Reduction of mountain pine beetle (Coleoptera: Scolytidae) attacks by verbenone in lodgepole pine stands in British Columbia

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The effect of the aggregation-inhibiting pheromone verbenone on mountain pine beetle attacks in lodgepole pine stands was assessed by affixing verbenone release devices on trees on a 10 × 10 m grid. In one experiment, aggregation to trees baited with an attractive combination of *trans*-verbenol, *exo*-brevicomin, and myrcene was reduced in verbenone-treated blocks compared with control blocks (attractive baits only). The mean number of trees with mass attacks ($\geq$31.3 attacks/m^2), mean percentage of available trees mass attacked, and mean total number of trees infested were reduced by 74.3, 66.7, and 58.5%, respectively. The ratio of 1987 attacks to 1986 attacks was reduced from 14.0 to 2.6. In a second experiment, using no attractive baits, verbenone caused similar but nonsignificant reductions. The mean number of trees with mass attacks, mean percentage of available trees mass attacked, and mean total number of trees infested were reduced by 75.2, 53.5, and 62.1%, respectively. The 1987 to 1986 attack ratio was reduced from 13.2 in control blocks to 0.2 in the verbenone-treated blocks, and the percentage of trees that were infested but not mass attacked was significantly increased, from 45.7% in the control blocks to 63.2% in the verbenone-treated blocks. We conclude that verbenone shows promise as a management tool for controlling the mountain pine beetle.

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Les effets de la verbénone, une phéromone inhibitant l'agrégation, sur les attaques du Dendroctone du pin dans les peuplements de Pin tordu ont été évalués en plaçant des dispositifs de dégagement de la verbénone sur des arbres dans un quadrillage de 10 × 10 m. Dans un essai, l'agrégation aux arbres au moyen de leurres formés d'un mélange attrayant de *trans*-verbénol, d'*exo*-brévicomin et de myrcène a été réduite dans les surfaces traitées à la verbénone par comparaison aux témoins (leurres attrayants seulement). Le nombre moyen des arbres sujets à des attaques massives (31,3 attaques/m^2), le pourcentage moyen d'arbres disponibles attaqués massivement, ainsi que le nombre total moyen d'arbres infestés ont été réduits de 74,3, 66,7 et 58,5%, respectivement. Le ratio 1987 à 1986 des attaques a été réduit de 14,0 à 2,6%. Dans un second essai ne comportant aucun leurre attrayant, la verbénone a produit des réductions semblables, bien que non significatives. Le nombre moyen des arbres sujets à des attaques massives, le pourcentage moyen d'arbres disponibles attaqués massivement ainsi que le nombre total moyen d'arbres infestés ont été réduits de 75,2, 53,5 et 62,1%, respectivement. Le ratio 1987 à 1986 des attaques a été réduit de 13,2 dans les témoins à 0,2 dans les surfaces traitées à la verbénone, et la proportion des arbres qui avaient été infestés mais non attaqués massivement a augmenté de façon significative, passant de 45,7% dans les témoins à 63,2% dans les surfaces traitées au verbénone. La conclusion qui se dégage est que la verbénone a un avenir prometteur en tant qu'outil d'aménagement potentiel pour le contrôle du Dendroctone du pin.

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Introduction

Aggregation-inhibiting semiochemicals have been identified from several species of bark beetles (Borden 1982), and their effects demonstrated in field trials. One of them, 3-methyl-2-cyclohexen-1-one (MCH), has been tested extensively in large-scale operational trials to protect wind-thrown Douglas-firs, *Pseudotsuga menziesii* (Mirb.) Franco, from attacks by the Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins (McGregor *et al.* 1984), and is commercially available for operational use.

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TABLE 1. Effects of verbenone on mountain pine beetle attacks in blocks baited with attractive pheromones, June–September, 1987, east of Kelowna, B.C.

Treatment	No. of mass-attacked trees	% available trees attacked	Total attacked trees	Attack ratio 1987:1986	% infested trees not mass attacked
Baits	79.4*a*	13.0*a*	126.8*a*	14.0*a*	41.1*a*
Baits and verbenone	20.4*b*	5.4*b*	42.2*b*	2.6*a*	50.4*a*

NOTE: Values are given as means per 1-ha block. Within columns, means followed by the same letter are not significantly different by analysis of variance ($p = 0.05$).

