

# A simplified tree bait for the mountain pine beetle

J.H. BORDEN<sup>1</sup> AND L.J. CHONG

Centre for Pest Management, Department of Biological Sciences, Simon Fraser University,  
Burnaby, B.C., Canada V5A 1S6

B.S. LINDGREN

Phero Tech Inc., 7572 Progress Way, RR 5, Delta, B.C., Canada V4G 1E9

E.J. BEGIN

British Columbia Forest Service, Invermere Forest District, 625 4th Avenue,  
Invermere, B.C., Canada V0A 1K0

T.M. EBATA

British Columbia Forest Service, Prince Rupert Forest Region, Bag 5000,  
Smithers, B.C., Canada V0J 2N0

L.E. MACLAUHLAN

British Columbia Forest Service, Kamloops Forest Region, 515 Columbia Street,  
Kamloops, B.C., Canada V2C 2T7

AND

R.S. HODGKINSON

British Columbia Forest Service, Prince George Forest Region, 1011 4th Avenue,  
Prince George, B.C., Canada V2L 3H9

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Seven, split-block experiments throughout British Columbia in 1989 tested the efficacy of binary tree baits containing the pheromones *trans*-verbenol and *exo*-brevicomin or ternary baits with the addition of the host tree kairomone myrcene for containing and concentrating infestations of the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, in stands of lodgepole pine, *Pinus contorta* var. *latifolia* Engelm. Attack densities on baited trees, attack frequencies of baited trees and trees within 10 m of the baited trees, and the ratios of newly attacked, green, trees to previously attacked, red, trees were generally statistically equal between sub-blocks containing binary or ternary baits. Where statistically significant differences occurred for one or more of the above criteria in one experiment, they were generally offset by statistically significant differences in the opposite direction in another experiment. Two individual-tree experiments in 1990 that supported the equality of binary and ternary baits indicated that raising the release rate of *trans*-verbenol in binary baits tended to reduce their efficacy (possibly because of contamination with the antiaggregation pheromone verbenone) and showed that increasing the release rate of *exo*-brevicomin tended to counteract this effect. When attack frequencies were subdivided by diameter class of available trees attacked, all baits were effective in inducing attack on available trees <30.0 cm diameter at breast height (1.3 m), but attack on baited and control trees ≥30 cm diameter at breast height was equal. Provided that the *trans*-verbenol in binary baits does not contain or autoxidize to verbenone, myrcene can be deleted from operational tree baits.

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L'utilisation d'arbres pièges à double appât, constitué des phéromones *trans*-verbénol et *exo*-brévicomine, et à triple appât, avec l'addition de la kairomone myrcène, dans le but de contenir et de concentrer les infestations de dendroctones du pin à bois lourd, *Dendroctonus ponderosae* Hopkins, fut testée à l'aide de sept dispositifs en tiroir établis en 1989 à travers la Colombie-Britannique dans des peuplements de pin de Murray, *Pinus contorta* var. *latifolia* Engelm. Les densités d'attaque sur les arbres pièges, les fréquences d'attaque sur les arbres pièges et sur ceux situés à moins de 10 m des arbres pièges ainsi que les ratios entre les arbres verts nouvellement attaqués et les arbres rouges déjà attaqués étaient généralement statistiquement égaux entre les sous-blocs contenant les arbres à double ou à triple appât. Lorsque des différences statistiquement significatives étaient décelées au niveau d'un ou de plusieurs critères dans un dispositif, elles étaient généralement contrebalancées par des différences significatives inverses dans un autre dispositif. Les résultats de deux expériences conduites en 1990 avec des arbres individuels confirmèrent l'égalité entre les double et triple appâts, indiquant ainsi que l'augmentation du taux d'émission de *trans*-verbénol des arbres pièges à double appât a tendance à réduire leur efficacité (vraisemblablement à cause d'une contamination avec la phéromone d'anti-agrégation, verbénone) et que l'augmentation du taux d'émission de *exo*-brévicomine a tendance à contrecarrer l'effet précédent. Lorsque les fréquences d'attaque étaient subdivisées par classe de diamètre d'arbres disponibles attaqués, tous les appâts étaient efficaces pour induire des attaques sur les arbres disponibles <30 cm en diamètre à hauteur de poitrine (1,3 m), mais les attaques sur les arbres pièges et témoins ≥30 cm en diamètre à hauteur de poitrine étaient égales. En assumant que la *trans*-verbénol sur les arbres pièges à double appât ne contient pas ou ne s'oxyde pas en verbénone, le myrcène peut être éliminé des programmes opérationnels d'arbres pièges.

