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Use of Semiochemicals of Secondary Bark Beetles to Disrupt Spruce Beetle Attraction and Survival in Alaska

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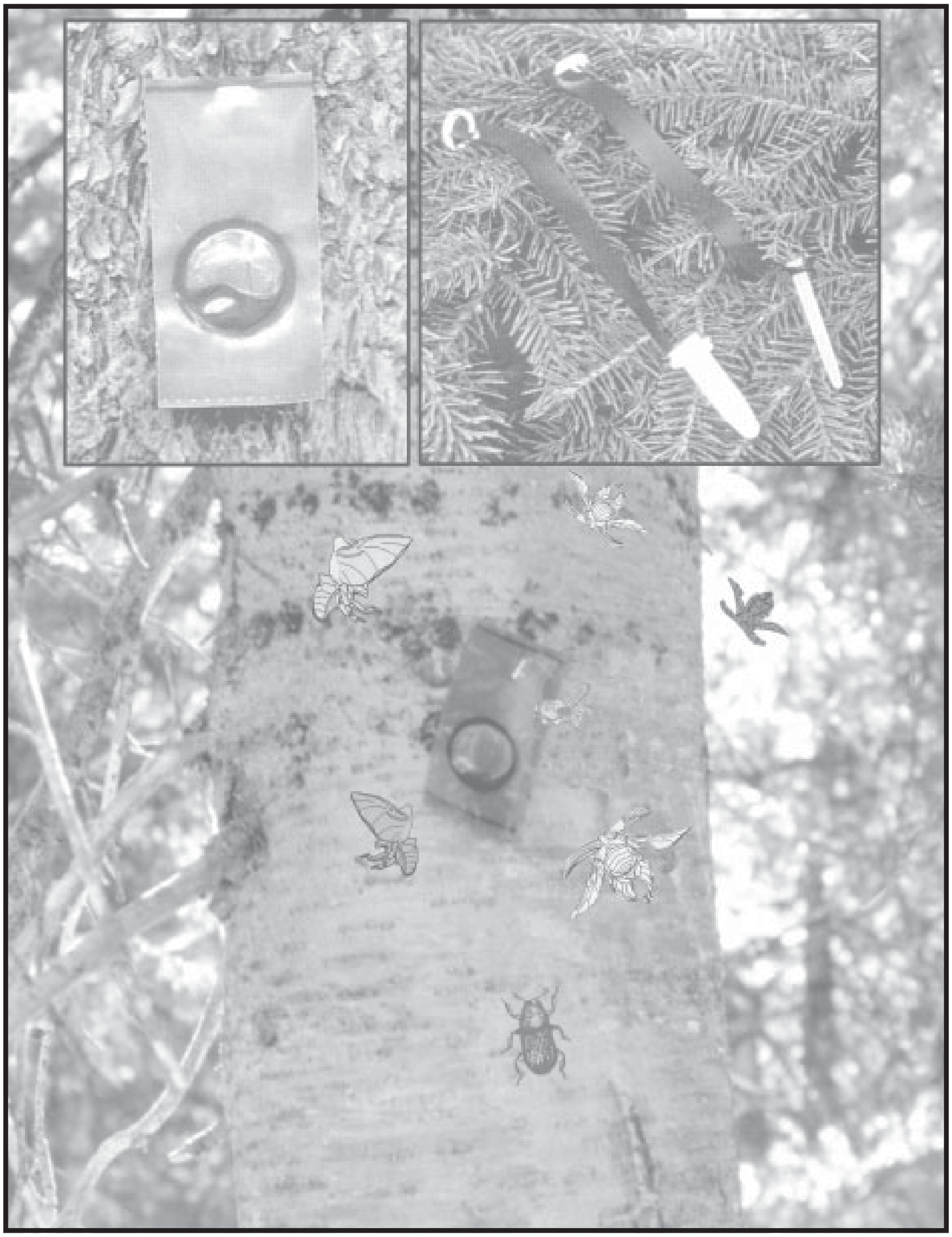

