Effect of Semiochemical Release Rate, Killing Agent, and Trap Design on Detection of *Tetropium fuscum* (F.) and Other Longhorn Beetles (Coleoptera: Cerambycidae)

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ABSTRACT Release rates of a blend of monoterpenes (spruce blend) and ethanol significantly affected mean trap catch of *Tetropium fuscum* (F.), *Tetropium castaneum* L., and *Tetropium cinnamopterum* Kirby. Addition of an ethanol lure to traps baited with the spruce blend lure was necessary to attract *T. castaneum* and *T. cinnamopterum* and significantly increased attraction of *T. fuscum.* The combination of spruce blend and ethanol at high release rates had the highest mean catch of *Tetropium* spp. and was the only lure treatment that resulted in capture of *T. fuscum* and *T. castaneum* (in Poland) in every test block, suggesting it would be the best for detection surveys among the lures tested. The effect of trap design on mean catch of *T. fuscum* was inconsistent. In one experiment, the larger collapsible cross-vane Colossus trap caught about twice as many beetles as the IPM-Intercept trap, but in two other experiments, mean catch did not differ significantly. Type of killing agent in the collecting bucket significantly affected mean catch of *T. fuscum.* Traps with liquid killing agent (50/50 mixture of propylene glycol and deionized water plus 0.5 ml/liter of Kodak Photo-Flo 200 and 12.5 mg/liter of Bitrex) in the collecting bucket caught more beetles than traps with an insecticidal (dichlorvos) strip. Although any of cross-vane traps tested seem suitable for trapping several cerambycid species, the Colossus trap with liquid killing agent is recommended for use as a detection tool for *T. fuscum* because it caught similar or greater numbers than the other trap types.

KEY WORDS semiochemicals, release rate, killing agent, *Tetropium fuscum*, Cerambycidae

Expansion of global trade and intercontinental human movement during the 20th century have greatly accelerated the rate of accidental introductions of nonnative species (Sailer 1978, Liebhold et al. 1995). Some of these alien species become invasive, i.e., they establish, proliferate, and spread in their new habitat, and cause significant ecological and economic damage (Mack et al. 2000, Pimental et al. 2000, Nowak et al. 2001, Simberloff 2002). It is far more cost effective to prevent invasions through international regulatory measures than to effect postentry control (Mack et al. 2000). Once a species has established, its containment and eradication are possible (Hoelmer and Grace 1989, Mack et al. 2000), but probability of success decreases with increasing population size (Sharov and Liebhold 1998, Liebhold and Bascompte 2003). Therefore, early detection of alien invasive species, when populations are small, is critical to the success of eradication or containment programs (Liebhold and Bascompte 2003).

The brown spruce longhorn beetle, *Tetropium fuscum* (F.) (Coleoptera: Cerambycidae), is a quarantine pest that was discovered near the port of Halifax, Nova Scotia, Canada, in 1999 (Smith and Hurley 2000). In Europe, *T. fuscum* infests mainly Norway spruce, *Picea abies* L. Karst., and is considered a secondary pest, breeding in recently felled trees or trees weakened by root rots or other factors (Juutinen 1955). In contrast to the situation in Europe, *T. fuscum* seems to act more aggressively in Nova Scotia, where it is infesting and killing red spruce, *P. rubens* Sarg., white spruce, *P. glauca* (Moench) Voss, black spruce, *P. mariana* (Mill.) B.S.P., and Norway spruce (Smith and Humble 2000, Sweeney et al. 2001). In Norway, <5% of *T. fuscum*–infested trees appeared healthy with green crowns (Juutinen 1955), whereas 67% of *T. fuscum*–infested spruce in Halifax had green and healthy crowns, with copious resin flow down the stem (O'Leary et al. 2003). O'Leary et al. (2003) found that trees with reduced growth rate and low vigor were more susceptible to *T. fuscum* than faster-growing trees and concluded the beetle was a threat to spruce forests in North America that were undergoing periods of stress and suppressed growth caused by drought, defoliator outbreaks, or a complex of factors. Because *T. fuscum* is considered a threat to the health of Canada's spruce forests, and the infestation in Halifax represents the only known population of the beetle

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in North America, an intensive program to contain and eradicate the beetle was undertaken in 2000 by a multiagency task force led by the Canadian Food Inspection Agency. To assist in this goal, we have been developing tools for survey and detection of *T. fuscum* that may be used to monitor the progress of the containment and eradication program and also for early detection of the beetle at sites that risk new introductions.

Several species of cerambycids are attracted to conifer volatiles such as monoterpenes and ethanol (Ikeda et al. 1980, Phillips et al. 1988, Chénier and Philogène 1989a, Morewood et al. 2002a, Allison et al. 2004). Sweeney et al. (2004) found that *T. fuscum* was attracted to a blend of monoterpenes (spruce blend) that simulated those emitted by red spruce and that ethanol synergized attraction of both *T. fuscum* and a related species, *Tetropium castaneum* L. However, mean catch of *T. fuscum* with the most attractive lure combination (spruce blend + ethanol) was fairly low (Sweeney et al. 2004); an improved lure and trap would increase the chances of detecting low populations of *T. fuscum.* Mean trap catch of cerambycids and other wood-boring beetles is affected by trap design (Chénier and Philogène 1989b, de Groot and Nott 2001, McIntosh et al. 2001, Morewood et al. 2002b), type of killing agent (i.e., wet versus dry) in the trap's collection container (Morewood et al. 2002b, de Groot and Nott 2003), chemical composition of the lure (Chénier and Philogène 1989a, Allison et al. 2004, Sweeney et al. 2004), and lure release rate (Miller and Borden 1990). In this study, as part of our overall objective to increase the efficacy of tools for detection of *T. fuscum,* we determined the effect of high and low release rates of spruce blend and ethanol, trap design, and type of killing agent on catch of *T. fuscum.* Conducting experiments in Poland as well as in Halifax allowed us to test the response to semiochemicals of different populations of *T. fuscum,* as well as other potentially invasive species of woodborers not known to be established in North America, such as *T. castaneum.*