Several *Dendroctonus* species utilize verbenone (4,6,6-trimethylbicyclo(3.1.1)-hept-3-en-2-one) as an aggregation-inhibiting pheromone (Renwick 1967; Pitman *et al.* 1969; Renwick and Vité 1970; Payne *et al.* 1978; Bedard *et al.* 1980; Ryker and Yandell 1983). Based on the success of the MCH trials (McGregor *et al.* 1984) and the encouraging results of a small verbenone pilot test for the control of mountain pine beetle, *D. ponderosae* Hopkins, in lodgepole pine, *Pinus contorta* Dougl. var. *latifolia* Engelm., in 1986 (B.S. Lindgren, unpublished data), we decided to test the effect of verbenone in lodgepole pine stands. Our objectives were (*i*) to assess if verbenone could prevent containment and concentration of moderate populations in blocks where trees had been baited with the attractants *trans*-verbenol, *exo*-brevicomin, and myrcene (Borden *et al.* 1983); and (*ii*) to determine if verbenone could induce mountain pine beetles to disperse from infested lodgepole pine stands.

Materials and methods

The experiments were laid out from 15 to 25 June, 1987, in lodgepole pine stands east of Kelowna, B.C. The lodgepole pine component varied from 72 to 96%, with minor components of Engelmann spruce, *Picea engelmanni* Parry, Douglas-fir, and subalpine fir, *Abies lasiocarpa* (Hook.) Nutt. Some blocks also contained minor components of western red cedar, *Thuja plicata* Donn, and western larch, *Larix occidentalis* Nutt. Stand density (all species) varied from 787 to 1216 stems/ha. The mean diameter at breast height (dbh) of lodgepole pine varied from 20 to 23 cm.

Experiment 1

Ten 1-ha blocks in lodgepole pine stands with low to moderate ($\bar{x} \pm 1$ SD = 13.6 ± 15.9 infested trees/ha) mountain pine beetle populations were baited with four mountain pine beetle tree baits (Phero Tech Inc., Vancouver, B.C.), releasing the aggregation pheromones *trans*-verbenol at 1 mg/24 h, and *exo*-brevicomin at 0.2 mg/24 h, and the host terpene myrcene at 18 mg/24 h. The baits were stapled 1.5–2.0 m high on the north side of susceptible (≥20 cm dbh) lodgepole pines in the corners of a 33 × 33 m square in the center of each block. In each of five paired replicates, one randomly selected block was treated with verbenone (chemical purity, 98.6%; optical purity, enantiomeric excess = (−)72%) released at 5–8 mg/24 h from bubble caps stapled to the north side of trees on a 10 × 10 m grid throughout the block. The total release rate of verbenone was 0.5–0.8 g/ha over 24 h at 25°C. Blocks were separated by a minimum of 100 m.

Experiment 2

Four 4-ha blocks were laid out in lodgepole pine stands with generally high ($\bar{x}$ ± SD = 86.7 ± 94.1 infested trees/ha) mountain pine beetle populations. An additional two blocks were laid out in an area with low ($\bar{x}$ ± 1 SD = 8.6 ± 9.3 infested trees/ha) beetle populations. In each of three pairs, one randomly selected block was treated with verbenone released at 5–8 mg/24 h from bubble caps applied on a 10 × 10 m grid, as in experiment 1, for a total verbenone release of 0.5–0.8 g/ha over 24 h at 25°C.

Assessment

Both experiments were assessed from 8 to 25 September, 1987, by 100% cruising in 50 m wide strips, mapping the distribution and recording the numbers of trees attacked in 1986 and 1987. The infestation rate was adjusted for stand density within the blocks, estimated for each block from 1 : 15 000 aerial color photographs, to give the percentage of available trees attacked. Attack densities were recorded by counting attacks at breast height in two 20 × 40 cm areas (total of 0.16 m^2 sampled) on opposite sides of each attacked tree. Trees with a total of five or more attacks within the sample areas (≥31.3/m^2) were classified as mass attacked, while those with fewer attacks were classified as not mass attacked. This is a conservative classification based on the conclusion by Raffa and Berryman (1983) that an attack density of 40/m^2 is necessary to overcome the resistance of a healthy tree. For experiment 1, the percentage of all attacks within the baited block that occurred within 10 m of a baited tree was calculated from the maps.

