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Operational Success of Verbenone Against the Mountain Pine Beetle in a Rural Community

John H. Borden, Glen R. Sparrow, and Nicole L. Gervan

Abstract. Pouches releasing verbenone, the antiaggregation pheromone of the mountain pine beetle, were stapled to 1191 lodgepole pines throughout 95 residential properties in four subdivisions at Lac le Jeune, British Columbia, in July 2005. Postflight assessment in October in three of the subdivisions, where almost all infested trees had been removed before beetle flight, revealed new mass attacks on 3.6% of 3857 available trees 17.5 cm or greater (7 in) dbh. In a fourth subdivision where no infested trees were removed, 19.6% of 634 available trees were mass-attacked. In contrast, 17.4% of 1145 available trees were mass-attacked within 25 m (27.5 yd) wide, verbenone-treated buffer strips on public forest land adjacent to the residential properties, and 48.3% of 4975 available trees were mass-attacked on untreated control areas beyond the buffer strips. We conclude that treatment with verbenone pouches at roughly 15 m (16.5 yd) centers is a useful tool for protecting trees from attack by the mountain pine beetle provided that verbenone is used as part of a multiyear integrated pest management program that also includes disposal of all infested trees on the area to be protected before beetle flight in midsummer.

Key Words. *Dendroctonus ponderosae*; integrated pest management; lodgepole pine; mountain pine beetle; pheromones; *Pinus contorta* var. *latifolia*; verbenone.

Lac le Jeune (Figure 1) is a rural community comprised of five separate subdivisions clustered around a lake of the same name. It rests on a high plateau between the southern British Columbia (B.C.) communities of Kamloops and Merritt. The forest in which the community is laid out is dominated by mature to overmature lodgepole pine, *Pinus contorta* var. *latifolia* Engelmann. By the fall of 2004, it was apparent that the heavily forested lots in four of the subdivisions (North Shore East, Townsite, Lookout, and Little Lake), as well as much of the surrounding forest, had developing infestations of the mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera: Curculionidae). The fifth subdivision (South Ridge) is in an immature stand and was not severely threatened. The risk outside the residential properties lay in growing infestations on Crown (publicly owned) land adjacent to the residences and in Lac le Jeune Park situated between the North Shore East and Townsite subdivisions.

The mountain pine beetle is an obligate tree killer (Raffa and Berryman 1983). Mass attack of individual trees in mid- to late summer is synchronized by aggregation pheromones produced by the attacking beetles. As the beetles construct their galleries, they sever resin canals in the inner bark and sapwood, releasing the free-flowing resin that can protect vigorous trees by "pitching out" the attacking beetles. To counter this defense, the beetles inoculate pathogenic fungi into the inner bark and sapwood. If the attack is synchronized and the attack density is greater than 40 new galleries per m^2 (36 per yd^2), the combined action of fungal growth and beetle mining will kill the tree before it can mount its secondary resistance mechanism, the production of large amounts of toxic resin.

In contrast, an excessively high attack density will leave too little inner bark for each beetle brood to prosper. To prevent this negative effect, the beetles use the antiaggregation pheromone verbenone (Ryker and Yandell 1983; Schmitz and McGregor 1990). It is produced in small amounts by oxidation of the host tree resin component α-pinene by the attacking beetles and in major amounts by symbiotic microorganisms associated with the beetles (Hunt and Borden 1990). As mass attack proceeds, verbenone, and certain other antiaggregation pheromones, surpass the aggregation pheromones *trans*-verbenol and *exo*-brevicomin as the predominant volatiles emanating from established galleries (Pureswaran et al. 2000; Pureswaran and Borden 2003). The progressive effect is to space out new attacks, deter incoming beetles from attacking the source tree, and to direct attack to adjacent trees (Borden et al. 1987), creating the "spot" infestations characteristic of developing mountain pine beetle infestations (Geiszler and Gara 1978; Geiszler et al. 1980).