Materials and Methods

Study Areas. Trapping experiments were conducted in Halifax, Nova Scotia, on McNabs Island and near Mount Saint Vincent University, and in compartment 496C in an old-growth forest near Białowieża, Poland. The forest on McNabs Island is dominated by white and red spruce and balsam fir, *Abies balsamea* L. Mill; the 5-ha forest adjacent to Mount Saint Vincent University is comprised mainly of red spruce. The Białowieża forest site in Poland was mixed deciduous forest, with the most common species being Norway spruce, English oak, *Quercus robur* L., European hornbeam, *Carpinus betulus* L., Scots Pine, *Pinus sylvestris* L., aspen, *Populus tremula* L., and European silver birch, *Betula pendula* Roth.

Trapping Experiments. Four trapping experiments were conducted from 2002 to 2004. Each was replicated in randomized complete block designs with 25–30 m between traps within blocks and 50–100 m between blocks. Traps were either placed directly on the ground (cross-vane pan traps) or were suspended from a rope tied between two spruce trees so that the trap was at least 1 m away from each tree, and the collecting bucket was <10 cm above the ground (Colossus and IPM-Intercept traps). Traps were checked weekly in Canada and every 2 wk in Poland. All cerambycid and buprestid specimens were preserved in 70% ethanol. Identification of *Tetropium* species and other cerambycids were made or confirmed by J. M. Gutowski, S. Laplante (Agriculture and Agri-Food Canada, Ottawa, Canada), J. Price, and J. Sweeney. Voucher specimens have been deposited at the Canadian Forest Service–Atlantic Forestry Centre, Fredericton, New Brunswick, Canada.

Table 1. Composition, purity, and average release rate of lures tested for attraction of *T. fuscum* and other cerambycid beetles in field trapping bioassays in Halifax, Nova Scotia and Białowieża, Poland, 2002–2004

Lure	Component	Percentage of lure composition	Purity (%)	Mean release rate (mg/d at 20°C)[a]	
				High release lures	Low release lures
Spruce blend[b]	Racemic α-pinene	44	97	2,000	207
	(−)-β-Pinene	19	98		
	(+)-3-Carene	10	93		
	(+)-Limonene	18	99		
	α-Terpinolene	9	92		
Ethanol	Ethanol	100	95	275	30

[a] Data provided by PheroTech.
[b] Release rate not determined for individual components.

Lure Composition and Release Rates. All lures were produced by PheroTech (Delta, British Columbia, Canada) and were stored at −18°C until used in the field. The "spruce blend" lure consisted of a blend of racemic α-pinene, (−)-β-pinene, (+)-3-carene, (+)-limonene, and α-terpinolene at relative concentrations similar to those observed in cortical volatiles of *T. fuscum*–infested red spruce (Sweeney et al. 2004), and was released at ≈2,000 (one lure per trap) and 414 mg/d (207 mg/d per lure × 2 lures per trap) from high and low release rate treatments, respectively (Table 1). Ethanol (one lure per trap) was released at 275 and 30 mg/d from high and low release rate treatments, respectively (PheroTech measured at 20°C; Table 1). Low release rate spruce blend lures were replaced after 4 wk in the field; the other lures have a field life of 90 d at 21–24°C, so were not replaced for the 6- to 8-wk duration of any given trapping experiment. Average release rates in the field were probably lower than these because mean daily temperatures (±SD; min., max.) recorded on McNabs Island during the trapping periods were 13.9 (0.10; 5.1, 28.0), 13.7 (0.13; 4.7, 23.9), and 14.1°C (0.11; 7.4, 28.3) in 2002, 2003, and 2004, respectively (http://www.climate.weatheroffice.ec.gc.ca/climateData/hourlydata_e.html). The mean daily temperature (±SD; min., max.) in Białowieża, Poland, from 20 May to 8 July 2003, was 16.6°C (0.34; 3.2, 30.2).

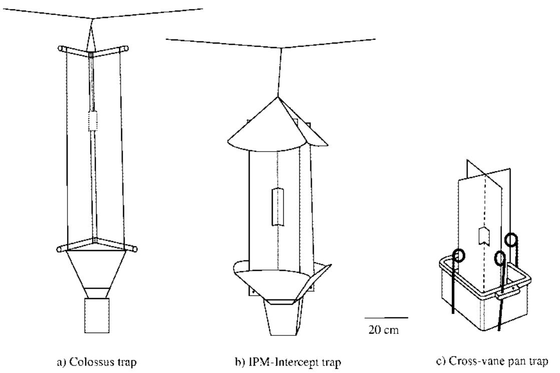

Fig. 1. Trap designs and their dimensions. The Colossus trap (a) has four flexible panels, each measuring 19 by 100 cm, above a funnel (48 cm square at the top opening by ≈40 cm deep) attached to a collecting cup (9.5 cm diameter by 21 cm deep) with a 0.38-m^2 cross-sectional area above the funnel. The IPM-Intercept trap (b) has two intersecting panels (30.5 by 80.5 cm) with a top and bottom funnel (40 cm square at the top opening by ≈20 cm deep), a collecting cup (13.5 by 13.5 by 14.5 cm deep), and a 0.18-m^2 cross-sectional area between the top and bottom funnels. The cross-vane pan trap (c) has two intersecting cross vanes (35 by 67 and 25 by 67 cm) that fit in a pan (23 by 33 by 17 cm deep) that rests on the ground, with a cross-sectional area estimated as 0.15 m^2 from mean vane width (30 cm) and height above pan (50 cm).

