: (1) upper Salmon River, (2) Frenchman Creek, and (3) upper Smiley Creek. Elevations ranged from 2,250 m to 2,500 m. About 75 percent of the trees were lodgepole pine. The remaining trees were Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco), quaking aspen (*Populus tremuloides* Michx.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.).

METHODS AND MATERIALS

The study consisted of 20 blocks, each containing four lodgepole pine trees at least 20 cm diameter at breast height, sizes susceptible to mountain pine beetle infestation (Cole and Amman 1969; Safranyik and others 1974). The four lodgepoles in each block selected for treatment were usually within an area 30 m in diameter. Four treatments were applied: (1) uninjured tree with no pheromone treatment; (2) heat-injured tree with no pheromone treatment; (3) heat-injured tree with two verbenone capsules (elution rate 6.5 mg/24 h/capsule at 22 °C) stapled 180 degrees apart on the trunk 2 m above ground level; and (4) heat-injured tree with two verbenone capsules and two ipsdienol capsules (elution rate 0.2 mg/24 h/capsule at 22 °C) stapled 90 degrees apart and alternating around the trunk 2 m above ground level (fig. 1).

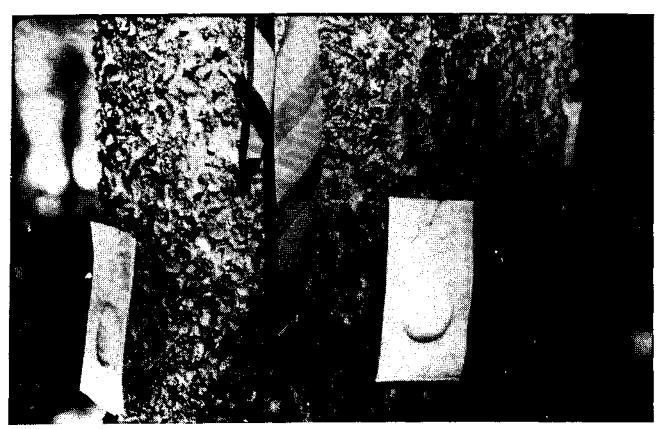

Figure 1—Ipsdienol and verbenone bubble capsules stapled on heat-treated lodgepole pine to prevent mountain pine beetle infestation.

Figure 2—Duff was cleared away from base of the tree and replaced by peat moss held by hardware cloth to obtain more uniform heat injury.

To ensure that beetles would be attracted to the block, mountain pine beetle bait (Phero Tech Inc., trans-verbenol, *exo*-brevicomin, and myrcene) was placed in the block. Our intent was to attract beetles into the block. They could then discriminate among treated trees for infestation. Baits were attached to the top of metal fenceposts 1.5 m above ground level. These baits were 3 to 5 m away from treated trees. Had the bait been put directly on a tree, that tree would almost certainly have become the focus of infestation. The number of baits used per block varied according to spacing of treated trees. No treated tree was to be farther than 5 m from a bait. Two baits were usually used, but sometimes three were needed. Blocks were widely distributed, but had to be at least 30 m apart to ensure that a large population of beetles in one block would not "spill over" into an adjacent block. Five blocks were placed in each of four areas: east side of the upper Salmon River, west side of the upper Salmon River, Frenchman Creek, and Smiley Creek. The distance between blocks ranged from 30 m to 2 km. The forest adjacent to each block contained three to six trees that were infested in 1991.

Natural duff was removed from the base of treated trees down to mineral soil. A ring of peat moss about 8 cm wide by 8 cm deep was placed around 70 percent of the tree's basal circumference (fig. 2). It was held in place by 12-mm mesh hardware cloth. After charcoal starter fluid was squirted on top, the peat moss was lit (fig. 3). Once the initial flame from the starter fluid died down (after about a minute), the peat moss smoldered in a manner similar to natural forest duff. Temperatures of 200 to 500 °C on the outer bark were measured with a digital thermometer during the smoldering process, ensuring adequate heat to kill the cambium (fig. 3). Pumper trucks and operators were on hand in case a fire got out of control, and also to extinquish all fires after adequate heating. Heat treatment and pheromone application were started July 14 and were completed July 17, 1992. By July 17, a few new beetle attacks had already been noted on treated trees.