[Traduit par la rédaction]

## Introduction

mountain pine beetle (MPB), *Dendroctonus ponderosae* (Coleoptera: Scolytidae), is a multibillion dollar pest of British Columbia (Borden 1990), and its management is a major concern. One management strategy is to use semiochemicals (message-bearing chemicals) (Nordlund 1981) in integrated pest management programs against the MPB (Borden 1985; McMullen et al. 1986; Borden 1990). The most commonly used tactics are containment and control of beetle populations prior to logging, and mop up operations on residual populations following sanitation-salvage logging (Borden et al. 1983b, 1983c, 1986; Gray and Borden 1989). Semiochemical compounds have been found to be the principal semiochemicals responsible for causing aggregations of MPBs on lodgepole pines, *Pinus contorta* var. *latifolia* Engelm., in British Columbia. These are the female-produced pheromone verbenol, the male-produced pheromone *exo*-brevicomin, and the host tree kairomone myrcene (Borden et al. 1983a, Borden et al. 1983).

There is considerable redundancy in the semiochemicals used to induce attack on trees (Borden et al. 1990). Research also indicated that tree baits comprising *trans*-verbenol and *exo*-brevicomin were as effective in inducing attack as the same two components used with myrcene. However, further experimental evidence was considered necessary to determine whether it could be recommended that myrcene be deleted from the baits used and accepted commercial tree bait. We report the results of a large, operational trial conducted throughout British Columbia in 1989, as well as the results of individual-tree experiments in 1990, which justify the conclusion that myrcene can be deleted from operational tree baits.

## Materials and methods

### Operational experiments

Split-block experiments (Fig. 1) were set up in June 1989 on stands of mature lodgepole pine near the following British Columbia Forest Districts (in parentheses): (1) Grand Forks (Boundary District), (2) Penticton (Penticton District), (3) Princeton (Merritt District), (4 and 5) Telkwa (Bulkley District), (6) Fort St. James (Fort St. James District), and (7) Invermere (Invermere District). The blocks ranged from 6.5 to 10.0 ha (Table 1). The split-block design compared the binary baits (*trans*-verbenol plus *exo*-brevicomin, with or without myrcene) to be compared with the standard, ternary baits (with or without myrcene) within the same infestation. Employing seven experiments in each of two baits to be compared in a wide range of locations and levels of infestation, from 1.6 trees/ha (Invermere) to 78.6 trees/ha (Princeton) (Tables 1, 3).

Myrcene was released from a separate device, and all other semiochemicals were deployed from individual receptacles in a sealed, polyethylene bag (semiochemicals and bags obtained from Phero Tech Inc., Vancouver, B.C.). The bags were stapled approximately 2 m high to the trunk of the bole of a large lodgepole pine (minimum diameter at breast height (DBH), 1.3 m) = 20 cm). Myrcene, *trans*-verbenol, and *exo*-brevicomin were released at 9.0, 1.0, and 0.2 mg per 24 h, respectively, as determined at 24°C in the laboratory.