Analysis

Analysis of variance was used, with assessment strips as subsamples (Gomez and Gomez 1984, Table 6.2). Percentage data (x) were arc sine square root transformed (x′) before analysis. Numbers of mass-attacked trees and total numbers of attacked trees were transformed as $x' = \log(x + 1)$ before analysis to correct for heterogeneity of variance. For the number of mass-attacked trees in experiment 2, the transformation did not correct the variance heterogeneity, so these data were analyzed by Friedman's test (Zar 1984). Frequency distributions of attack densities were analyzed by a χ^2 test for goodness of fit and by a G-test for independence (Sokal and Rohlf 1969).

Results

In experiment 1, the number of mass-attacked trees (≥31.3 attacks/m^2), the percentage of available trees mass attacked, and the ratio of the 1987 mass attack to the 1986 attack were all significantly higher in blocks with baits only than in blocks with baits and verbenone (Table 1). There was no difference between the two treatments in the percentage of all attacks, including unsuccessful attacks, that occurred within 10 m of the baited trees, or in the percentage of trees that were classified as not mass attacked.

In experiment 2, the number of mass-attacked trees, the percentage of available trees mass attacked, and the ratio of the 1987 mass attack to the 1986 attack were higher, though not significantly, in control blocks than in verbenone-treated blocks (Table 2). Furthermore, the percentage of trees infested but not mass attacked was significantly higher in the verbenone-treated blocks than in the control blocks.

Block × treatment interactions were significant for all parameters in experiment 2, except the number of trees infested but not mass attacked, because the beetle population was low in one replicate, resulting in few attacks in both control and treatment blocks.

Analysis of mean frequency distributions and percent

TABLE 2. Effects of verbenone on mountain pine beetle attacks in blocks with existing beetle populations, June–September, 1987, east of Kelowna, B.C.

Treatment	No. of mass-attacked trees[a]	% available trees attacked	Total attacked trees	Attack ratio, 1986:1987	% infested trees not mass attacked
Blank control	100.8	21.3*a*	141.0*a*	13.2*a*	45.7*a*
Verbenone	25.0	11.4*a*	53.5*a*	0.2*a*	63.2*b*

NOTE: Within columns, means followed by the same letter are not significantly different by analysis of variance ($p = 0.05$). Block × treatment interactions are significant, except for percentage of infested trees not mass attacked.
[a]Means not significantly different at $p = 0.05$, Friedman's test (Zar 1984).

