

# Host Volatile Attractants and Traps for Detection of *Tetropium fuscum* (F.), *Tetropium castaneum* L., and Other Longhorned Beetles (Coleoptera: Cerambycidae)

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**ABSTRACT** Cortical and sapwood volatiles were collected in situ from red spruce, *Picea rubens* (Sarg.), trees infested with *Tetropium fuscum* (F.), to determine the relative concentrations and enantiomer ratios of monoterpenes emitted. This information was used to create a synthetic “spruce blend” lure that was tested in various trap designs for efficacy in capturing *T. fuscum*, and *Tetropium castaneum* L. in field bioassays conducted on McNabs Island, Nova Scotia, in 2001 and 2002 and in Poland and Switzerland in 2002. Response of other cerambycid species was measured opportunistically. Cross-vane pan traps baited with spruce blend caught significantly more *T. fuscum* than unbaited traps or traps baited with racemic  $\alpha$ -pinene, ethanol, or both. The addition of an ethanol lure to spruce blend-baited traps significantly increased capture of *T. fuscum* and *T. castaneum*. There were no significant differences among trap designs in mean catch of either *Tetropium* species. Spruce blend was also significantly attractive to *Monochamus urussovii* (Fischer) and, when paired with an ethanol lure, was significantly attractive to *Spondylis buprestoides* L. *Asemum striatum* L. was significantly attracted to racemic  $\alpha$ -pinene but was not attracted to spruce blend or spruce blend plus ethanol. None of the lures tested were significantly attractive to *Stictoleptura rubra* L. or *Alosterna tabacicolor* (DeGeer).

**KEY WORDS** attractants, Cerambycidae, host volatiles, *Tetropium fuscum*, traps

THE BROWN SPRUCE LONGHORN beetle (BSLB), *Tetropium fuscum* (F.) (Coleoptera: Cerambycidae), is a quarantine pest recently found established near the port of Halifax, Nova Scotia, Canada (Smith and Hurley 2000). In its native Europe, the BSLB attacks weakened Norway spruce, *Picea abies* L. Karst. (Juutinen 1955), but in Nova Scotia, it is infesting and killing apparently healthy red spruce, *Picea 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). Other conifers reported to be susceptible to BSLB in Europe include *P. pungens* Engelm. (Juutinen 1953), *P. sitchensis* (Bong.) Carr. (Francke-Grosmann 1954), *Abies alba* Mill. (Schaufuss 1916), *Pinus sylvestris* L. (Reineck 1919), and occasionally, *Larix* spp. (Schaufuss 1916).

Because of the risk it poses to the health of Canada's forests and forest sector, a multi-agency task force led by the Canadian Food Inspection Agency was established; its primary goal is to eradicate the only known population of BSLB from Canada.

A successful eradication program requires accurate delimitation of the target quarantine pest organism through surveys. An attractant-baited trap capable of detecting the presence of BSLB at low densities would be an effective and efficient tool for monitoring the progress of an eradication program and for early detection of BSLB at seaports and other high-risk sites.

Unlike most Lepidoptera, few cerambycids seem to use long-range pheromones to locate mates; rather, they depend on attraction to olfactory cues from their hosts (Hanks 1999). Positive response to monoterpenes, ethanol, and other conifer volatiles has been shown for some species of cerambycids (Gardiner 1957, Ikeda et al. 1980, Phillips et al. 1988, Chénier and Philogène 1989b, Allison et al. 2001, 2003, de Groot and Nott 2001, Morewood et al. 2002a), but little is known of the BSLB's response to host volatiles. In 1990, BSLB adults (originally misidentified as the native beetle, *T. cinnamopterum* Kirby) were captured on turpentine-baited traps intended to capture bark beetles in Point

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Pleasant Park (Robertson 1990). In 2000, multiple funnel traps baited with various combinations of 5:95 (+):(-)- $\alpha$ -pinene and ethanol (at release rates of 2.2 and 1.8 g/d, respectively, at 30°C) and the aggregation pheromone of *Ips typographus* L. were not attractive to the BSLB (J. S., unpublished data).