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Abstract

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Field experiments using baited multiple-funnel traps and baited felled trees were conducted to test the hypothesis that semiochemicals from secondary species of scolytids could be used to disrupt spruce beetle (*Dendroctonus rufipennis* (Kirby)) attraction. Semiochemicals from three secondary species of scolytids, (*Ips perturbatus* (Eichhoff)) [(±)-ipsdienol], *Dryocoetes affaber* (Mannerheim) [(±)-*exo*- and (±)-*endo*-brevicomin], and *Polygraphus rufipennis* (Kirby) [methyl butenol] were used to disrupt spruce beetle trap catches and reduce attacks on felled trees. Trap catches of spruce beetles were reduced by 87 percent by the combinations of semiochemicals from these secondary scolytids. Addition of MCH (methylcyclohexenone) to these semiochemicals reduced attack density by 62 to 87 percent. Results indicate that inducing attacks by *I. perturbatus* and *D. affaber* on felled susceptible host trees by using semiochemicals could be a viable method to minimize spruce beetle attack and brood development.

Keywords: *Dendroctonus rufipennis*, *Ips perturbatus, Dryocoetes affaber, Polygraphus rufipennis,* bark beetle, semiochemicals, Lutz spruce (*Picea x lutzii)*, Alaska.

Summary

Field experiments were conducted from 1991 to 1993 on the Chugach National Forest in south-central Alaska. Semiochemicals from secondary species of bark beetles such as *Ips perturbatus* (Eichhoff) [(±)-ipsdienol], *Dryocoetes affaber* (Mannerheim) [(±)-*exo*- and (±)-*endo*-brevicomin], and *Polygraphus rufipennis* (Kirby) [methyl butenol] were added to traps baited with spruce beetle binary lure (frontalin plus α-pinene) to disrupt attraction of the spruce beetle. These same semiochemicals were placed on felled Lutz spruce at intervals along the tree bole to reduce attack density, gallery construction, and brood production. The addition of (±)-*exo*- and (±)-*endo*-brevicomin plus methyl butenol, and (±)-*exo*- and (±)-*endo*-brevicomin plus (±)-ipsdienol disrupted trap catch of spruce beetles. The addition of either (±)-*exo*- and (±)-*endo*-brevicomin plus 3-methyl-2-cyclohexen-1-one (MCH), or (±)-ipsdienol plus MCH to trees baited with spruce beetle lures (frontalin plus α-pinene) reduced attack density by 87 percent and 62 percent, respectively, in stands with high populations of spruce beetles. The addition of MCH to trees baited with frontalin plus α-pinene and (±)-ipsdienol reduced gallery construction by 40 percent and brood production by 50 percent in high populations. In low and medium populations of spruce beetles, the addition of (±)-*exo*- and (±)-*endo*-brevicomin plus (±)-ipsdienol and MCH to spruce beetle-baited trees disrupted gallery construction by 63 percent (low) and 77 percent (medium) and brood production by 83 percent (low) and 81 percent (medium).

Contents

Introduction

The spruce beetle (*Dendroctonus rufipennis* (Kirby)) infests most species of *Picea* in North America (Schmid and Fyre 1977). White spruce (*Picea glauca* (Moench) Voss), Sitka spruce (*P.* sitchensis (Bong.) Carr.), and the hybrid Lutz spruce (*P. X lutzii* Little) are the major hosts in Alaska (Werner and others 1977). Most spruce beetle infestations in Alaska occur in white and Lutz spruce stands. Infestations have expanded throughout south-central Alaska since 1974 and in the last 10 years have killed trees on 1 416 450 ha of forest. Low populations of spruce beetles usually breed in wind-thrown trees where they can increase rapidly to epidemic levels (Holsten and others 1991). Wind-thrown trees are the most productive breeding sites for spruce beetles; they may absorb and produce up to 10 times the number of beetles a standing tree will absorb or produce (Dyer and Taylor 1971, Hodgkinson 1985). When spruce beetle populations in wind-thrown trees increase to high levels, emerging beetles may then enter susceptible, large-diameter, green standing timber. Almost all spruce beetle infestations in standing timber originate from wind-thrown trees or shaded right-of-way clearing debris (Holsten and others 1991). The death of individual trees and entire stands represents large annual losses in forest resources including wildlife habitat (Holsten and others 1995, Werner and Holsten 1983). Beetle-killed timber also increases fuel loads within stands, which increases the risk of a catastrophic wildfire (Schulz 1995).