Experiment 1: Effect of High and Low Release Rates of Spruce Blend and Ethanol. Trap catch was compared among six lure treatments: all four combinations of high and low release rate lures of spruce blend + ethanol, spruce blend alone at high release rate, and an unbaited control. The experiment was conducted on McNabs Island from 3 June to 22 July 2003, with 15 replicates per treatment, and in Białowieża from 20 May to 8 July 2003, with 10 replicates per treatment. On McNabs Island, cross-vane pan traps (de Groot and Nott 2001) were used with a 0.05% solution of Kodak Photo-Flo 200 in water in the collecting pan to reduce surface tension. In Poland, IPM-Intercept traps (IPM Technologies, Portland, OR) were used with a 50% solution of ethylene glycol in the collecting bucket.

Experiments 2–4: Effect of Different Trap Types and Killing Agents. Three experiments were conducted to compare the efficacy of different trap designs and killing agents. All traps were baited with spruce blend and ethanol; low release rate lures were used in 2002 and 2003, and high release rate lures were used in 2004.

In experiment 2, conducted on McNabs Island from 5 June to 8 August 2002, the mean catch of *T. fuscum* was compared among four different trap types: (1) Colossus trap (developed by Simon Fraser University, Burnaby, British Columbia, Canada and PheroTech; Fig. 1a) with a 2.5 by 5-cm strip of Hercon Vaportape II (Hercon Environmental, Emigsville, PA), which releases the insecticide dichlorvos (2,2-dichlorovinyl dimethyl phosphate) placed in the collecting bucket (Colossus-dry); (2) Colossus trap with a 1% solution of dish detergent in water (Colossus-wet); (3) IPM-Intercept trap with cross-vanes coated with a surfactant (Rain-X; Pennzoil-Quaker State, Burlington, Ontario, Canada) to make them more slippery to beetles attempting to land (Fig. 1b) (de Groot and Nott 2003) and with a 2.5 by 5-cm strip of Vaportape II in the collecting bucket (Fig. 1b); and (4) cross-vane pan trap (Fig. 1c) with a 1% solution of dish detergent in water in the pan. There were seven replicates (blocks) per treatment.

In experiment 3, the effect of trap design and type of killing agent on mean catch per trap of *T. fuscum* and other cerambycids was tested in a 2 by 2 factorial experiment with 15 replicates per treatment, from 10 June to 22 July 2003, on McNabs Island. The two trap types were the Colossus and the IPM-Intercept traps. The killing agents in the collecting cups were either a 50:50 mixture of propylene glycol and deionized water plus 0.5 ml/liter of Kodak Photo-Flo 200 and 12.5 mg/liter of Bitrex (wet) or a piece of Vaportape II (dry).

In experiment 4, mean catch of *T. fuscum* in Colossus versus IPM-Intercept traps, both with wet killing agent (as described above), was compared in a randomized complete block design with five replicates (blocks), from 9 June to 15 July 2004. Four trap blocks were set up on McNabs Island and one block was set up at Mount Saint Vincent University.

Data Analysis. For experiments 1–3, data for mean total catch per trap and mean total catch per square meter of cross-vane surface area were transformed by either log(y + 1) or square root, depending on which produced residuals that best fit the normal distribution (Shapiro and Wilk test) (Zar 1999), and subjected to analysis of variance (ANOVA) (SAS Institute 1999–2001). Means were compared using the Ryan-Einot-Gabriel-Welsh range test or Tukey's test of rank data with an experiment-wise type I error rate of 5% (SAS Institute 1999–2001). Loss of data because of trap disturbance happened infrequently, but if a trap was found to be vandalized, we deleted that week's catch data from the season totals for all treatments in the affected block. For experiment 4, a paired *t*-test was used to test for differences between the Colossus and IPM Intercept traps in mean total catch and mean total catch per square meter of cross-vane surface area.

Results

Experiment 1: Effect of Release Rate of Spruce Blend and Ethanol. Mean catch of *T. fuscum, T. castaneum,* and *T. cinnamopterum* Kirby was significantly greater in traps baited with high release rates of both spruce blend and ethanol (SBHI + ETHI), than in traps baited with low release rate lures (SBLO + ETLO; Fig. 2). At low release rates, the combination of spruce blend and ethanol (SBLO + ETLO) was significantly attractive to *T. fuscum* (Fig. 2a and b), but not *T. cinnamopterum* (Fig. 2c) or *T. castaneum* (Fig. 2d), compared with the unbaited traps (CONT). The only traps that consistently captured *T. fuscum* (in Canada and Poland) and *T. castaneum* (in Poland) in