Experiments were evaluated from 15 to 25 September 1989. On each side of each block was checked. The location and attack status, either mass attacked ( $\geq 31.25$  attacks/m<sup>2</sup>) or lightly attacked ( $< 31.25$  attacks/m<sup>2</sup>), of each newly infested tree were noted, as was the location of each tree infested the previous year. The DBH of each baited tree was measured, and the attack density was counted in two 20 × 40 cm areas at eye level on the east and west sides of the tree (total sample area = 0.16 m<sup>2</sup>). To establish a relationship between attack density and diameter profile (Table 1), the DBH of each tree with a DBH within 10 m of every fourth baited tree was also

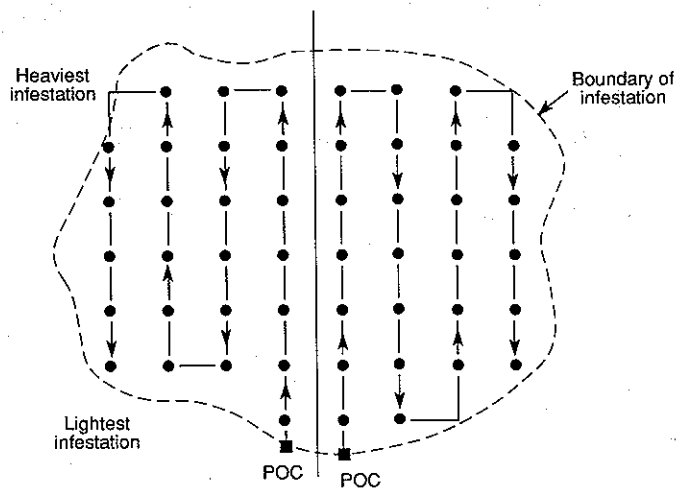


FIG. 1. Layout of split-block experiment to compare binary and ternary baits for containment and concentration of MPB infestations. The plot split ideally so as to divide heavy and light infestation equally. POC, point of commencement. Arrows indicate direction of lines, trees were baited (dots) at 50-m centres (4 trees/ha), and lines were flagged for easy re-entry.

measured. The numbers of attacked and mass-attacked trees in these plots were counted to obtain a measure of the ability of the baits to concentrate infestations.

Ratios of newly attacked (green) trees to trees attacked in the previous year (red trees) (green/red, or G/R ratios) over the entire sub-block were calculated for each treatment. Because the paired treatments were adjacent, beetles emerging from red trees could have flown into either sub-block before responding to a bait; therefore, the G/R ratios for each treatment were based on the number of red trees in the entire block divided by the area covered by each treatment.

Within each experiment, paired means were compared by two-tailed *t*-tests, and proportions were compared by  $\chi^2$ -tests (Zar 1984). In all cases  $\alpha = 0.05$ .

### Individual-tree experiments

Two experiments with identical treatments and a randomized complete block design were established in 1990. The first experiment consisted of 13 replicates and was set up on 6 July approximately 40 km north of Invermere, British Columbia. The second, 15-replicate experiment was established on 12 July, approximately 25 km north of Penticton, British Columbia. Six treatments were applied to reassess the necessity for myrcene and to determine the effect of raising the release rate of either or both of *trans*-verbenol and *exo*-brevicomin. Ternary and binary baits, with and without myrcene, with release rates of 9.0, 1.0, and 0.2 mg per 24 h for myrcene, *trans*-verbenol, and *exo*-brevicomin, respectively, comprised two treatments. *trans*-Verbenol and *exo*-brevicomin were also tested at two high release rates, 2.0 and 2.5 mg per 24 h, respectively, and at the two high-low and low-high dosage combinations. Experimental baits were formulated and affixed to lodgepole pines as in the operational experiments. An empty polythene bag was used for the control treatment. The distance between baited trees was 30–50 m in both experiments.

The Invermere experiment was assessed on 20 September and the Penticton experiment, from 10 to 11 September 1990. On each baited tree, attack densities were measured on the east and west sides in 20 × 40 cm areas, and the DBH was recorded. Trees  $\geq 15$  cm DBH within 10 m of the baited trees were classified as above, as not attacked, lightly attacked, or mass attacked, and the DBH was recorded.