Research on the use of semiochemicals to manipulate bark beetle populations has increased in the Pacific Northwest during the past 20 years (Borden 1982, 1985, 1989). This includes the use of both synthetic aggregation and antiaggregation semiochemicals to prevent or reduce attack density of spruce beetles (Holsten 1994, Werner 1994, Werner and Holsten 1995). This strategy has several advantages: (1) use of traditional insecticides is minimal, (2) resistance of bark beetles to some groups (antiaggregants) of semiochemicals might be impossible because successful brood development would be prevented, and (3) unlike insecticide treatment, little direct mortality to parasites and predators would occur.

Three beetle-produced compounds, 1-methyl-2-cyclohexen-1-ol (MCOL) (Dixon and others 1992); 1,5-dimethyl-6,8-dioxabicyclo [3.2.1] octane (frontalin) (Gries and others 1988, Kinzer and others 1971, Libbey and others 1985); and 3-methyl-2-cyclohexen-1-one (MCH) (Rudinsky and others 1974) play a significant role in the communication system of the spruce beetle. The aggregation pheromone frontalin and MCOL, along with the host tree monoterpene α-pinene, mediate host selection and aggregation (Werner 1994; Werner and Holsten 1995; Wieser and others 1989, 1991). MCH inhibits spruce beetle attacks and reduces brood production and development when attacks are successful (Holsten and Werner 1984, 1985, 1986, 1987; Holsten 1994; Holsten and others 1992; Werner 1994; Werner and Holsten 1995).

Intraspecific competition in attack and emergence density of bark beetles is nonlinear and characteristic of populations where survival is density dependent (Berryman 1974). Safranyik and Linton (1985) report the effects of intraspecific competition on the reproductive biology of spruce beetle. Their results indicate the presence of density-dependent compensatory processes within spruce beetle populations. Thomson and Sahota (1981) showed that competition exists between parent adults during egg gallery construction and that it reduces gallery length and construction. These characteristics of intraspecific competition are also present in interspecific competition when more than one species coinhabits the same host (Birch 1957; Borden 1996; Brian 1956; Byers and Wood 1980; Paine and Hanlon 1991; Poland 1997; Poland and Borden 1994, 1998a, 1998b; Rankin and Borden 1991).

The frequency of co-occurrence of scolytid species within a discrete area of the phloem is a useful indicator of their potential for competition (Paine and Hanlon 1991). Host attraction for secondary scolytids that compete with spruce beetles for space and food resources may reduce spruce beetle development and survival. Brian (1956) describes two forms of competition. Interference competition occurs when one species damages the feeding resource of another species. Exploitation competition, the ability to detect, occupy, and retain vacant resources necessary for survival is described by Rankin and Borden (1991) for the pine engraver [*Ips pini* (Say)] and mountain pine beetle (*Dendroctonus ponderosae* Hopkins). Rankin and Borden (1991) found that *I. pini* coexists with *D. ponderosae* in lodgepole pine (*Pinus contorta* var. *latifolia* Engelmann) but that coexistence causes a reduction in numbers of progeny. Other instances of interspecific, semiochemical-based competition have been documented (Birch and Light 1977, Birch and Wood 1975, Birch and others 1980, Borden 1982, Borden and others 1992, Byers 1989, Byers and Wood 1980, Furniss and Livingston 1979, Light and others 1983, Rankin and Borden 1991).