The blocks were revisited in May 1993 to assess the results. Mountain pine beetle infestation between ground level and 2 m high on the trunk was estimated by two methods. Light attack densities (unsuccessfully attacked trees) were estimated by counting attacks over the entire lower 2 m of the tree trunk and dividing by the surface area to obtain the number of attacks per dm^2. Egg gallery density was estimated by measuring the length of up to five galleries, taking the average length, and multiplying by the attack density. Heavily attacked trees (mass attack, strip attack, and a few unsuccessful attacks) were sampled for attack and gallery densities by removing two 231-cm^2 areas of bark and counting attacks and measuring galleries. Samples were taken from different sides of the tree, or on the same side when only a narrow strip of bark was successfully infested (fig. 4). Trees were classified

Figure 3—Smoldering peat moss generated bark surface temperatures of up to 500 °C.

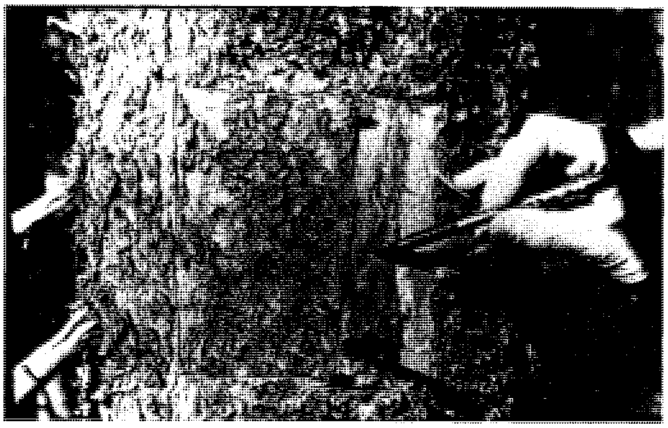

Figure 4—Infested lodgepole pine sampled for mountain pine beetle attack and egg gallery densities.

into four categories: (1) unattacked; (2) unsuccessfully attacked—light attack density and low gallery density with galleries invaded by pitch, preventing successful brood production; (3) strip attacked—vertical strip of bark was attacked at sufficient density to ensure some beetle brood survival; and (4) mass attacked—entire circumference of the lower trunk attacked, brood present, tree dead. The term "pitch-out" is frequently used in a way that is misleading. If a tree pitches the attacking beetles out, it is considered too vigorous for them to overcome. However, the reason for most pitch-outs is not high tree vigor but low attack and gallery densities. We use the less confusing term "unsuccessful attack" in this paper.

Data were subjected to Fisher's Exact Test (2-Tail) to determine independence between tree treatment and beetle infestation.

RESULTS AND DISCUSSION

Fisher's Exact Test (2-Tail) showed that tree treatment and beetle infestation were not independent ($P < 0.015$). Therefore, beetle response was significantly affected by pheromone treatments. For comparisons of the effects of pheromone treatments, treatments were divided into check treatments and pheromone treatments because there was little difference between the two check treatments and between the two pheromone treatments. In general, the two groups of check trees (uninjured and heat injured) had more unattacked trees, more mass-attacked trees, and fewer unsuccessfully attacked trees than pheromone-treated trees. The checks had 11 uninfested trees compared to 4 for pheromone-treated trees; the checks had 11 mass-attacked trees compared to only 3 for pheromone-treated trees; the checks had 5 strip-attacked trees compared to 3 for pheromone-treated trees; and the checks had 13 unsuccessfully attacked trees compared to 30 for the pheromone-treated trees (table 1). The small number of mass-attacked pheromone-treated trees, and the large number of unsuccessfully attacked pheromone-treated trees suggest the pheromones had a decided effect on the beetles' infestation behavior.

Ipsdienol did not appear to have any antiaggregative effect. When bubble capsules containing ipsdienol were placed on trees that also had verbenone bubble capsules attached to them, the beetles' response was similar to that achieved with verbenone alone. Verbenone alone resulted in three trees remaining uninfested, while verbenone plus ipsdienol resulted in only one tree remaining uninfested (table 1). The numbers of strip-attacked trees were one for verbenone alone and two for verbenone plus ipsdienol with four mass-attacked trees for verbenone alone and two for verbenone plus ipsdienol. The numbers of unsuccessfully

Table 1—Numbers and percentages of lodgepole pine infested by mountain pine beetle for four treatments, Sawtooth National Recreation Area, ID, 1992