The effects of treatments on attack density on baited trees were assessed by analysis of covariance, as were the percents of trees  $\geq 15$  cm DBH within 10 m of the baited trees that were attacked. For attack density data, DBH was used as a covariate, since attack density

TABLE 1. Stand characteristics and frequency of infestation by MPBs in 10 m radius plots around five baited lodgepole pines per treatment sub-block, 1989

Expt.	Location and block area	Bait treatment	No. of trees in plot	DBH of trees in plot (cm)	No./ha of lodgepole pine	Infestation frequency	
						% infested	% mass attacked
1	Grand Forks (10.0 ha)	Ternary	4.0±0.5	25.4±1.5	510±57	78.7±13.7	78.7±13.7
		Binary	21.5±7.7	18.1±0.4*	2739±985ns	3.0±5.9*	15.5±4.2*
2	Penticton (9.8 ha)	Ternary	18.4±3.3	18.0±0.4	2344±424	70.6±5.4	48.0±11.3
		Binary	30.4±3.9	16.6±0.3*	3872±501*	56.4±4.6ns	46.6±3.3ns
3	Princeton (10.0 ha)	Ternary	19.2±6.9	17.5±0.4	2446±876	55.4±12.2	44.0±14.2
		Binary	19.4±4.8	19.0±0.4*	2471±617ns	64.0±3.9ns	49.4±5.5ns
4	Telkwa (8.8 ha)	Ternary	15.8±3.1	28.4±0.7	2012±398	47.4±14.5	26.0±4.6
		Binary	6.8±1.4	35.4±1.1*	867±177*	77.6±10.2ns	65.8±8.8*
5	Telkwa (6.5 ha)	Ternary	2.8±0.5	40.4±2.9	350±61	66.7±11.8	66.7±11.8
		Binary	11.0±3.8	31.1±1.1*	1402±478ns	68.2±14.3ns	59.6±18.8ns
6	Fort St. James (10.0 ha)	Ternary	5.0±1.7	38.4±1.8	637±213	26.2±9.2	26.2±9.2
		Binary	4.4±2.4	38.9±1.8ns	560±308ns	51.4±21.6ns	51.4±21.6ns
7	Invermere (9.0 ha)	Ternary	15.4±2.8	23.9±0.7	1961±353	22.0±4.8	11.2±3.8
		Binary	24.6±3.6	21.1±0.5*	3133±459ns	28.6±10.0ns	22.0±9.4ns

NOTE: Values represent the mean ± SE. Paired means marked by an asterisk are significantly different; *t*-test,  $P < 0.05$ . ns, Not significant.

and DBH are positively correlated (Gray and Borden 1989). The number of trees assessed was used as a covariate for percent data, since the percent of available trees attacked by MPBs is negatively correlated with tree density (Cole and Amman 1969). Before analysis, homogeneity of slopes among the treatments was confirmed (Zar 1980). Percent data were transformed by  $x' = \arcsin \sqrt{p}$ , where  $p$  is the proportion, with 0 replaced by  $0.25n$ , and 1 by  $1 - (0.25n)$  (Zar 1980). The effects of baiting *versus* no baiting, myrcene *versus* no myrcene, dose of *exo*-brevicomin and *trans*-verbenol, respectively, and the interaction of these dose effects were assessed by orthogonal contrasts (Little and Hills 1978). Percent data were sorted by four DBH classes, 15.0–19.9, 20.0–24.9, 25.0–29.9, and ≥30.0 cm, for assessment of differential bait effects among DBH classes by a *G*-test of frequency distributions (Sokal and Rohlf 1969). For this comparison, data for the two experiments were pooled. In all cases  $\alpha = 0.05$ .

## Results and discussion

### Operational experiments

The binary baits were fully competitive with the ternary baits (Tables 1–3). Natural variability in the selected stands resulted in some significant differences between sub-blocks in DBH of baited trees and those surrounding them (Tables 1, 2) and in stand density (Table 1), but there was no consistent relationship between any of these stand characteristics and the various measures of infestation by MPBs.