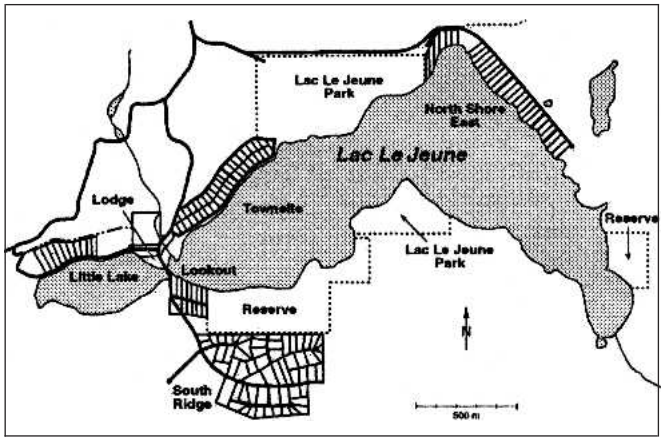

Figure 1. Map of Lac le Jeune, B.C., showing five subdivisions.

It has long been known that verbenone could deter attack by the mountain pine beetle in forest stands treated with slow-release bubble-cap devices affixed to trees (Amman et al. 1989; Lindgren et al. 1989) or aerially applied pheromone-impregnated plastic pellets (Shea et al. 1992). However, it was not widely used as a pest management tool because of inconsistent results on different species of trees, from one year to the next, and in different geographic areas (Bentz et al. 1989; Lister et al. 1990; Gibson et al. 1991; Shea et al. 1992; Amman and Lindgren 1995).

Eventually, three approaches were taken to resolve the problem of inconsistency: combining verbenone with repellent nonhost angiosperm bark volatiles, increasing the dose, and integrating repellent and attractive semiochemicals in a push–pull tactic (Borden et al. 2006). Huber and Borden (2001) found that combining verbenone bubble caps with a seven-component nonhost volatile blend provided almost complete protection of treated pairs of lodgepole pines compared with almost 100% successful attack on nearby untreated pairs. However, because of cost and regulatory concerns, Borden et al. (2006) used a simplified three-component blend. This blend was effective alone in deterring attack when deployed at 16 points in a 10 m (11 yd) grid in 40 × 40 m (44 × 44 yd) plots; however, when combined with verbenone, it did not improve on the deterrent effect of verbenone alone. Raising the dose of verbenone approximately sixfold over the 4 mg per day release rate from bubble caps improved the efficacy and consistency of verbenone in treated stands (Progar 2003; Bentz et al. 2005).

The high-dose verbenone pouch (Pherotech International Inc., Delta, B.C., Canada; trade name "No Vacancy Pack") releases verbenone from a polyurethane substrate at approximately 25 mg (0.4 gr) per 24 hr at a constant 20°C (68°F) and 100 mg (1.5 gr) per 24 hr at 30°C (86°F). It was effective in deterring attack in small plots or stands grid-treated with the pouch at 10 or 15 m (11 or 16.5 yd) centers (Borden et al. 2003; Progar 2003, 2005; Bentz et al. 2005). The pouch has been registered as a pesticide with the U.S. Environmental Protection Agency since 2000 and was registered with Canada's Pest Management Regulatory Agency in 2006. In the spring of 2005, Pherotech was looking for opportunities to conduct operational trials with the new Canadian product. The senior author (JHB) was therefore pleased to receive a request from the second author to test the pouch at Lac le Jeune.

MATERIALS AND METHODS

The residents of Lac le Jeune raised over $9000 for purchase of pouches for treatment of residential properties, and additional funding was obtained from Dr. Lorraine Maclauchlan of the B.C. Ministry of Forests and Range, Kamloops Region, for treatment of adjacent Crown land. To reduce the risk of attack from within their properties, the residents removed most of the infested trees (for exceptions, see "Results" and "Discussion"). However, no infested trees were removed from any property in the Little Lake subdivision, which is owned entirely by seasonal residents.