The most important arthropod factor impacting spruce beetle populations is interspecific competition with other scolytid species (Gara and others 1995). Small scolytid species competed with spruce beetles in 73 percent of collected bark samples (100 cm^2) in which spruce beetles were found.

The engraver beetle (*I. perturbatus* (Eichhoff)), a common scolytid that inhabits spruce stands in Alaska, is attracted by racemic ipsdienol (Werner 1993). Other competitor scolytids found feeding in spruce are *Dryocoetes affaber* (Mannerheim) and *Polygraphus rufipennis* (Kirby) (Gara and others 1995, Werner and Holsten 1984, 1995). These three scolytids commonly attack felled trees or standing trees that were attacked initially by spruce beetles.

Field studies conducted from 1980 to 1991 in south-central and interior Alaska identified several scolytid pheromones and host terpenes such as seudenol, frontalin, and α-pinene as aggregants for the spruce beetle (Werner and Holsten 1995). Frontalin dispersed from sticky traps also caught *Dryocoetes affaber* and *P. rufipennis*. Field trapping experiments in interior Alaska indicated that (±)-ipsdienol caught more *I. perturbatus* in sticky traps and trap trees than (±)-ipsenol and a combination of both (Werner 1993).

This information led to the hypothesis that attracting species of secondary bark beetles to suitable spruce beetle hosts may interfere with spruce beetle development and survival, thereby reducing the probability of spruce beetle population buildup, which could develop into a major infestation. We also hypothesize that, in addition to formulated MCH treatments, an increase in secondary scolytid infestation could reduce even further the attack density and brood production of spruce beetles, thereby reducing the potential of an outbreak.

The objective of this study was to test the feasibility of using semiochemicals of secondary scoltyids, in addition to application of formulated MCH, to disrupt or repel attack by spruce beetle in order to reduce attack densities, gallery development, brood establishment, and survival.

Materials and Methods

The study, conducted over a 3-year period between 1991 and 1993, consisted of a trapping experiment using multiple-funnel traps during year one and a felled tree experiment during years two and three. In the trapping experiment, the efficacy of various pheromones of secondary scolytid species in masking the pheromone of spruce beetles in baited multiple-funnel traps was evaluated. In the felled tree experiments, the successful semiochemicals from the trapping study along with MCH were tested on felled uninfested Lutz spruce to determine their efficacy on (1) reducing attractiveness of spruce beetles to felled host material, and (2) increasing populations of secondary scolytids, which might compete for limited space and food resources.

Chemical Descriptions

Stands of Lutz spruce in the Chugach National Forest, 96 km south of Anchorage, Alaska, were used for the first year of the experiment (1991). Spruce stands contained mature trees with less than two infested trees per hectare. Treatments consisted of four different scolytid semiochemicals: the spruce beetle lure [α-pinene (0.7 mg/day) plus (R)-(-)-frontalin (0.1 mg/day)]; *Dryocoetes affaber* [(±)-*exo* and (±)-*endo*, 50:50 brevicomin) (0.2 mg/day)]; *P. rufipennis* [2-methyl-3-buten-2-ol (2.5 mg/day)]; and *I. perturbatus* [(±)-ipsdienol (0.2 mg/day)]. All release devices were obtained from Phero Tech Inc., Delta, British Columbia. Chemical purities, chiralities, and release devices for the spruce beetle lure were as follows: α-pinene, >99 percent pure, (-)-enantiomer, closed polyethylene microcentrifuge tubes; and frontalin >99 percent pure, flex lures.