Similar percents of the trees baited with binary and ternary baits were infested (lightly attacked plus mass attacked) as well as mass attacked by MPBs (Table 2). A significantly higher percent of binary-baited trees infested in the Fort St. James experiment was offset by a significantly greater percent of ternary-baited trees mass attacked in the Invermere experiment. There was no difference in attack densities on trees baited with binary or ternary baits (Table 1). Both types of baits were equal in their ability to concentrate attack around the baited trees (Table 1), with two offsetting instances of significant differences in mass-attacked trees.

For the entire blocks, there were five instances of significant differences between the percents of attacked trees that were mass attacked (Table 3), three in favor of sub-blocks with ternary baits and two with binary baits. Similarly, in comparing *G/R* ratios (Table 3), two comparisons disclosed significantly higher ratios for infested trees in sub-blocks with binary baits, compared with one in favor of the ternary baits. For mass-attacked trees, the two significant differences in *G/R* ratios were offsetting.

Despite the fact that in some instances unknown factors caused there to be significant differences, the equality of the binary and ternary baits is particularly emphasized by the fact that in most cases there were no significant differences in paired measures of induced attack (Tables 1–3).

### Individual-tree experiments

In both experiments, all five experimental treatments induced similar levels of attack frequency and density (Table 4). Analysis of covariance generally indicated strong treatment effects. Orthogonal contrasts revealed that all bait treatments significantly increased attack densities, as well as the percent of available trees lightly attacked and mass attacked, over the control. In the Invermere experiment, there was a significant interaction of *exo*-brevicomin and *trans*-verbenol doses, indicating that a high *trans*-verbenol dose tended to reduce attack density, but that a high *exo*-brevicomin dose counteracted this effect (Table 4). Although not significant in the Penticton experiment, the trend is similar (Table 4). A possible explanation is that *trans*-verbenol is always contaminated by a minor percent of the antiaggregation pheromone verbenone. Furthermore, *trans*-verbenol may autooxidize to verbenone under some circumstances (Hunt et al. 1989). An increased release rate of *trans*-verbenol would thus lead to an increase of verbenone, which may cause a decrease in attack density.

Analysis of frequency distributions within four different DBH classes revealed that at DBHs <30 cm, there were

TABLE 2. Frequency of infestation by MPBs and attack densities on lodgepole pine trees baited in 1989 with ternary or binary baits (myrcene deleted)

Expt.	Bait treatment	DBH of baited trees (cm) <sup>a</sup>	Infestation frequency			Attack density on baited and infested trees (no./m <sup>2</sup> ) <sup>a</sup>
			No. of trees	% infested <sup>b</sup>	% mass attacked <sup>b</sup>	
1	Ternary	29.2±1.2	20	100.0	100.0	105.3±7.6
	Binary	25.2±0.7*	20	100.0ns	100.0ns	102.2±8.9ns
2	Ternary	22.3±0.6	19	100.0	94.7	122.1±10.9
	Binary	21.3±0.5ns	20	100.0ns	100.0ns	122.5±6.1ns
3	Ternary	22.2±0.9	20	100.0	100.0	98.5±7.7
	Binary	22.3±0.7ns	20	100.0ns	100.0ns	111.3±10.3ns
4	Ternary	35.5±1.4	14	100.0	100.0	149.6±15.0
	Binary	38.5±1.5ns	21	95.2ns	85.7ns	113.8±11.6ns
5	Ternary	40.1±2.5	14	100.0	100.0	125.0±9.7
	Binary	39.2±2.3ns	12	100.0ns	91.7ns	139.8±23.5ns
6	Ternary	47.5±1.8	20	95.0	75.0	55.6±7.4
	Binary	48.3±1.4ns	20	70.0*	70.0ns	69.2±5.2ns
7	Ternary	29.0±1.1	17	100.0	58.9	47.6±8.2
	Binary	28.9±1.2ns	19	100.0ns	88.2*	45.6±7.0ns

<sup>a</sup>Values represent mean ± SE. Paired means marked by an asterisk are significantly different; *t*-test, *P* < 0.05. ns, Not significant.