In the third week of July 2005, when flight and attack by emergent beetles appeared imminent, a group of volunteer residents deployed 1191 pouches on private property under direction of the second author. Pouches were stapled to the north face of trees at maximum reach from the ground, approximately 2 to 2.5 m (2.2 to 2.75 yd). The intent was to space pouches approximately 15 m (16.5 yd) apart in a more or less even grid. However, perhaps realizing that the danger lay outside their properties, the volunteers tended to concentrate placement of pouches near boundaries facing the untreated infestations on Crown forest land or the park. In the end, the desired density of pouches was achieved (Table 1) with a mean density of 53.6 pouches/ha (21.7 pouches/A) over the four treated subdivisions [15 m (16.5 yd) centers would be 44.4 pouches/ha (18.0 pouches/A) and 10 m (11 yd) centers would be 100 pouches/ha (40.5 pouches/A)]. An additional 197 pouches were deployed in a 25 m (27.5 yd) wide buffer strip within the Crown forest bounding the treated subdivisions. Some pouches were placed slightly beyond the 25 m (27.5 yd) strip.

The efficacy of the verbenone treatment was evaluated during a 7-day period beginning on 15 October 2005. Every lodgepole pine with a diameter at breast height [dbh = 1.3 m (1.4 yd)] 17.5 cm or greater (7 in) was examined for attack in each of the 95 residential properties in the four subdivisions, in the verbenone buffer strips, and in an untreated "control" block extending into the Crown forest at least 100 m (110 yd) beyond the buffer strip (Table 1; Figure 2). Because the control plot in the Crown forest adjacent to the Lookout subdivision was only 50 m (55 yd) wide, the buffer and control zones were not evaluated separately. The respective total ar-

Table 1. Site characteristics and verbenone pouch treatment density in four subdivisions at Lac le Jeune, B.C.

Characteristics and treatment	Location	Control area	Verbenone buffer	Residential area	All areas combined[z]
Area [ha (A)]	North Shore East	6.25 (15.4)	1.56 (3.9)	8.64 (21.3)	16.45 (40.6)
	Townsite	4.88 (12.1)	1.25 (3.1)	6.12 (15.1)	12.25 (30.3)
	Little Lake	1.50 (3.7)	0.29 (0.7)	3.58 (8.8)	5.37 (13.3)
	Lookout	0.82 (2.0)	—	2.78 (6.9)	3.60 (8.9)
No. red trees/ha (/A)[y]	North Shore East	—	—	—	12.8 (5.2)
	Townsite	—	—	—	36.8 (14.9)
	Little Lake	—	—	—	29.0 (11.7)
	Lookout	—	—	—	33.0 (13.4)
No. available green trees ≥17.5 cm (6.9 in) dbh/ha (/A)	North Shore East	288.0 (116.6)	214.1 (86.7)	198.1 (80.2)	233.8 (94.7)
	Townsite	520.9 (210.9)	626.4 (253.6)	247.4 (100.2)	395.0 (159.9)
	Little Lake	203.3 (82.3)	96.6 (39.1)	207.0 (83.8)	200.0 (81.0)
	Lookout	395.1 (160.0)	—	185.3 (75.0)	233.1 (94.4)
No. verbenone pouches/ha (/A)	North Shore East	—	70.5 (28.5)	62.8 (25.4)	64.0 (25.9)
	Townsite	—	47.2 (19.1)	57.4 (23.2)	55.6 (22.5)
	Little Lake	—	79.3 (32.1)	44.7 (18.1)	47.3 (19.1)
	Lookout	—	—	49.3 (20.0)	49.3 (20.0)

[z]Control area excluded for no. verbenone pouches/ha.