Trapping Experiments

Trapping experiments used 12-unit multiple-funnel traps (Lindgren 1983), and an unbaited multiple-funnel trap was used as a control. Traps were hung from a rope suspended between two trees at a height of 2 m and spaced at 30-m intervals. Traps were hung with the bottom of the collection container 0.3 m from ground level. Traps were checked weekly and beetles collected and counted. Twelve treatments were replicated five times in a completely randomized design. Treatment positions were rerandomized weekly.

Statistical Analysis for Trapping Experiments

The total number of bark beetles caught per species for each of the treatments was subjected to an ANOVA. Differences between means were tested by using the Tukey (1953) HSD test at a probability level of $P = 0.05$.

Felled Tree Experiments

Stands of Lutz spruce at Quartz Creek and Summit Lake on the Chugach National Forest located on the Kenai Peninsula in south-central Alaska were used for these experiments. Stands with less than two infested trees per hectare were classified as having low spruce beetle population densities (Summit Lake), whereas stands with more than six infested trees per hectare were classified as high spruce beetle population densities (Quartz Creek). Uninfested trees were felled in late April 1992 in a north-south direction with the crown toward north and were not limbed in order to simulate windthrow and right-of-way slash.

This experiment used the semiochemicals from all four species of scolytids as well as the spruce beetle antiaggregation pheromone MCH. Semiochemicals were dispersed from bubble caps or polyethylene eppendorf tubes. Nine treatments (table 1) were replicated five times on each of the two sites (45 trees per site) in a complete randomized design. Four sets of semiochemical baits were stapled to the top side of felled trees and spaced at 4.5-m intervals starting 3.3 m from the butt end of the tree. Unbaited trees served as controls. Trees were spaced at 50-m intervals.

Treatment effects were evaluated by removing three circular bark samples (100 cm^2) from the top and two sides of each sample tree in the four areas of the bole where the baits were located. A gas-powered drill equipped with a circular cutting blade was used to remove bark samples in late July following successful beetle attack and colonization. Bark disks were placed in zip-lock bags and stored in a freezer at -5 °C until brood and gallery counts were made.

Table 1—Mean (+ SD) number of scolytids caught in multiple funnel traps by various bark beetle pheromones alone and in combination in Alaska, 1991[a]

Treatment	*D. rufipennis*	*P. rufipennis*	*D. affaber*	*I. perturbatus*
Spruce beetle bait	141.8 + 223.8a	0.59 + 1.3b	6.62 + 36.2b	0.00 + 0.0b
(±)-exo/endo-brevicomin	25.7 + 37.7c	0.25 + 0.6b	0.63 + 1.8b	0.06 + 0.2b
Methyl butenol	1.7 + 2.1e	1.16 + 2.3b	16.0 + 32.2a	0.03 + 0.2b
(±)-ipsdienol	24.6 + 41.8c	1.28 + 2.8a	1.28 + 2.7b	0.25 + 0.5b
Spruce beetle bait plus (±)-exo/endo-brevicomin	55.8 + 68.6b	1.06 + 1.9b	1.25 + 2.0b	0.31 + 0.8b
Spruce beetle bait plus methyl butenol	28.5 + 44.5c	3.00 + 4.7a	21.00 + 47.8a	0.03 + 0.1b
Spruce beetle bait plus (±)-ipsdienol	94.2 + 150.6b	0.47 + 1.3b	3.44 + 17.1b	17.97 + 70.4a
Spruce beetle bait plus (±)-*exo/endo*-brevicomin plus methyl butenol	19.2 + 25.0d	0.91 + 1.3b	11.50 + 25.1ab	0.00 + 0.0b
Spruce beetle bait plus (±)-*exo/endo*-brevicomin plus (±)-ipsdienol	30.8 + 60.8c	0.38 + 0.7b	2.12 + 4.4b	0.41 + 0.9b
Spruce beetle bait plus methyl butenol plus (±)-ipsdienol	17.9 + 42.6d	0.44 + 0.7b	13.84 + 24.9ab	0.06 + 0.3b
Spruce beetle bait plus (±)-*exoo/endo*-brevicomin plus methyl butenol plus (±)-ipsdienol	47.3 + 75.2b	1.59 + 3.4a	22.66 + 53.8a	0.16 + 0.6b
Control	6.7 + 10.4e	0.38 + 0.8b	0.16 + 0.5b	0.03 + 0.2b

[a] Mean values within columns followed by the same letter are not significantly different ($P < 0.05$, Tukey [1953] studentized range test [HSD]).