<sup>b</sup>Paired percents marked by an asterisk are significantly different;  $\chi^2$ -test, *P* < 0.05. ns, Not significant.

TABLE 3. Relationship between red trees infested by MPBs in 1988 and newly infested green trees for split plots baited with ternary or binary baits (myrcene deleted)

Expt.	No. of red trees <sup>a</sup>	Bait treatment	No. of newly infested green trees			Green/red ratio	
			Total	Mass attacked <sup>b</sup>		All trees <sup>b</sup>	Mass-attacked trees <sup>b</sup>
				No.	%		
1	105	Ternary	155	116	74.8	1.48	1.10
	105	Binary	235	139	59.1*	2.23*	1.32ns
2	377	Ternary	751	519	69.1	1.99	1.37
	393	Binary	987	701	71.0ns	2.51*	1.78*
3	170	Ternary	494	387	78.3	2.91	2.28
	170	Binary	357	249	69.7*	2.10*	1.46*
4	31	Ternary	127	100	78.7	4.10	3.23
	47	Binary	256	128	50.0*	5.45ns	2.72ns
5	17	Ternary	55	40	72.7	3.23	2.35
	14	Binary	50	36	72.0ns	3.57ns	2.57ns
6	15	Ternary	25	18	72.0	1.67	1.20
	15	Binary	25	25	100.0*	1.67ns	1.67ns
7	7	Ternary	85	45	52.9	12.14	6.43
	7	Binary	141	93	66.0*	20.14ns	13.29ns

<sup>a</sup>Adjusted for area covered by each treatment.

<sup>b</sup>Paired percents or ratios marked by an asterisk are significantly different;  $\chi^2$ -test, *P* < 0.05. ns, Not significant.

significantly more trees mass attacked and fewer trees not attacked around baited compared with control trees (Fig. 2). However, there was no significant effect of baits on trees

≥30 cm DBH. Relatively few trees of any DBH were lightly attacked. It is known that the mountain pine beetle preferentially attacks large-diameter lodgepole pine trees (Cole and

TABLE 4. Frequency of infestation by MPBs and attack densities in two, individual-tree experiments in 1990 comparing tree baits with and without myrcene, and binary baits with low and high release rates of *trans*-verbenol and *exo*-brevicomin

Experimental location	No. of replicates	Semiachemical release rate (mg/24 h)			Infestation frequency			Attack density on baited or control trees (no./m <sup>2</sup> ) <sup>bc</sup>
		Myrcene	<i>trans</i> -Verbenol	<i>exo</i> -Brevicomin	No. available trees <sup>a</sup>	% lightly attacked <sup>b</sup>	% mass attacked <sup>b</sup>	
Invermere	13	—	—	—	16.9±7.2	7.9	18.7	23.6±45.9
		—	1.0	0.2	23.2±6.8	16.6	29.6	103.8±47.9
		—	1.0	2.5	20.2±7.0	15.6	38.7	103.8±36.0
		—	2.0	0.2	23.2±7.9	13.0	35.7	93.3±36.0
		—	2.0	2.5	22.4±8.5	11.6	36.0	130.8±33.7
Penticton	15	9.0	1.0	0.2	17.8±8.5	12.7	36.6	111.5±35.8
		—	—	—	24.9±9.7	9.0	19.2	15.4±31.0
		—	1.0	0.2	23.8±10.0	13.4	44.8	127.5±38.7
		—	1.0	2.5	23.5±11.0	14.0	45.7	121.3±41.6
		—	2.0	0.2	29.4±15.0	16.4	38.3	97.9±40.8
		—	2.0	2.5	25.7±15.5	15.3	40.7	119.2±33.9
		9.0	1.0	0.2	27.4±13.6	15.3	43.1	120.8±22.9

<sup>a</sup>Within 10 m of baited or control trees. Values represent mean ± SD.

<sup>b</sup>For all semiochemical treatments, results are significantly different from the controls; orthogonal contrasts,  $P < 0.05$ . See text for description of interaction between semiochemical treatments.

<sup>c</sup>Values represent mean ± SD.