[y]Red trees scarce in residential areas because most red trees removed. A beetle emerging from a red tree in one of the three areas is capable of attacking any living tree in all three areas. Therefore, red trees/ha calculated for all three areas combined.

eas of residential properties, buffer zones, and untreated zones evaluated were 21.1 ha (52.1 A), 3.1 ha (7.7 A), and 13.5 ha (33.3 A). A total of 10,611 trees were examined for attack. Mass attack was determined by numbers of pitch tubes indicating attack densities exceeding 31.3 per m^2 (37.6 per yd^2) and/or copious amounts of boring dust in bark crevices and around the root collar.

Within each subdivision, the percentages of available trees 17.5 cm or greater (7 in) dbh that were mass-attacked were compared by χ^2 tests for multiple proportions. The ratios per ha of newly attacked green trees to previously infested red trees (the G:R ratio) (Maclauchlan and Brooks 1999) within the verbenone-treated residential and buffer areas were compared with those in the control areas by paired χ^2 tests. In all cases, $\alpha = 0.05$.

RESULTS AND DISCUSSION

In three of the subdivisions (North Shore East, Townsite, and Lookout), the treatment was highly successful (Figures 2 and 3). The percentages of available trees 17.5 cm or greater (7 in) dbh mass attacked in the residential properties ranged from 90.6% to 95.7% lower than in the untreated control zones, and the percentages in the verbenone buffer strips for the North Shore East and Townsite subdivisions were intermediate between those in the residential and control zones. In the Little Lake subdivision, the proportion of available trees mass-attacked in the verbenone-treated residential properties was significantly lower by only 46.2% than in the untreated control zone. This unacceptable level of control emphasizes the peril of not removing all infested trees before verbenone treatment.

At Little Lake, all 10 residential properties had mass-attacked trees on them. Of the remaining 85 residential lots in the other three subdivisions, only 24 (28.2%) had mass-attacked trees (Figure 2). Fifteen of these had apparent edge effects, where infestation on seven properties occurred close to the boundary nearest to the Crown land, and at Townsite, where a cluster of eight properties nearest to the western boundary of the heavily infested park sustained some attack. A cluster of five infested lots at Townsite were apparently impacted by beetles emerging from infested trees left as rubbing posts in a horse paddock on one of the lots. The residents of two adjacent properties at North Shore East that sustained some attack had felled, but not removed, their infested trees. Instead, they had cut them into firewood bolts ≈30 cm (≈12 in) long and piled them on the property, in one case stacking the wood between two living mature lodgepole pines, both of which were subsequently mass-attacked.

Another measure of infestation growth is the G:R ratio. These ratios closely tracked the percentages of available trees mass-attacked ranging from 2.5 to 11.4 in the control zones, 0.7 to 3.6 in the verbenone buffer zones, and 0.2 to 1.4 in the residential properties (Table 2). A single exception to the trend for the percentages of available trees to become attacked (Figure 3) occurred at Little Lake, where the G:R ratio was significantly lower than in the control area only in the verbenone buffer zone (Table 2).