Our objectives were to develop a host volatile-based lure and test its effect on capture of *T. fuscum* and other cerambycids in field trapping bioassays. Experiments were replicated in Europe to test the response to host volatiles of *T. fuscum* from different populations, as well as *T. castaneum* L., a species more common in Europe than *T. fuscum* (Juutinen 1955) and also on the list of quarantine pests regulated by the Canadian Food Inspection Agency (<http://www.inspection.gc.ca/english/plaveg/protect/listpespare.shtml#T>) (Anonymous 2000). We compared the relative efficacy of various trap designs and determined the effect of ethanol, alone or in combination with spruce monoterpenes, on the capture of *T. fuscum*, *T. castaneum*, and other cerambycids.

## Materials and Methods

### Study Areas

Host volatiles were collected from BSLB-infested red spruce in Point Pleasant Park, a 75-ha, mainly forested, park in Halifax, Nova Scotia (NS). Trapping experiments were conducted in four areas: (1) McNabs Island, Halifax, NS; (2) Point Pleasant Park; (3) Develier (blocks 1–10) and Mont Crosin (blocks 11–15) in the Jura mountains in Switzerland; and (4) compartments 496C (blocks 1–10) and 494C (blocks 11–15) in an old-growth forest near Białowieża, Poland. The forest on McNabs Island is dominated by *Picea glauca*, *Picea rubens*, and *Abies balsamea* L. Mill. Point Pleasant Park is dominated by *P. rubens*, *Pinus strobus* L., and *P. glauca* with *P. abies*, *Acer rubrum* L., and *Betula papyrifera* Marsh. also present. In Switzerland, the most common trees species at Develier were *P. abies*, *A. alba*, *Pinus sylvestris*, *Fagus sylvatica* L., *Acer pseudoplatanus* L., and *Crataegus monogyna* Jacq. The site at Mont Crosin was dominated by *P. abies* and *A. alba*. In the Białowieża forest, compartment 494C was dominated by old-growth *P. sylvestris* and *P. abies*, with *Betula pendula* Roth less common; compartment 496C was mixed deciduous forest, with *P. abies*, *Quercus robur* L., *Carpinus betulus* L., *P. sylvestris*, *Populus tremula* L., and *B. pendula* as the most common species.

### Spruce Volatiles

Live hosts infested with *T. fuscum* remain attractive to the beetle and may be reinfested for 4–5 consecutive yr before they completely wither and die (Juutinen 1955). Thus, live, *T. fuscum*-infested red spruce trees were selected as suitable attractive hosts from which to sample cortical volatiles. Samples were collected 23–24 May 2001, corresponding with the beginning of *T. fuscum* adult activity (May–August) (Juutinen 1955). Volatiles were sampled from 14

spruce trees with signs of *T. fuscum* infestation in Point Pleasant Park using Solid Phase Micro Extraction (SPME; Supelco, Bellefonte, PA) as follows. A cork borer was used to remove a 1.5-cm-diameter section of bark and phloem from each sample tree at about breast height and at a random cardinal direction. A 125-ml Teflon separatory funnel was placed over the freshly exposed sapwood and phloem and held in place with a 10 by 10-cm collar of "Rug Gripper" (a peel and stick plastic sheet product; MANCO, Avon, OH) and thumbtacks. A 100- $\mu$ m polydimethylsiloxane fiber, held within a syringe, was inserted through a small hole in the capped end of the separatory funnel. The fiber was exposed to volatiles for 2–3 h, sealed, and kept refrigerated until analysis by gas chromatography (GC)-mass spectrometry. Volatile components were desorbed from the SPME fibers in the GC injection port (on-column; 0.53- $\mu$ m retention gap) at 250°C onto an Rt- $\beta$ DEXsm chiral separation column (30 m by 0.32 mm i.d. by 0.25  $\mu$ m df; Restek Corp., Bellefonte, PA). The column temperature program used was 60–200°C at 4°C/min, with an initial hold of 1 min. Retention times were compared with available standards and electron ionization mass spectra searched against Wiley and National Institute of Science and Technology (NIST) libraries. The mean relative concentrations of the most prevalent and commercially available monoterpenes were used to create a synthetic "spruce blend" attractant.