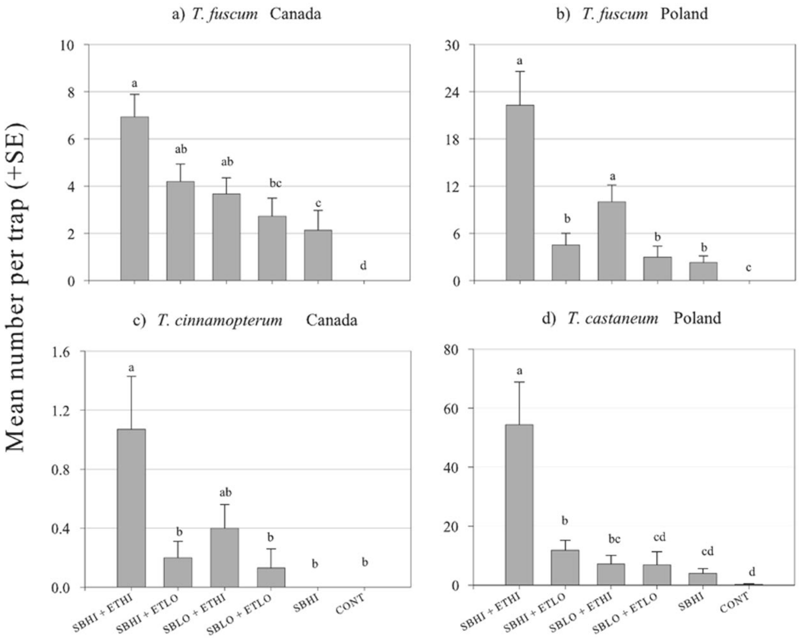

Fig. 2. Mean catch per trap (±SE) of *Tetropium* spp. in 2003 in traps baited with spruce blend (SB) and ethanol (ET) at high (HI) or low (LO) release rates, or in unbaited traps (CONT). (a) *T. fuscum,* Canada. (b) *T. fuscum,* Poland. (c) *T. cinnamopterum,* Canada. (d) *T. castaneum,* Poland. Within each graph, means with different letters were significantly different (a, b, and d: ANOVA and Ryan-Einot-Gabriel Welsh range test on data transformed by log(y + 1) with an experiment-wise type I error rate of 5%; c: ANOVA and Tukey's test of rank data, $\alpha = 0.05$).

every block were those baited with high release rate lures of both spruce blend and ethanol. All other lure treatments failed to detect one or both *Tetropium* species in one or more blocks. Block effects were significant for *T. castaneum* ($F = 2.47$; df = 9,45; $P = 0.022$) but were not significant for *T. cinnamopterum* ($F = 1.71$; df = 14,70; $P = 0.07$) or *T. fuscum* in Poland ($F = 0.86$; df = 9,45; $P = 0.57$) or Canada ($F = 1.55$; df = 14,70; $P = 0.12$).

The high release rate spruce blend lure alone (SBHI) was significantly attractive to *T. fuscum* (Fig. 2a and b), but not *T. cinnamopterum* (Fig. 2c) or *T. castaneum* (Fig. 2d), compared with the unbaited traps. Depending on its release rate, ethanol increased attraction of *Tetropium* spp. when added to traps baited with spruce blend. Adding a high release rate ethanol lure to the high release rate spruce blend lure significantly increased attraction of all three *Tetropium* species (Fig. 2). Adding a low release rate ethanol lure (ETLO) to the high release rate spruce blend lure increased attraction of *T. fuscum* in Canada (Fig. 2a) and *T. castaneum* (Fig. 2d), but not *T. fuscum* in Poland (Fig. 2b) or *T. cinnamopterum* (Fig. 2c), compared with the high release rate of the spruce blend lure alone.

In addition to *Tetropium* species, other cerambycid species were captured in Canada (Appendix 1) and Poland (Appendix 2), but only *Rhagium inquisitor* L., *Asemum striatum* L., *Oxymirus cursor* L., *Strangalepta abbreviata* (Germar), and *Rhagium mordax* (DeGeer) were captured in high enough numbers in experiment 1 to warrant statistical analysis. The combination of spruce blend at high release rate and ethanol at low release rate was significantly attractive to *R. inquisitor* in Canada ($F = 2.67$; df = 5,70; $P = 0.029$; Fig. 3a), whereas high release rate ethanol combined with spruce blend at either high or low release rates was significantly attractive to *R. inquisitor* in Poland ($F = 4.97$; df = 5,45; $P = 0.001$; Fig. 3b) compared with the unbaited traps. Lure treatment did not significantly affect mean catch of *A. striatum* ($F = 1.89$; df = 5,70; $P = 0.11$; Fig. 3c), *O. cursor* ($F = 1.15$; df = 5,45; $P = 0.35$; Fig. 3d), *S. abbreviata* ($F = 0.41$; df = 5,70; $P = 0.84$; Fig. 3e), or *R. mordax* ($F = 1.80$; df = 5,45; $P = 0.13$; Fig. 3f). Block effects were significant for *A. striatum* ($F = 2.89$; df = 14,70; $P = 0.002$) but were insignificant for the other species (ANOVA, $P > 0.05$).

Experiments 2–4: Effect of Different Trap Types and Killing Agents. In experiment 2, mean catch of *T. fuscum* did not differ significantly among trap types (Fig. 4; $F = 2.03$; df = 3,18; $P = 0.15$) or blocks ($F = 0.77$; df = 6,18; $P = 0.61$). There was also no difference in mean catch per square meter cross-vane surface area among traps ($F = 0.78$; df = 3,18; $P = 0.87$) or blocks ($F = 0.24$; df = 6,18; $P = 0.60$). No other cerambycid species was caught in sufficient numbers for meaningful analysis.