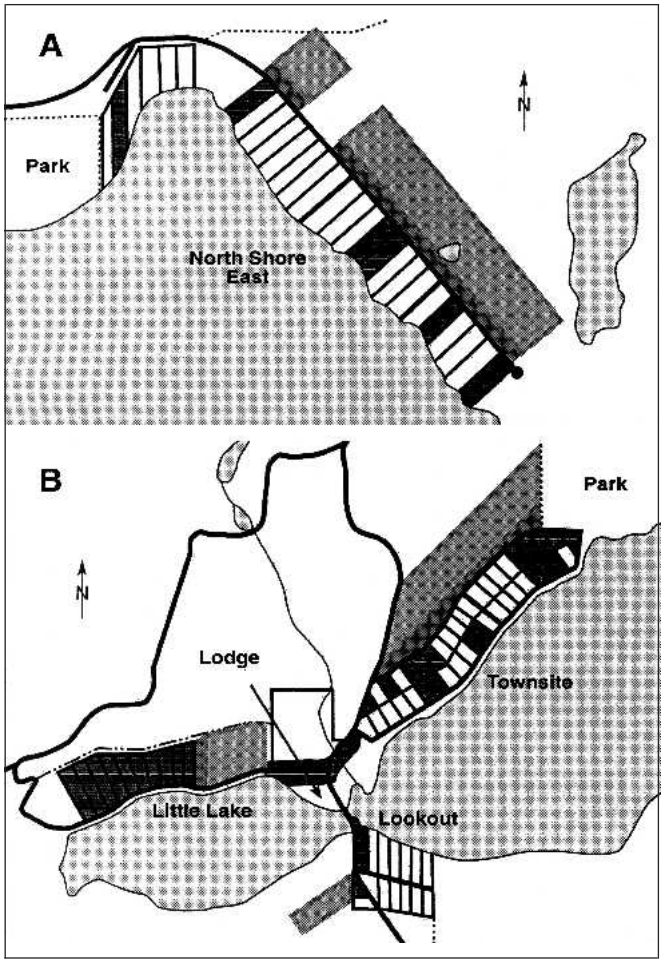

Figure 2. Detailed maps of verbenone-treated subdivisions at Lac le Jeune (A: North Shore East; B: Townsite, Little Lake, and Lookout) showing individual residential lots (shaded) that sustained mass attack in 2005 on one or more lodgepole pines, 25 m (27.5 yd) wide verbenone-treated buffer zones (dark shading) on Crown forest land, and control areas (light shading) on Crown forest land extending at least 100 m (110 yd) beyond the verbenone buffer zones.

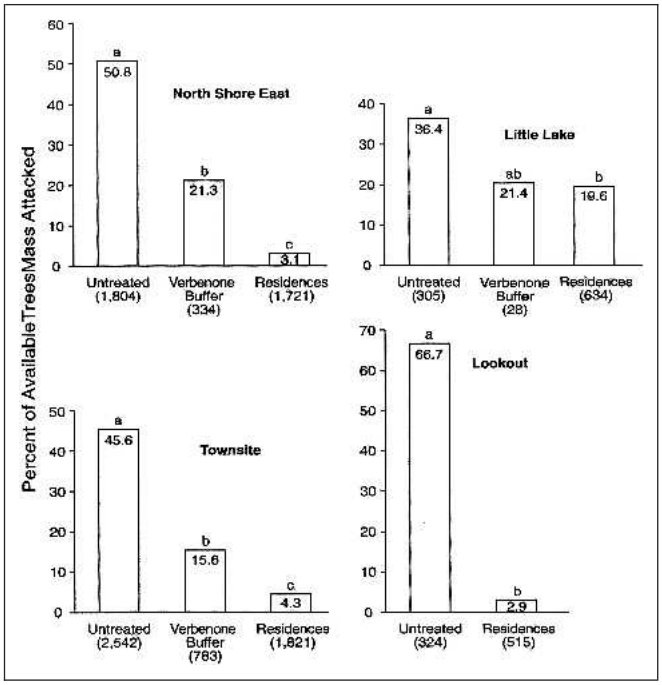

Figure 3. Comparison of percentages of available lodgepole pines 17.5 cm or greater (7 in) dbh mass attacked by the mountain pine beetle in untreated forests on Crown land, in verbenone-treated buffer strips on Crown land, and in residential properties in four subdivisions at Lac le Jeune, B.C. Numbers in parentheses below bars are the number of available trees. Bars within a subgraph with the same letter are not significantly different, χ^2 test for multiple proportions, $P \leq 0.05$.

The mean G:R ratio of 7.1 for all four control areas indicates that the infestation in the Lac le Jeune region increased over sevenfold during the summer of 2005. Coupled with the overall 48.3% of available trees mass-attacked in all four control areas, there is compelling evidence that the verbenone treatment was challenged by an explosive outbreak. Faced with that threat, the very low overall infestation rate of 3.6% of 3857 available trees in the three residential areas from which infested trees were removed in the winter of 2004 through 2005 was quite remarkable.