### Trapping Experiments

**Effect of Spruce Blend and Trap Design on Catch.** The effect of spruce blend on the capture of *T. fuscum* and *T. cinnamopterus* in different trap designs was tested on McNabs Island, NS, from 14 June to 16 August 2001 and from 14 May to 7 August 2002. Each lure consisted of a 15-ml, low-density polyethylene bottle that released spruce blend at a rate of 150 mg/d at 24°C (Phero Tech 1997). In each year, a factorial experiment was run with three trap types, either baited with two spruce blend lures ( $\approx$ 300 mg/d) or left unbaited to serve as controls, for a total of six treatments. In 2001, the trap types were (1) 12-unit multiple funnel trap (Lindgren 1983, Phero Tech 1997); (2) Intercept panel trap (IPM Technologies, Portland, OR); and (3) cross-vane pan trap (de Groot and Nott 2001). In 2002, the funnel trap was replaced with IPM-Intercept panel traps that had been coated with Rain-X (Pennzoil-Quaker State, Burlington, Ontario, Canada). Rain-X is a commercial product normally used on automobile windshields that has been applied to plastic trap surfaces to reduce friction and increase beetle capture rates (de Groot and Nott 2003). This experiment was also replicated in Switzerland from 25 May to 30 July 2002 to test the effect of spruce blend and trap design on the capture of *T. fuscum* and *T. castaneum*.

**Effect of Spruce Blend, Racemic  $\alpha$ -Pinene, and Ethanol on Catch.** We compared mean catch of *T. fuscum* and other cerambycids in traps baited with one of six different treatments: (1) spruce blend; (2) racemic

$\alpha$ -pinene; (3) spruce blend + ethanol; (4) racemic  $\alpha$ -pinene + ethanol; (5) ethanol; and (6) unbaited. This experiment was conducted: in Point Pleasant Park, NS, from 20 June to 15 August 2001; on McNabs Island, NS, from 16 May to 8 August 2002; and in Białowieża, Poland, from 27 May to 8 July 2002. Multiple funnel traps were used in 2001, and cross-vane pan traps were used in 2002. Ethanol was dispensed from commercial lures (Phero Tech 1997) at a release rate of 40–60 mg/d (at 20°C) per trap. Spruce blend was released at  $\approx$ 300 mg/d per trap (two lures). The release rate of  $\alpha$ -pinene differed between years. In 2001, we placed two  $\alpha$ -pinene lures per trap; therefore, its release rate was equivalent to that of total monoterpenes released from two spruce blend lures. In 2002, we placed only one  $\alpha$ -pinene lure per trap; therefore, its release rate was approximately the same as that for the  $\alpha$ -pinene component released from two spruce blend lures.

All field-trapping experiments were replicated in randomized complete block designs with 25–30 m between traps within blocks and 50–100 m between blocks. There were 10 replicates/treatment in 2001 and 15 replicates/treatment in 2002. All traps had a 1% solution of dish detergent in water in the collecting pan or bucket. Lures were replaced every 4 wk. Traps were checked weekly, and all beetle specimens were preserved in 70% ethanol. Identifications of *Tetropium* species and other cerambycids (collected at these sites) were made or confirmed by J. M. Gutowski (Poland), C. Cocquemot (Switzerland), S. Laplante (Halifax), and G. Smith (Halifax). Voucher specimens have been retained at the Atlantic Forestry Centre (Fredericton, Canada) and the Forest Research Institute (Białowieża, Poland).