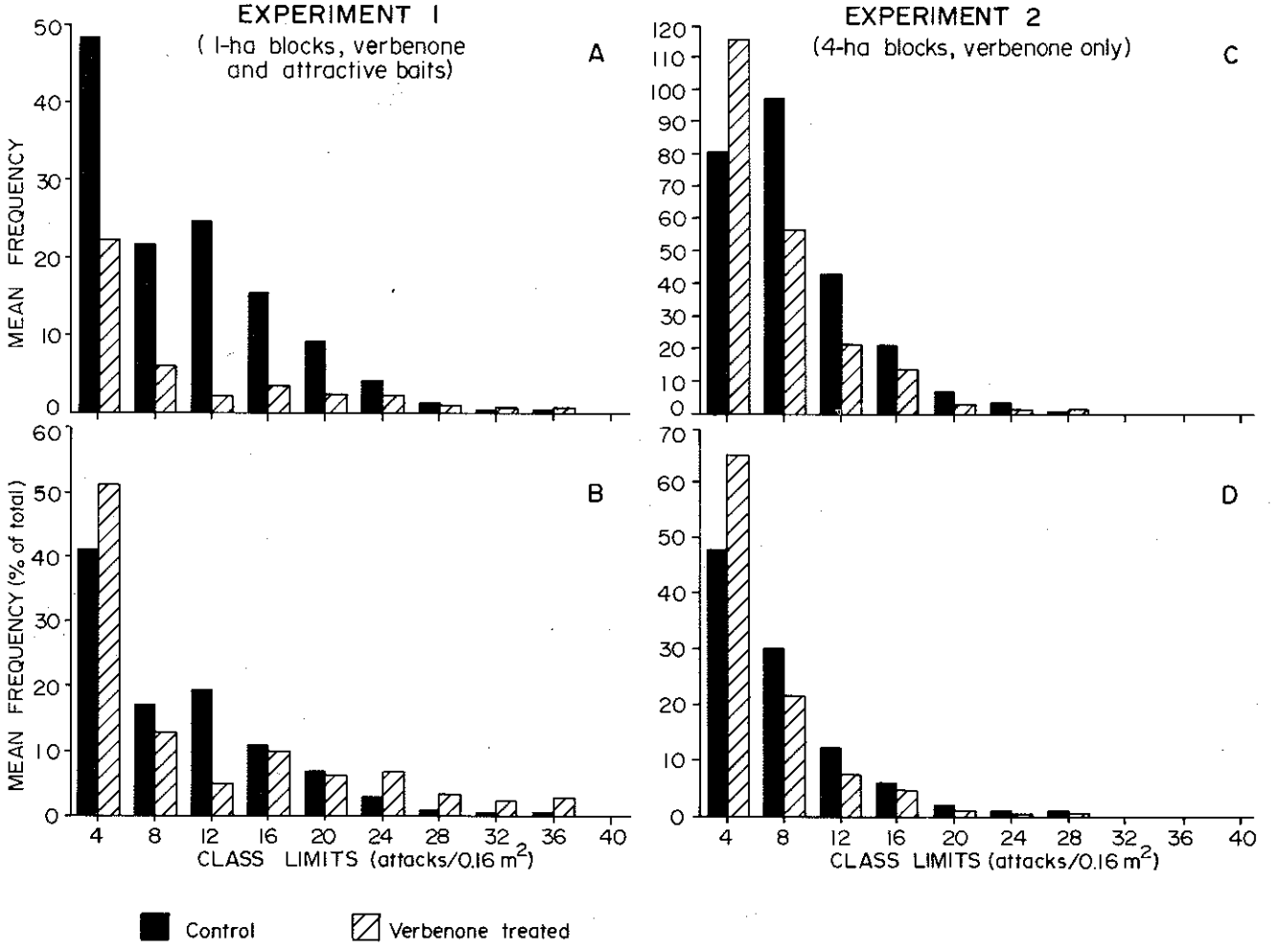

FIG. 1. Effect of verbenone on attack densities in all baited blocks (A and B) in experiment 1, and in all unbaited blocks (C and D) in experiment 2. Mean frequency distributions are significantly different at $p = 0.005$ (G-test for independence) (A and C) and percent distributions are significantly different at $p = 0.005$ (B) and $p = 0.05$ (D) (χ^2 test for goodness of fit).

frequency distributions of attack density classes for both experiments (Fig. 1) demonstrated clearly that in the presence of verbenone, the frequency distributions of attack density classes were significantly different from those in blocks without verbenone, with a higher proportion of the attacks in low attack density classes.

Discussion

The data for experiment 1 strongly suggest that the verbenone treatment deterred the response of mountain pine beetles to baited lodgepole pines. In particular, the reductions of 74.3% in mass-attacked trees, 66.7% in available trees mass attacked, and 58.5% in total attacks, and the reduction in the ratio of mass-attacked trees in 1987 to attacked trees in 1986 from 14.0:1 in control blocks to 2.6:1 in the treated blocks, demonstrate that verbenone is a potent aggregation inhibitor.

The data from experiment 2 appear equally encouraging. Significance between treatment and controls could not be established with only three replicates, two additional replicates having been destroyed by logging. Nevertheless, mass attacks were reduced by 75.2%, percentage of available trees mass attacked by 53.5%, total attacks by 62.1% and the 1987:1986 attack ratio from 13.2:1 in the control blocks to 0.2:1 in the verbenone-treated blocks. Furthermore, the percentage of infested trees not mass attacked was signifi-

cantly higher in the verbenone-treated blocks than in the control blocks, indicating that without baits to concentrate the beetles and focus their attacks, verbenone reduced the probability of mass attack occurring. The shift toward lower attack density frequencies in verbenone-treated blocks compared with untreated blocks in both experiments (Fig. 1) further demonstrates this effect.

Our data corroborate those of Amman *et al.* (1989), who used identical application rates and a similar experimental design combining the objectives of our experiments 1 and 2. The results of both studies suggest that verbenone may have great potential in dispersing beetles from attacked stands that cannot be treated by other methods, for instance, protecting forests on sensitive watersheds, and small, high-value stands, e.g., in recreational or urban areas, from attack. However, further studies are needed to verify treatment effects and refine methodology. Moreover, new tactics should be tested, such as combining verbenone treatment in one area with attractive baits in an adjacent or surrounding stand.

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