This study was repeated in 1993 on stands of Lutz spruce with medium population densities of spruce beetle (three to four infested trees per hectare) and was located along Falls Creek Road on the Kenai Peninsula.

Statistical Analysis for Felled Tree Experiments

Response variables measured for the felled tree experiments included the number of spruce beetle attacks, number of egg galleries, and number of brood produced. Data transformation using parametric tests were used for treatments with small sample sizes and for equal and unequal sample sizes. Means were subjected to ANOVA and the Newman-Keuls test ($P = 0.05$) (SAS Institute Inc. 1986).

Results and Discussion

In the 1991 trapping study using multiple funnel traps, the spruce beetle lure (frontalin plus α-pinene) tested alone attracted the most spruce beetles. Spruce beetles responded positively to methyl butenol and (±)-ipsdienol but not to (±)-*exo*- and (±)-*endo*-brevicomin when tested alone (table 2). Spruce beetle catch was reduced by 87 percent when (±)-*exo*- and (±)-*endo*-brevicomin plus (±)-ipsdienol, and (±)-*exo*- and (±)-*endo*-brevicomin plus methyl butenol were added to traps with spruce beetle lures (table 2). *Ips. perturbatus* was caught primarily in traps baited with the spruce beetle bait plus (±)-ipsdienol (table 2). Every bait with (±)-*exo*- and (±)-*endo*-brevicomin attracted *D. affaber.* Traps baited with (±)-*exo*- and (±)-*endo*-brevicomin alone, and combinations of spruce beetle bait plus (±)-*exo*- and (±)-*endo*-brevicomin, and spruce

Table 2—Comparison of semiochemicals that induce competition of secondary scolytids with spruce beetles in felled trees in areas with high and low population densities in Alaska, 1992[a]

Treatment	No. of beetle attacks	No. of beetle galleries	No. of beetle brood
High population			
Control	0.58 + 0.2d	2.07 + 0.8d	13.27 + 4.9c
Spruce beetle lure	0.47 + 0.2d	1.71 + 0.6c	10.49 + 3.9b
Spruce beetle lure plus (±)-*exo/endo*-brevicomin	0.36 + 0.1c	1.73 + 0.6c	12.62 + 6.1c
Spruce beetle lure plus (±)-ipsdienol	0.38 + 0.2c	1.42 + 0.4b	9.66 + 5.4b
Spruce beetle lure plus (±)-ipsdienol plus (±)-*exo/endo*-brevicomin	0.51 + 0.2d	1.87 + 0.8c	13.42 + 9.5c
Spruce beetle lure plus MCH	0.38 + 0.3c	1.64 + 0.9c	5.47 + 1.8a
Spruce beetle lure plus (±)-*exo/endo*-brevicomin plus MCH	0.06 + 0.1a	1.06 + 0.4a	10.03 + 13.5b
Spruce beetle lure plus (±)-ipsdienol plus MCH	0.18 + 0.2a	1.02 + 0.3a	5.27 + 2.4a
Spruce beetle lure plus (±)-*exo/endo*-brevicomin plus (±)-ipsdienol plus MCH	0.27 + 0.2b	1.24 + 0.7b	8.33 + 6.6b
Low population			
Control	0.29 + 0.2b	1.04 + 0.6b	8.53 + 6.7c
Spruce beetle lure plus	0.24 + 0.2b	1.53 + 0.5c	14.42 + 4.5d
(±)-*exo/endo*-brevicomin	0.16 + 0.2a	2.16 + 0.9d	17.37 + 4.3e
Spruce beetle lure plus (±)-ipsdienol	0.26 + 0.2b	1.69 + 1.2c	13.20 + 9.2d
Spruce beetle lure plus (±)-ipsdienol plus (±)-*exo/endo*-brevicomin	0.18 + 0.3a	1.16 + 0.7b	9.45 + 9.4c
Spruce beetle lure plus MCH	0.13 + 0.1a	0.69 + 0.5a	4.49 + 3.3b
Spruce beetle lure plus (±)-*exo/endo*-brevicomin plus MCH	0.24 + 0.2b	0.1.11 0.9b	5.96 + 4.2b
Spruce beetle lure plus (±)-ipsdienol plus MCH	0.18 + 0.2a	1.24 + 0.8b	11.22 + 8.8c
Spruce beetle lure plus (±)-*exo/endo*-brevicomin plus (±)-ipsdienol plus MCH	0.11 + 0.1a	0.56 + 0.5a	2.49 + 2.6a