In experiment 3, trap design significantly affected mean total catch per trap of *T. fuscum* ($F = 26.9$; df = 1,42; $P < 0.0001$; Fig. 5a), *T. cinnamopterum* ($F = 11.8$; df = 1,42; $P = 0.001$; Fig. 5b), *A. striatum* ($F = 15.4$; df = 1,42; $P = 0.0003$; Fig. 5c), *R. inquisitor* ($F = 12.6$; df =

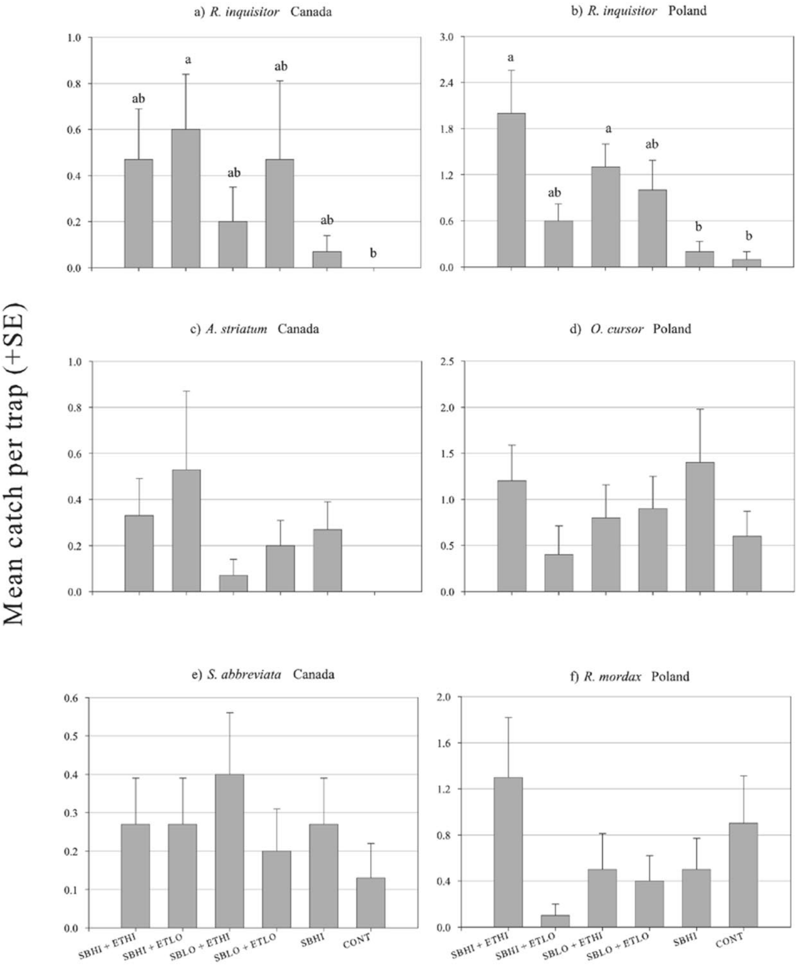

Fig. 3. Mean catch per trap (±SE) of cerambycid beetles in 2003 in traps baited with spruce blend (SB) and ethanol (ET) at high (HI) or low (LO) release rates or in unbaited traps (CONT). (a) *Rhagium inquisitor*, Canada. (b) *R. inquisitor*, Poland. (c) *Asemum striatum*, Canada. (d) *Oxymirus cursor*, Poland. (e) *S. abbreviata*, Canada. (f) *R. mordax*, Poland. Within each graph, means with the same letters or no letters were not significantly different (ANOVA and Ryan-Einot-Gabriel Welsh range test on data transformed by log(y + 1), $\alpha = 0.05$ (b and d); ANOVA and Tukey's test on ranked data, $\alpha = 0.05$ (a, c, e, and f).

1,42; $P = 0.001$; Fig. 5d), and *Anthophylax attenuatus* (Haldeman) ($F = 16.5$; df = 1,42; $P = 0.0002$; Fig. 5e), with greater mean catch in the Colossus traps than the Intercept traps. When trap catch was expressed as the number of *T. fuscum* per cross-sectional surface area of the trap panels, the effect of trap design remained significant for all species: *T. fuscum* ($F = 13.4$; df = 1,42; $P < 0.001$), *T. cinnamopterum* ($F = 9.2$; df = 1,42; $P = 0.004$), *A. striatum* ($F = 13.6$; df = 1,42; $P = 0.0006$), *R. inquisitor* ($F = 9.2$; df = 1,42; $P = 0.004$), and *A. attenuatus* ($F = 13.4$; df = 1,42; $P = 0.0007$).

The type of killing agent significantly affected catch of *T. fuscum* ($F = 8.1$; df = 1,42; $P = 0.007$; Fig. 5a) and *R. inquisitor* ($F = 5.9$; df = 1,42; $P = 0.02$; Fig. 5d) only, with greater catch in wet than dry traps. The interaction between trap type and killing agent was not significant for mean catch per trap of any species ($P > 0.05$), but was significant for mean catch per square meter of surface area of *T. cinnamopterum* ($F = 4.0$; df = 1,42; $P = 0.05$). Block effects were significant for *T. cinnamopterum* ($F = 1.9$; df = 14,42; $P = 0.04$) and *A. striatum* ($F = 2.1$; df = 14,42; $P = 0.04$) only.

In experiment 4, mean catch (±SE) of *T. fuscum* in Colossus wet traps (5.6 ± 1.4) and IPM-Intercept wet traps (5.0 ± 1.8) did not differ significantly ($t = 0.24$, df = 4, $P = 0.82$), nor did mean catch per surface area ($t = -0.70$, df = 4, $P = 0.52$).