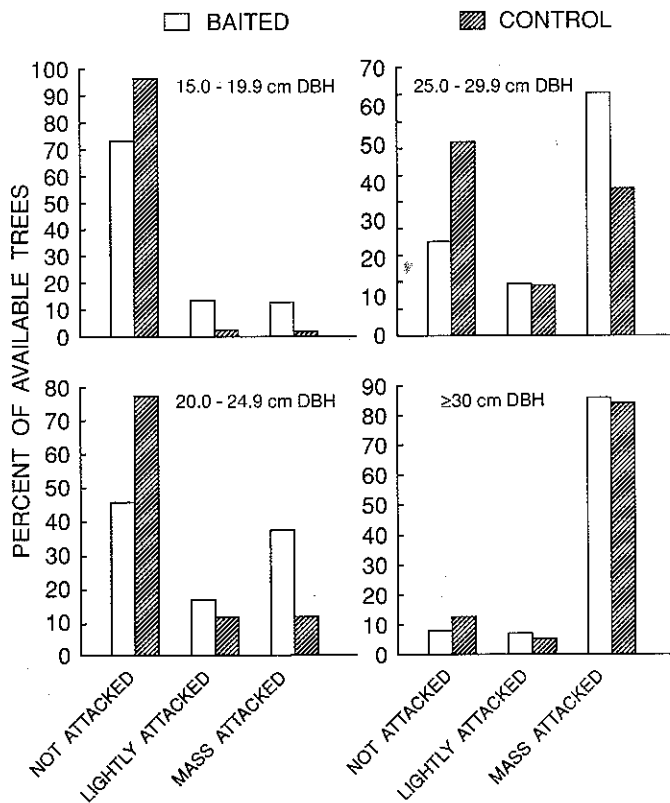


FIG. 2. Distribution of MPB attack frequency by diameter class of available trees within 10 m of 140 semiochemical-baited trees and 28 unbaited control trees. Data were pooled for all semiochemical and control treatments in two 1990 experiments (Table 4).

Amman 1969; Safranyik et al. 1974; Borden et al. 1983a). In our experiments, the baits apparently concentrated beetles within the stands, artificially increasing the risk of attack, which in turn resulted in all large-diameter trees being attacked.

### Practical implications

Our results (Tables 1–4) corroborate the results of Borden et al. (1990), indicating that myrcene is redundant and unnecessary for MPB tree baits, as long as the two pheromones present on the tree, *trans*-Verbenol and *exo*-brevicomin, evidently act efficiently to attract beetles to a tree, whereupon the initial attacks apparently cause the severed resin ducts to release sufficient myrcene, and other monoterpenes, to potentiate the aggregative effect. In traps, where there is no natural source of monoterpenes, myrcene is required to optimize the attraction (Conn et al. 1983; Borden et al. 1987).

The results on DBH distribution of attacked trees (Fig. 2) suggest that in stands of small-diameter trees, it is crucial to place baits on the largest available trees (Borden 1990) to optimize the power of the baits to concentrate attack by the MPB. In stands of large-diameter trees, selection of the largest possible bait trees may be less important. These data also indicate that in experimental work, the best measurement of bait efficacy will be obtained if experiments are conducted in stands of small-diameter trees, where natural secondary attraction will not override treatment effects to any significant degree.

*trans*-Verbenol can autoxidize under some circumstances to verbenone, a highly active antiaggregation pheromone (Ryan and Yandell 1983; Hunt et al. 1989). When this happened in the field, the potency of baits comprising *trans*-verbenol and *exo*-brevicomin was greatly reduced, although myrcene was able to override the antiaggregative effect of the unexpected verbenone (Borden et al. 1990). However, the purity of *trans*-verbenol can be assured by chemists, and the autoxidation problem has been eliminated through the use of antioxidants. Therefore, on the basis of our results, it should be possible to eliminate myrcene from operational baits, thus reducing their cost, and eliminating problems with leakage from bait receptacles and unpleasant odors in storage.

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