[a] Spruce beetle population density, low <2, high >6 infested trees per hectare. Mean values within columns followed by the same letter are not significantly different ($P < 0.05$, Tukey [1953] standardized range test [HSD]).

beetle bait plus (±)-*exo*- and (±)-*endo*-brevicomin plus methyl butenol and (±)-ipsdienol caught the highest number of *D. affaber* (table 1). An insignificant number of *P. rufipennis* adults were attracted to traps baited with the semiochemicals when tested alone or in various combinations.

It appears that dispersing spruce beetles are repelled when they come into contact with pheromones from secondary scolytids; a chemical message possibly indicating a colonized host. Conversely, the addition of the spruce beetle bait to (±)-*exo*- and (±)-*endo*-brevicomin and to (±)-ipsdienol increased trap catches of the competing secondary scolytids, except *P. rufipennis* (table 1). These secondary species are apparently keying into the pheromone of spruce beetle as an indicator of potential host material (e.g., a spruce beetle infested tree).

The study continued in 1992 in stands of Lutz spruce with low and high population densities of spruce beetles. The number of spruce beetle attacks, beetle galleries, and brood were compared among felled green trees baited with the spruce beetle baits and various combinations of (±)-ipsdienol, (±)-*exo*- and (±)-*endo*-brevicomin, and MCH. The addition of pheromones from secondary scolytid species or MCH significantly reduced attack densities of spruce beetles in stands with both high and low population densities (table 2). The largest significant reduction in attack density and brood production of spruce beetle, for both study sites, was obtained when a combination of (±)-*exo*- and (±)-*endo*-brevicomin plus MCH was added to trees with the spruce beetle baits. The addition of either (±)-*exo*- and (±)-*endo*-brevicomin plus MCH, or (±)-ipsdienol plus MCH to trees baited with spruce beetle lures reduced attack density by 87 percent and 62 percent, respectively, in stands with high populations of spruce beetles (table 2). The addition of MCH to trees baited with spruce beetle lures plus (±)-ipsdienol reduced gallery construction by 40 percent and brood production by 50 percent in high populations (table 2). In low and medium populations of spruce beetles, the addition of (±)-*exo*- and (±)-*endo*-brevicomin plus (±)-ipsdienol and MCH to trees baited with spruce beetle lures disrupted gallery construction by 63 percent (low population) and 77 percent (medium) and brood production by 83 percent (low) and 81 percent (medium population) (tables 2 and 3).

When populations of spruce beetles were high, numbers of galleries and brood production were significantly lower (table 2). This could have been caused by increased competition from secondary scolytid species. Combinations of the spruce beetle baits plus MCH, and the spruce beetle baits plus (±)-ipsdienol plus MCH resulted in the least number of spruce beetle brood produced. At low densities of spruce beetles, the lowest numbers of brood as well as the lowest attack densities were found on trees baited with (±)-*exo*- and (±)-*endo*-brevicomin plus (±)-ipsdienol and MCH. The high variability of the data for brood density, however, suggests that low numbers of brood could be an artifact. The addition of MCH to trees with spruce beetle baits and those trees baited with pheromones from secondary scolytid species repelled spruce beetle attack.