	Infestation category[1]									
Treatment	Uninfested		Mass attack		Strip attack		Unsuccessful attack		Total	
	No.	*Percent*	*No.*	*Percent*	*No.*	*Percent*	*No.*	*Percent*	*No.*	*Percent*
Uninjured	6	30.0	5	25.0	1	5.0	8	40.0	20	100
Heat-injured	5	25.0	6	30.0	4	20.0	5	25.0	20	100
Verbenone	3	15.0	2	10.0	1	5.0	14	70.0	20	100
Verbenone + ipsdienol	1	5.0	1	5.0	2	10.0	16	80.0	20	100
Totals	15	18.6	14	17.5	8	10.0	43	53.9	80	100

[1]Uninfested trees had no mountain pine beetle attacks; mass-attacked trees were killed; strip-attacked trees had only a vertical strip of bark killed; unsuccessfully attacked trees had light attack density and low gallery density with galleries invaded by pitch, preventing successful brood production.

Table 2—Mountain pine beetle attack densities and gallery densities for three infestation categories[1] among four tree treatments, Sawtooth National Recreation Area, ID, 1992

Treatment	Mass attack: Attack density	Mass attack: Gallery density	Strip attack: Attack density	Strip attack: Gallery density	Unsuccessful attack: Attack density	Unsuccessful attack: Gallery density
	Attacks/dm²	*cm/dm²*	*Attacks/dm²*	*cm/dm²*	*Attacks/dm²*	*cm/dm²*
Uninjured	$N = 5$		$N = 1$		$N = 8$	
Mean	1.04	25.29	1.30	24.19	0.11	0.98
Standard deviation	.47	11.71	—	—	.22	2.28
Heat-injured	$N = 6$		$N = 4$		$N = 5$	
Mean	1.12	36.37	1.19	24.19	.19	1.46
Standard deviation	.48	14.23	.57	8.60	.26	1.55
Verbenone	$N = 2$		$N = 1$		$N = 14$	
Mean	.98	22.68	1.08	23.64	.15	2.07
Standard deviation	.15	1.36	—	—	.28	5.09
Verbenone + ipsdienol	$N = 1$		$N = 2$		$N = 16$	
Mean	.65	17.59	1.52	36.29	.30	2.13
Standard deviation	—	—	.30	11.66	.36	2.40
All treatments	$N = 14$		$N = 8$		$N = 43$	
Mean	1.04	29.12	1.27	27.15	.20	1.81

[1]Mass-attacked trees were killed; strip-attacked trees had only a vertical strip of bark killed; unsuccessfully attacked trees had a light attack density and low gallery density with galleries invaded by pitch, preventing successful brood production.

attacked trees were similar, 14 for the verbenone treatment and 16 for verbenone plus ipsdienol.

We thought this test would show whether fire-injured trees were more or less attractive to mountain pine beetles. The data (table 1) suggest that fire-injured trees may be somewhat more attractive. Six of the heat-injured trees were mass attacked compared to five of the uninjured check trees, and four of the heat-injured trees were strip attacked compared to one of the uninjured check trees. In addition, five of the heat-injured trees were unsuccessfully attacked compared to eight of the uninjured trees. Attack and egg gallery densities of heat-injured trees were somewhat higher than those of uninjured check trees (table 2). These data suggest that heat-injured trees may be more attractive to the beetles. This finding cannot be demonstrated statistically in our study. However, results from fixed plots and extensive surveys in fire-injured stands of lodgepole pine in Yellowstone Park show little infestation by mountain pine beetles (Amman and Ryan 1991; Ryan and Amman, in press). Infestation is spread across all fire-injury classes, thus indicating no fire-injury preference by mountain pine beetles (Amman and others 1993). These differences in infestation for fire-injured and uninjured trees are not conclusive; additional work is needed to determine whether fire-injured trees are more attractive to mountain pine beetles.

CONCLUSIONS

We conclude that:

- Verbenone had a pronounced effect on attacking mountain pine beetles, resulting in more trees being attacked; however, most of the attacks were unsuccessful.
- The use of ipsdienol capsules in conjunction with verbenone did not increase the antiaggregative effect.
- Additional work is needed to determine if fire-injured lodgepole pine trees are more attractive to mountain pine beetles than uninjured trees.

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