This is the first report of operational success of verbenone used as part of an integrated pest management (IPM) program in a residential setting. In this case, the IPM program was comprised of four components: assessment of the problem, disposal of infested trees, application of verbenone, and reassessment of the problem. The poor effectiveness of verbenone at Little Lake indicates that disposal of infested trees must be a basic tenet of such an IPM program. In support of

Table 2. Ratios of newly mass-attacked green trees per ha to previously attacked red trees per ha (G:R ratio) in control, verbenone buffer, and residential areas in three subdivisions at Lac le Jeune, B.C.[z]

	G:R ratio[y]		
Location	Control area	Verbenone buffer	Residential area
North Shore East	11.5	3.6**	0.5**
Townsite	6.5	2.6**	0.3**
Little Lake	2.5	0.7**	1.4 NS
Lookout	7.9	—	0.2**

[z]Red trees averaged over entire area for each subdivision.
[y]Probability of significant difference from control area (χ^2 test) indicated by $^{**}P \leq 0.05$.
NS, not significant.

this contention, Progar (2003) successfully used verbenone pouches to protect trees in a park from attack for 2 years. However, because of park policy that prohibited cutting and removing infested trees, protection broke down over the next 3 years (Progar 2005).

In 2006, operation of the IPM program at Lac le Jeune (potentially for another 2 to 3 years until the infestation outside of the subdivisions had run its course) became the responsibility of the residents and certain other stakeholders. Additional components of an area-wide IPM program were implemented, but not all essential tactics were pursued. The B.C. Ministry of Environment carried out a commercial harvesting operation to remove all infested trees from Lac le Jeune Park during the winter of 2005 through 2006. The residents again removed all infested trees from their properties, some paid for prophylactic spraying of uninfested trees with the insecticide carbaryl (Sevin XLR, Bayer CropScience, Research Triangle Park, NC) (Hastings et al. 2001), and verbenone pouches were deployed as in 2005. However, to reduce the risk of invasion of beetles from Crown land, the IPM program should have included harvesting of the adjacent Crown forest extending approximately 500 m (550 yd) beyond the boundaries of the residential subdivisions. Although cutting permits were in place, the B.C. Ministry of Forests and Range did not ensure that this harvesting was done before the beetle flight in 2006. Assuming an average sevenfold growth rate of the beetle population, as in 2004 through 2005 (Table 2), with fully half of the trees on Crown land already infested, a massive spillover onto the residential properties would have been expected if harvesting on Crown land did not occur.

A small survey in late September 2006 confirmed this prediction. Twenty-five trees were inspected for new attack at seven sites: two in Lac le Jeune Park, two each in North Shore East and Townsite, and one in Lookout. Of the 175 trees sampled, 89% were mass-attacked. This unfortunate outcome reinforces Progar's (2005) conclusion that the optimal use of verbenone demands the full implementation of an IPM program, in which disposal of infested trees is a major component. Given this commitment, we feel that in addition to their use in rural residential areas, verbenone-based IPM programs can be efficacious against the mountain pine beetle in many other locations, most of them involving relatively small areas of high-value trees. These include resorts, campgrounds, parks, and private recreational lands as well as forest stands of high ecological and social value, e.g., wildlife refuges, watersheds, critical riparian zones, and other sensitive ecosystems.