### Data Analysis

Total season's catch per trap of *T. fuscum* and other cerambycid species for which >30 beetles were captured per location and experiment were transformed by square root and subjected to analysis of variance (ANOVA). When main effects were significant and interactions were not significant, means were compared using the Ryan-Einot-Gabriel-Welsh (REGW) range test with an experiment-wise type I error rate of 5% in SAS-GLM (SAS Institute 2001). Loss of data because of trap disturbance happened infrequently in both years. However, if a trap was found vandalized on a weekly check, we deleted that week's catch data from the season totals for all treatments in the affected block.

## Results

### Spruce Volatiles

Monoterpenes and sesquiterpenes (plus some oxygenated monoterpenes) constituted a mean of 34 and 66% by volume, respectively, of volatiles collected in situ from red spruce cortex. The most common monoterpenes were 40:60 (+):(-)- $\alpha$ -pinene, (-)- $\beta$ -pinene,

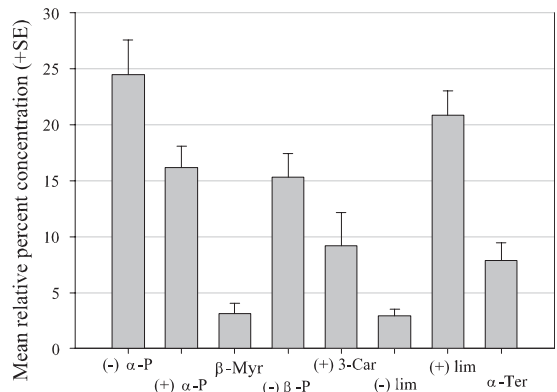


Fig. 1. Mean relative percentage concentration of monoterpenes in cortical volatiles of *T. fuscum*-infested red spruce sampled in situ in May 2001 ( $n = 14$ ). (-)  $\alpha$ -P, (-)  $\alpha$ -pinene; (+)  $\alpha$ -P, (+)- $\alpha$ -pinene; (-)  $\beta$ -P, (-)- $\beta$ -pinene;  $\beta$ -Myr,  $\beta$ -myrcene; (+) 3-Car, (+)-3-carene; (-) lim, (-)-limonene; (+) lim, (+)-limonene;  $\alpha$ -Ter,  $\alpha$ -terpinolene.

(+)-3-carene, (+)-limonene, and  $\alpha$ -terpinolene (Fig. 1). The identity of many of the sesquiterpenes could not be confirmed because we lacked standards for retention time comparisons. Sesquiterpenes that could be identified positively were (-)-*trans*-caryophyllene,  $\alpha$ -humulene, (-)- $\alpha$ -cubebene, and (+)-longifolene (junipene), but their presence was much less consistent than the monoterpenes. Five of the trees released significant amounts of sesquiterpenes, five a mixture of sesquiterpenes and oxygenated monoterpenes, and the remaining four released mostly oxygenated monoterpenes. For these reasons, we did not include sesquiterpenes in our synthetic lure. The spruce blend attractant was made by combining the five most prevalent, commercially available terpenes in similar relative concentrations, except that racemic  $\alpha$ -pinene [49.4:50.6 (+):(-)] was used instead of an exact 40:60 (+):(-) blend of optical isomers, primarily because of lower cost.