Discussion

Release rates of spruce blend and ethanol significantly affected mean catch of *T. fuscum*, *T. castaneum*, and *T. cinnamopterum.* Addition of an ethanol lure to traps baited with the spruce blend lure was necessary for attraction of *T. castaneum* and *T. cinnamopterum* and significantly increased attraction of *T. fuscum.* The combination of spruce blend and ethanol at high release rates had the highest mean catch of *Tetropium*

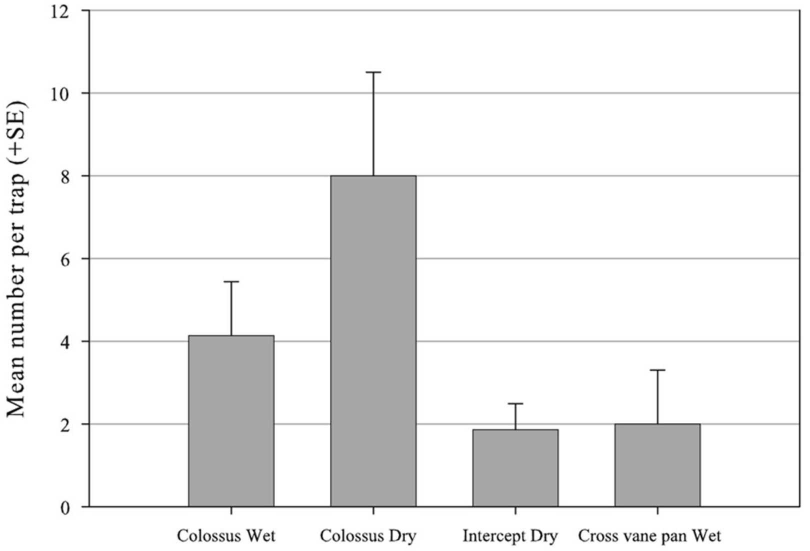

Fig. 4. Mean catch (±SE) of *T. fuscum* on McNabs Island from 5 June to 8 August 2002 in Colossus, IPM-Intercept, or cross-vane pan traps baited with spruce blend plus ethanol. Wet traps contained a 1% solution of dish detergent in water in the collecting cup or pan; dry traps contained a dichlorvos strip in the collecting cup. Catch did not differ significantly among traps (ANOVA, $F = 2.03$; df $= 3,18$; $P = 0.15$).

spp. and was the only lure treatment that resulted in capture of *T. fuscum* and *T. castaneum* (in Poland) in every test block, suggesting it would be the best, among the lures tested, for detection surveys.

Greater catches of *Tetropium* spp. in traps baited with higher release rates of volatiles may have occurred because beetles were drawn from a larger area around the trap, higher host volatile concentrations better simulated a preferred host condition (i.e., wounded, stressed, freshly cut), or both. Several species of cerambycids have been shown to be attracted to such host volatiles as monoterpenes and ethanol (Chénier and Philogène 1989a, Allison et al. 2004, Sweeney et al. 2004, and references therein), using them to locate and recognize suitable hosts (Hanks 1999). Most cerambycids are host specific and specialize on hosts in a particular physiological state (Linsley 1959, Hanks 1999). For example, girdled Virginia pine, *Pinus virginiana* Mill., attracted greater numbers of *Monochamus carolinensis* (Olivier) and *M. s. scutellatus* (Say) than did ungirdled controls (Hines and Heikkenen 1977), and in another study, wounded or diseased ponderosa pine, *Pinus ponderosa* P. and C. Lawson, attracted greater numbers of *Spondylis upiformis* Mannerheim than did unwounded trees (Owen et al. 2005). Both *T. fuscum* and *T. castaneum* usually infest live spruce that have been weakened by a prior agent, such as decay fungi, drought, or defoliators, but also readily infest freshly cut spruce logs (Juutinen 1955).

Monoterpenes such as α-pinene, β-pinene, and limonene have been shown to increase in concentration in conifers that have been inoculated with fungi (Raffa and Berryman 1982, Lieutier et al. 1989, Klepzig et al. 1995) or exposed to methyl jasmonate, which induces a defense response in many conifers (Martin et al. 2002). Ethanol is also usually found in higher concentrations in the bark and sapwood of diseased trees (Gara et al. 1993) and stressed conifers (Kimmerer and Kozlowski 1982) than in healthy trees. The increased capture of *T. fuscum* and *T. castaneum* in traps baited with the combination of spruce blend and ethanol at high release rates suggests that the beetles were responding to the kinds of volatiles and concentrations associated with stressed hosts.

Except for comparisons of baited versus unbaited traps, there are surprisingly few reports in the literature on response of cerambycids to different release rates of host volatiles. Miller and Borden (1990) found increased trap catches of *Monochamus clamator* (LeConte) with increased release rates of β-phellandrene. Morewood et al. (2002a) found that ethanol increased trap catch of *Xylotrechus longitarsis* Casey when added to traps baited with α-pinene, but the release rate of ethanol had no significant effect. In our study, the effect of ethanol release rate on cerambycid catch differed among species, populations of *T. fuscum,* and release rate of the spruce blend lure with which it was combined, but catch of each *Tetropium* species was consistently highest in traps baited with high release rate lures of both ethanol and spruce blend. Reddy et al. (2005) found that attraction of *Hylotrupes bajulus* L. increased when the release rate (dose) of a blend of synthetic monoterpenes was doubled (from 1 to 2 vials) but decreased at very high release rates (8–10 vials). It is possible that trap catch of *T. fuscum* would also decline if release rates of spruce blend and ethanol were excessively high, but this remains to be tested.

For reasons of economy, we did not test ethanol alone at high release rates, and thus we cannot determine whether it is attractive to *T. fuscum* or other