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Résumé. Des pochettes contenant du verbenone, un phéromone anti-aggrégation du dendroctone du pin des montagnes, ont été attachées sur 1191 pins tordus latifoliés de 95 propriétés résidentielles au sein de quatre subdivisions à Lac Le jeune en Colombie-Britannique en juillet 1995. Une estimation après le vol au sein de trois des subdivisions, là où la plupart des arbres infestés ont été abattus avant le vol des dendroctones, a révélé une nouvelle attaque massive sur 3,6% des 3857 arbres encore présents de 17,5 cm et plus de DHP. Au sein de la quatrième subdivision où aucun arbre infesté n'avait été abattu, 19,6% des 634 arbres étaient massivement attaqués. Par comparaison, 17,4% des 1145 arbres étaient massivement attaqués dans un rayon de 25 m, le verbenone ayant créé des zones-tampon sur les forêts publiques adjacentes aux propriétés résidentielles, et 48,3% des 4975 arbres étaient massivement attaqués dans les zones sans contrôle au-delà des zones-tampon traitées. Nous en concluons que les traitements avec des pochettes de verbenone aux 15 m d'espacement constituent un outil efficace pour protéger les arbres contre l'attaque par le dendroctone du pin des montagnes, et ce dans la mesure où le verbenone est employé au sein d'un programme intégré sur plusieurs années qui inclut l'abattage et la disposition de tous les arbres infestés d'un territoire avant le vol des dendrcotones au milieu de l'été.

Zusammenfassung. Im Juli 2005 wurden kleine Beutel mit verströmendem Verbenon, dem Antivereinigungspheromon des Bergkiefer-Käfers in 1.191 Küstenkiefern verteilt auf 95 Wohngebiete in vier Unterabteilungen in Lac le Jeune, BC untergebracht. Nach dem Flug bei einer Untersuchung in drei der untersuchten Regionen, wo nahezu alle befallenen Bäume entfernt wurden, entwickelten sich neue Masse Attacken an 3.6 % der verfügbaren Bäume mit einem Stammdurchmesser von ≥ 17,5 cm. In einer vierten Abteilung, wo kein befallener Baum entfernt wurde, wurden 19.6 % von 634 möglichen Bäumen befallen. Im Kontrast dazu wurden 17.4 % von 1.145 möglichen Bäumen Opfer einer Massenattacke innerhalb eines 25 m breiten, mit Verbenon behandelten Pufferstreifens auf öffentlichem, benachbarten Gelände, und 48,3 % von 4.975 möglichen Bäumen wurden in den unkontrollierten Kontrollflächen außerhalb der Streifen Opfer einer Massenattacke. Wir schließen daraus, dass die Behandlung mit Verbenon-Säckchen in einem Umkreis von 15 m ein nützliches Bekämpfungsmittel gegen den Bergkiefern-Käfer darstellt, unter der Voraussetzung, dass Verbenon als Teil eines mehrjährigen Integrierten Pflanzenschutz-Programms eingesetzt wird, welches auch die Entfernung von allen befallenen Bäumen aus dem betroffenen gebiet vorsieht, um einen Schutz vor dem Ausflug der Käfer im Mittsommer zu gewährleisten.

Resumen. Se colocaron bolsas liberadoras de verbenone, la feromona de antiagregación del escarabajo del pino montañés, a 1,191 postes de pino a través de 95 propiedades residenciales en cuatro subdivisiones en Lac le Jeune, BC en Julio de 2005. Se hicieron evaluaciones posteriores en tres subdivisiones, donde casi todos los árboles infestados habían sido removidos antes de la emergencia de los escarabajos, revelando nuevos ataques en masa en 3.6% de 3,857 árboles disponibles con DAP ≥17.5 cm (7 in). En una cuarta subdivisión, donde no habían árboles infestados removidos, 19.6% de 634 árboles disponibles fueron atacados en masa. En contraste, 17.4% de 1,145 árboles disponibles fueron atacados en masa dentro de 25 m de amplitud, los tratamientos con verbenone en bosques públicos adyacentes a las propiedades residenciales, y 48.3% de 4,975 árboles disponibles fueron atacados en masa en áreas de control no tratadas atrás de los barreras. Se concluye que los tratamientos con verbenone en aproximadamente 15 m de radio son una herramienta útil para proteger los árboles del ataque por el escarabajo del pino de montaña, indicando que verbenone es usado como parte de un plan de manejo de plagas multi-integrado que también incluye la remoción de todos los árboles infestados en el área a ser protegida antes de la emergencia del escarabajo a mediado del verano.