The results of the 1993 field test (table 3) conducted in stands with medium populations of spruce beetles showed similarities as well as differences to the previous two studies. The addition of (±)-ipsdienol, and combinations of (±)-ipsdienol plus MCH, (±)-*exo*- and (±)-*endo*-brevicomin plus MCH, and (±)-*exo*- and (±)-*endo*-brevicomin plus (±)-ipsdienol and MCH to trees with spruce beetle baits reduced the number of spruce beetle attacks. Again, the addition of (±)-*exo*- and (±)-*endo*-brevicomin plus (±)-ipsdienol and MCH to trees with spruce beetle baits resulted in the highest reduction of spruce beetle attacks, gallery construction, and brood production (table 3).

Table 3—Comparison of semiochemicals that induce competition of secondary scolytids with spruce beetles in felled trees in areas with medium population densities in Alaska, 1993[a]

Treatment	No. beetle attacks	No. beetle galleries	No. beetle brood
Control	0.40 + 0.5c	1.00 + 0.9d	17.73 + 11.9c
Spruce beetle lure	0.47 + 0.4c	0.95 + 0.5d	15.67 + 4.7c
Spruce beetle lure plus (±)-*exo/endo*-brevicomin	0.95 + 0.7d	1.82 + 0.7e	25.90 + 14.1d
Spruce beetle lure plus (±)-ipsdienol	0.09 + 0.2a	0.36 + 0.4b	13.27 + 7.9c
Spruce beetle lure plus (±)-*exo/endo*-brevicomin plus (±)-ipsdienol	0.44 + 0.5c	1.05+ 0.6d	16.84 + 8.4c
Spruce beetle lure plus MCH	0.22 + 0.4b	0.60 + 0.7c	6.29 + 5.8b
Spruce beetle lure plus (±)-*exo/endo*-brevicomin plus MCH	0.07 + 0.2a	0.35 + 0.4b	7.40 + 7.6b
Spruce beetle lure plus (±)-ipsdienol plus MCH	0.11 + 0.2a	0.35 + 0.5b	6.67 + 7.7b
Spruce beetle lure plus (±)-*exo/endo*-brevicomin plus (±)-ipsdienol plus MCH	0.13 + 0.3a	0.22 + 0.3a	2.98 + 4.4a

[a] Medium spruce beetle population density is <2 infested trees per hectare. Mean values within columns followed by the same letter are not significantly different ($P < 0.05$, Tukey [1953] studentized range test [HSD]).

This treatment caused additional reductions in attacks and brood production of 40 and 52 percent, respectively, compared with the addition of MCH alone. The addition of (±)-*exo-* and (±)-*endo*-brevicomin and (±)-*exo-* and (±)-*endo*-brevicomin plus (±)-ipsdienol to spruce beetle baited trees had no effect on the parameters measured in stands with medium spruce beetle population levels, unlike the low population results (tables 2 and 3).

Conclusions

The results from these field experiments indicate that the use of the spruce beetle antiaggregant MCH in conjunction with pheromones from secondary scolytids can be used to significantly reduce spruce beetle attack, gallery construction, and brood levels in felled, susceptible host trees. This could prevent potential colonization of standing trees and subsequent initiation of a large spruce beetle infestation.

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English Equivalents

When you know:	Multiply by:	To find:
Celsius (°C)	1.8 and add 32	Fahrenheit
Square centimeters (cm^2)	2.54	Inches
Hectares (ha)	2.47	Acres
Kilometers (km)	0.621	Miles
Meters (m)	3.281	Feet
Milligrams (mg)	0.001	Ounces
Millimeters (mm)	0.254	Inches

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