### Trapping Experiments

**Effect of Spruce Blend and Trap Design on Catch.** The spruce blend was attractive to *T. fuscum* on McNabs Island in 2001 ( $F = 61.6$ ;  $df = 1,45$ ;  $P < 0.0001$ ; Fig. 2a) and 2002 ( $F = 44.0$ ;  $df = 1,70$ ;  $P < 0.0001$ ; Fig. 2b) and to *T. castaneum* in Switzerland ( $F = 5.7$ ;  $df = 1,70$ ;  $P = 0.02$ ; Fig. 2d). Too few *T. cinnamopteron* were trapped (11 in total) to warrant statistical analysis, but all were caught in spruce blend-baited traps (Fig. 2c). Only one *T. fuscum* was captured in Switzerland. There was no significant effect of trap design (2001:  $F = 0.89$ ;  $df = 2,45$ ;  $P = 0.42$ ; 2002:  $F = 1.05$ ;  $df = 2,70$ ;  $P = 0.35$ ) or trap  $\times$  lure interaction (2001:  $F = 0.89$ ;  $df = 2,45$ ;  $P = 0.42$ ; 2002:  $F = 1.15$ ;  $df = 2,70$ ;  $P = 0.32$ ) on trap catch. Blocks had no significant effect on catch of *T. fuscum* in 2001 ( $F = 1.90$ ;  $df = 9,45$ ;  $P = 0.08$ ) and 2002 ( $F = 1.01$ ;  $df = 14,70$ ;  $P = 0.47$ ) or *T. castaneum* ( $F = 1.62$ ;  $df = 14,70$ ;  $P = 0.09$ ).