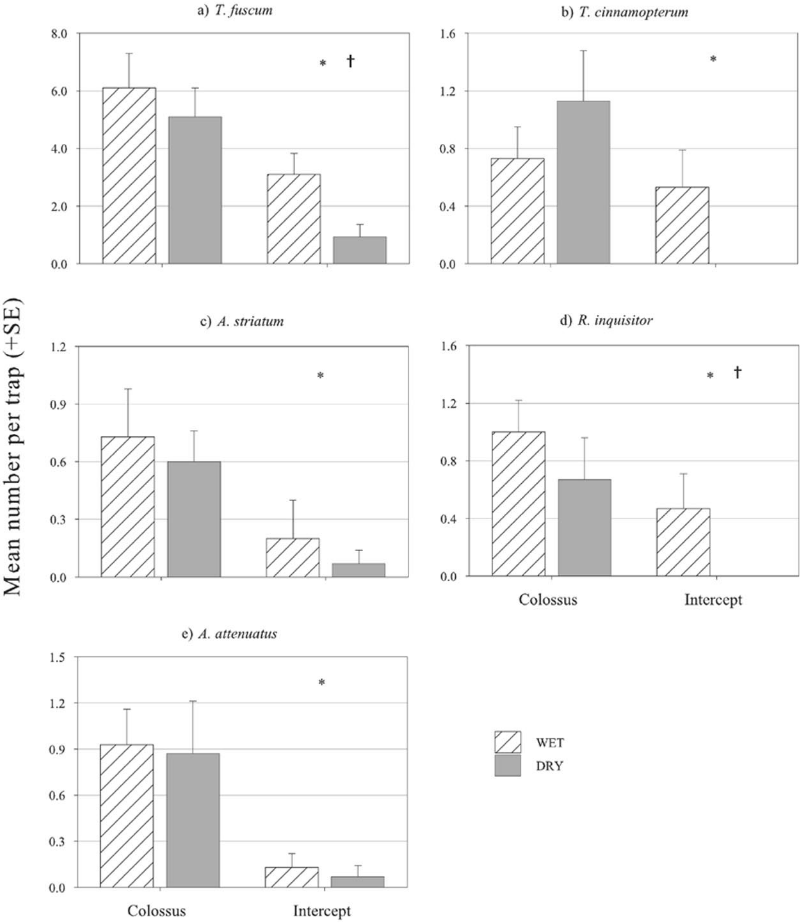

Fig. 5. Mean catch (±SE) of cerambycids on McNabs Island from 10 June to 22 July 2003 in Colossus versus IPM-Intercept traps with wet versus dry collecting buckets: (a) *T. fuscum,* (b) *T. cinnamopterum,* (c) *A. striatum,* (d) *R. inquisitor,* and (e) *A. attenuatus.* All traps were baited spruce blend plus ethanol. *Significant trap effect; †significant killing agent effect (ANOVA on data transformed by log(y + 1) (b and c) or square root (a, d, and e) $P < 0.05$.

cerambycid species or whether its effect was additive or synergistic when combined with the spruce blend lure. However, in recent experiments, we found that mean catch of *T. fuscum, T. castaneum, R. inquisitor,* and *O. cursor* in traps baited with ethanol at high release rates did not differ significantly from catch in unbaited traps (J.S., unpublished data). At low release rates, ethanol was not attractive to *T. fuscum, T. castaneum,* or *Spondylis buprestoides* L., but significantly increased capture of all three species when added to traps baited with low release rate spruce blend lures (Sweeney et al. 2004). These data indicate that ethanol by itself (at the release rates tested) is not attractive to *T. fuscum* but that it enhances attraction when combined with the spruce blend lure.

The combination of spruce blend and ethanol seemed quite selective to *Tetropium* spp. among the Cerambycidae. Although we trapped 41 different species of cerambycids in Halifax and Poland combined, most of the specimens in Halifax (74%) and Poland (89%) were *Tetropium* spp. that had been caught in traps baited with spruce blend and ethanol lures. *Tetropium* spp. accounted for none (in Halifax) and only 11% (in Poland) of the cerambycids caught in unbaited traps, suggesting their relative dominance among cerambycid specimens was not caused by relatively high population densities. The few non-*Tetropium* cerambycid species, for which we trapped >30 specimens, infest recently dead conifers (*R. inquisitor, A. striatum*) (Linsley 1962, Yanega 1996, Sama 2002), dead and decaying wood of conifers and hardwoods (*R. mordax, O. cursor, S. abbreviata*) (Yanega 1996, Sama 2002), or moist, decaying hardwood logs (*A. attenuatus*) (Yanega 1996). Of these species, only the Holarctic species, *R. inquisitor,* was significantly attracted to traps baited with certain combinations of spruce blend and ethanol lures. Gardiner (1957) reported attraction of *R. inquisitor* to turpentine, but Chénier and Philogène (1989a) found no differences in trap catch of *R. inquisitor* between unbaited controls and various combinations of monoterpenes and ethanol. The differences in response to the lure combinations between the Halifax and Polish populations of *R. inquisitor* is not surprising, because the populations are widely separated geographically and breed in different conifer species. Lack of significant attraction of *A. striatum* to the spruce blend or combinations of spruce blend and ethanol agrees with previous studies (Chénier and Philogène 1989a; Sweeney et al. 2004) that showed α-pinene was attractive to *A. striatum,* but that the addition of other monoterpenes or ethanol had no effect.

The effect of trap type on mean catch of *T. fuscum* and other cerambycids was inconsistent among experiments, but in terms of mean catch, the Colossus traps always performed as well as or better than other trap types. Significantly greater catch of *T. fuscum* and other cerambycids per square meter of surface area in the Colossus traps versus the Intercept traps, as observed in experiment 2, suggests that size of catch depended on more than simply a larger surface area for intercepting beetles. In contrast, Pajares et al. (2004) found no difference in catch of *Monochamus galloprovincialis* (Olivier) in multiple funnel traps versus cross-vane traps, despite a 32% larger trapping surface area on the cross-vane traps. All the trap designs that we tested roughly simulated the silhouette of a tree trunk, which has been suggested as a close-range visual stimulus for host location for many species of bark beetles and wood-borers (Tilden et al. 1983, Chénier and Philogène 1989b, Wyatt et al. 1997, de Groot and Nott 2001, Morewood et al. 2002b). It is conceivable that the larger silhouette of the Colossus trap is a more attractive visual stimulus to *T. fuscum* than the smaller Intercept trap, because *T. fuscum* prefers larger-diameter hosts (Juutinen 1955). However, this supposition was not supported in experiment 4, when neither catch per trap nor catch per square meter of surface area differed between Colossus and Intercept traps. In experiment 4, traps were baited with high release rate lures of spruce blend and ethanol, whereas low release rate lures were used in experiment 3. It is possible that higher release rates of volatiles overrode any difference in visual stimulus between the trap types.

The greater catch in wet than in dry traps could be caused by a greater rate of escape from dry traps than wet traps or perhaps by a repellent effect of dichlorvos on beetles. Dichlorvos has been variously reported as repellent to spruce budworm male moths (Sanders 1986) and medflies, *Ceratitis capitata* (Wiedemann) (Katsoyannos et al. 1999), but was found not repellent to stable flies, *Stomoxys calcitrans* L. (Bartlett 1985). Mean catch of *T. fuscum* was 3.3 times greater in wet than in dry IPM Intercept traps, but was almost the same in wet versus dry Colossus traps. The results for *T. cinnamopterum* were similar, with little difference in mean catch between wet and dry Colossus traps but zero catch in dry Intercept traps. These results suggest that the dichlorvos was not repellent to the beetles and that the difference in catch between wet and dry traps was caused by greater escape from dry cups, particularly for Intercept traps. de Groot and Nott (2003) found that dry traps, with or without the insecticide dichlorvos, caught significantly fewer cerambycids than wet traps. Similarly, Morewood et al. (2002b) found greater catch of several cerambycids species in multiple funnel traps with wet (soapy water) versus dry collecting cups with no killing agent and attributed the difference to greater escape of beetles from the dry cups. It is possible that fewer beetles escaped from Colossus traps than from IPM-Intercept traps, because the former have deeper collecting cups with steeper sides. It would be useful to compare Colossus and Intercept traps fitted with the same type of collecting cups to discern the relative influence of collecting cups versus cross vane design on trapping efficacy.

Baiting traps with high release rate lures of spruce blend and ethanol should significantly increase the probability of detecting *T. fuscum* and *T. castaneum* where they are present compared with lures with low release rates. A wet killing agent (with a 50:50 mixture of propylene glycol and deionized water plus 0.5 ml/liter of Kodak Photo-Flo 200 and 12.5 mg/liter of Bitrex in the collecting cups) should be used whenever feasible because this not only had greater mean catch of *T. fuscum* compared with dry traps but also preserves better quality voucher specimens. When traps are serviced on a regular basis (every 1–2 wk), specimens from dry traps are subject to greater decay and mechanical damage (e.g., from predators and carrion beetles and during cleaning and sorting) than those from wet traps and are also less suitable for extraction of DNA (L. Humble and G. Smith, personal communication). Although all the cross-vane traps tested seemed suitable for trapping several cerambycid species, in terms of efficacy at detecting *T. fuscum,* the Colossus trap is recommended because it caught similar or greater numbers than the other trap types. Other factors affecting the usefulness of trap types, such as ease of handling, cost, and durability, were not evaluated in this study.

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Appendix 1. List of Cerambycidae captured in host volatile-baited traps in Halifax, Nova Scotia, Canada, on McNabs Island (MI) in 2002 and 2003, and at Mount Saint Vincent University (MSV) in 2003

Subfamily and species	Location	No. specimens
Spondylidinae		
Asemum striatum L.	MI	55
	MSV	2
Tetropium fuscum (F.)	MI	658
	MSV	12
Tetropium cinnamopterum Kirby	MI	75
Cerambycinae		
Microclytus compressicollis (Lap. de Cast. and Gory)	MI	1
Phymatodes dimidiatus (Kirby)	MI	1
Xylotrechus undulatus (Say)	MI	11
Lepturinae		
Anthophylax attenuatus (Haldeman)	MI	35
	MSV	1
Anthophylax viridis LeConte	MI	3
Anthophylax cyaneus (Haldeman)	MI	1
Evodinus monticola monticola (Randall)	MI	19
Judolia m. montivagans (Couper)	MI	2
Neoalosterna capitata (Newman)	MI	1
Pidonia ruficolis (Say)	MI	3
Rhagium inquisitor (L.)	MI	59
	MSV	2
Sachalinobia rugipennis rugipennis (Newman)	MI	4
Strangalepta abbreviata (Germar)	MI	36
Lamiinae		
Acanthocinus pusillus Kirby	MI	1
Monochamus notatus (Drury)	MI	4
Monochamus scutellatus scutellatus (Say)	MI	11
Pogonocherus penicillatus LeConte	MI	4

Appendix 2. List of Cerambycidae captured in host volatile-baited traps near Białowieża, Poland in 2003

Subfamily and species	No. specimens
Spondylidinae	
Arhopalus rusticus L.	1
Asemum striatum	1
Spondylis buprestoides L.	2
Tetropium castaneum L.	847
Tetropium fuscum (F.)	421
Cerambycinae	
Callidium coriaceum (Paykull)	1
Obrium brunneum (F.)	1
Phymatodes testaceus L.	1
Plagionotus arcuatus L.	3
Lepturinae	
Alosterna tabacicolor (DeGeer)	6
Cortodera femorata (F.)	5
Oxymirus cursor L.	53
Pachyta quadrimaculata L.	9
Rhagium inquisitor L.	52
Rhagium mordax (DeGeer)	37
Lamiinae	
Acanthocinus aedilis L.	1
Agapanthia villosoviridescens (DeGeer)	1
Leiopus nebulosus L.	3
Monochamus saltuarius (Gebler)	2
Monochamus urussovii (Fischer)	4
Pogonocherus fasciculatus (DeGeer)	7