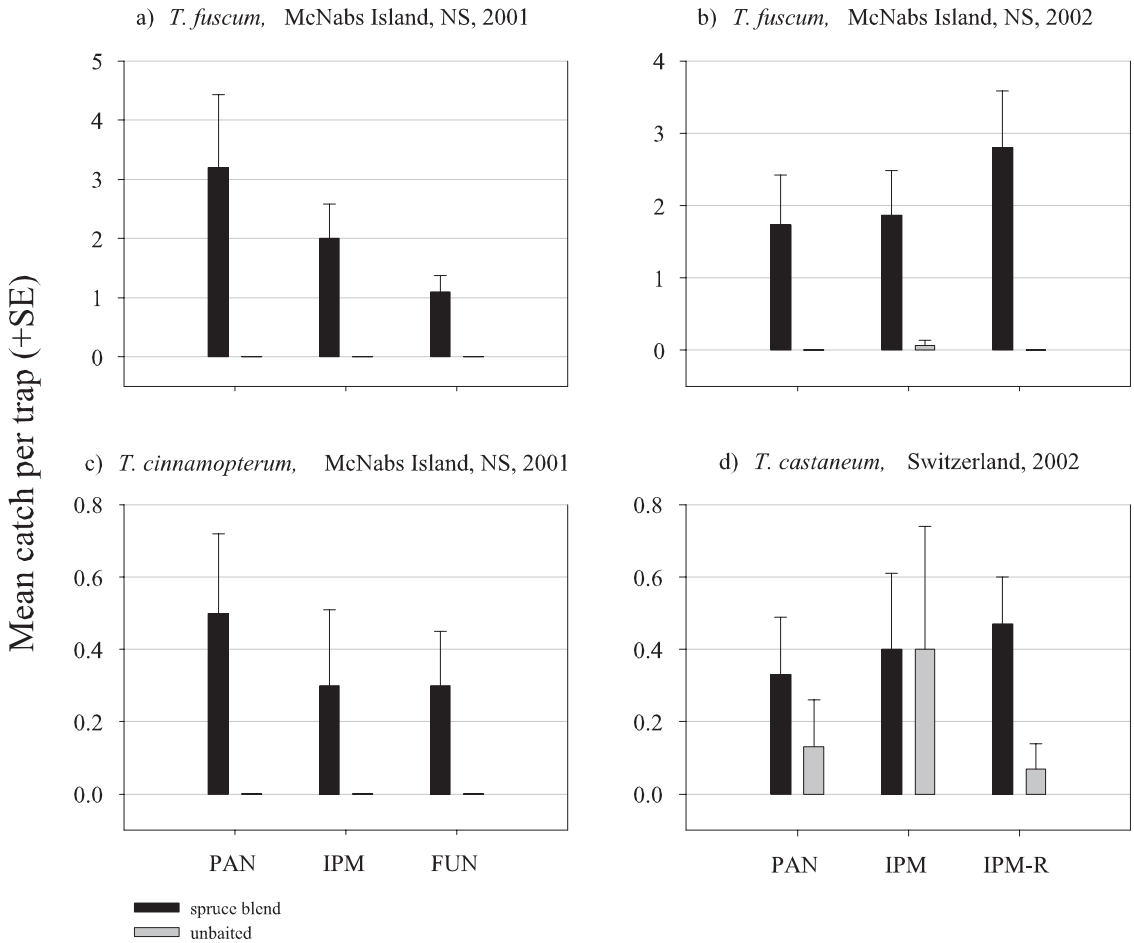


Fig. 2. Mean catch per trap ( $\pm$ SE) in cross-vane pan traps (PAN), IPM Intercept traps (IPM), IPM traps coated with Rain-X (IPM-R), and multiple funnel traps (FUN), either baited with spruce blend or unbaited on McNabs Island, NS (a,b,c) and in Switzerland (d). a) *T. fuscum*, 2001; b) *T. fuscum*, 2002; c) *T. cinnamopterus*, 2001; d) *T. castaneum*, 2002. Mean catch of *T. fuscum* and *T. castaneum* differed significantly between baited and unbaited traps but not among trap types (ANOVA,  $P < 0.05$ ; analyses performed on data transformed by square root). Data for *T. cinnamopterus* (c) were not analyzed because of low total catch.

**Effect of Spruce Blend, Racemic  $\alpha$ -Pinene, and Ethanol on Catch.** The effect of lure type on mean catch was significant for *T. fuscum* on McNabs Island ( $F = 40.8$ ;  $df = 5,70$ ;  $P < 0.0001$ ) and Poland ( $F = 11.4$ ;  $df = 5,70$ ;  $P < 0.0001$ ) and for *T. castaneum* ( $F = 8.0$ ;  $df = 5,70$ ;  $P < 0.0001$ ). Too few *T. fuscum* (seven) were caught in multiple funnel traps in 2001 (Fig. 3a) for meaningful analysis. The addition of an ethanol lure to traps baited with spruce blend increased capture of both *T. fuscum* (Fig. 3b and c) and *T. castaneum* (Fig. 3d) compared with traps baited with spruce blend alone. Ethanol and  $\alpha$ -pinene, alone or combined, were not significantly attractive to either *T. fuscum* (Fig. 3b and c) or *T. castaneum* (Fig. 3d). Traps baited with spruce blend alone captured significantly more *T. fuscum* than unbaited control traps on McNabs Island (Fig. 3c), but not in Poland (Fig. 3b). In contrast to results in Switzerland, the spruce blend alone was not significantly attractive to *T. castaneum* in Poland (Fig.

3d). Blocks had no significant effect on catch of *T. fuscum* (McNabs Island:  $F = 0.80$ ;  $df = 14,70$ ;  $P = 0.67$ ; Poland:  $F = 0.89$ ;  $df = 14,70$ ;  $P = 0.57$ ) or *T. castaneum* ( $F = 0.91$ ;  $df = 14,70$ ;  $P = 0.56$ ).

#### Capture of Other Cerambycid Species

The total number of cerambycid species, including *Tetropium* spp., captured in Nova Scotia, Switzerland, and Poland, was 33, 14, and 31, respectively (Appendix 1, 2). Of these, only five species were captured in large enough numbers ( $>30$ ) in a given experiment to warrant statistical analysis: *Asemum striatum* L., *Spondylis buprestoides* L., *Monochamus urussovii* (Fischer), *Alosterna tabacicolor* (DeGeer), and *Stictoleptura rubra* L. The type of lure significantly affected mean catch of *A. striatum* ( $F = 15.0$ ;  $df = 5,45$ ;  $P < 0.0001$ ), *S. buprestoides* ( $F = 5.81$ ;  $df = 5,20$ ;  $P = 0.002$ ), and *M. urussovii* (Fischer) ( $F = 3.47$ ,  $df = 5,70$ ;  $P = 0.007$ ; Fig. 4a–c). Racemic

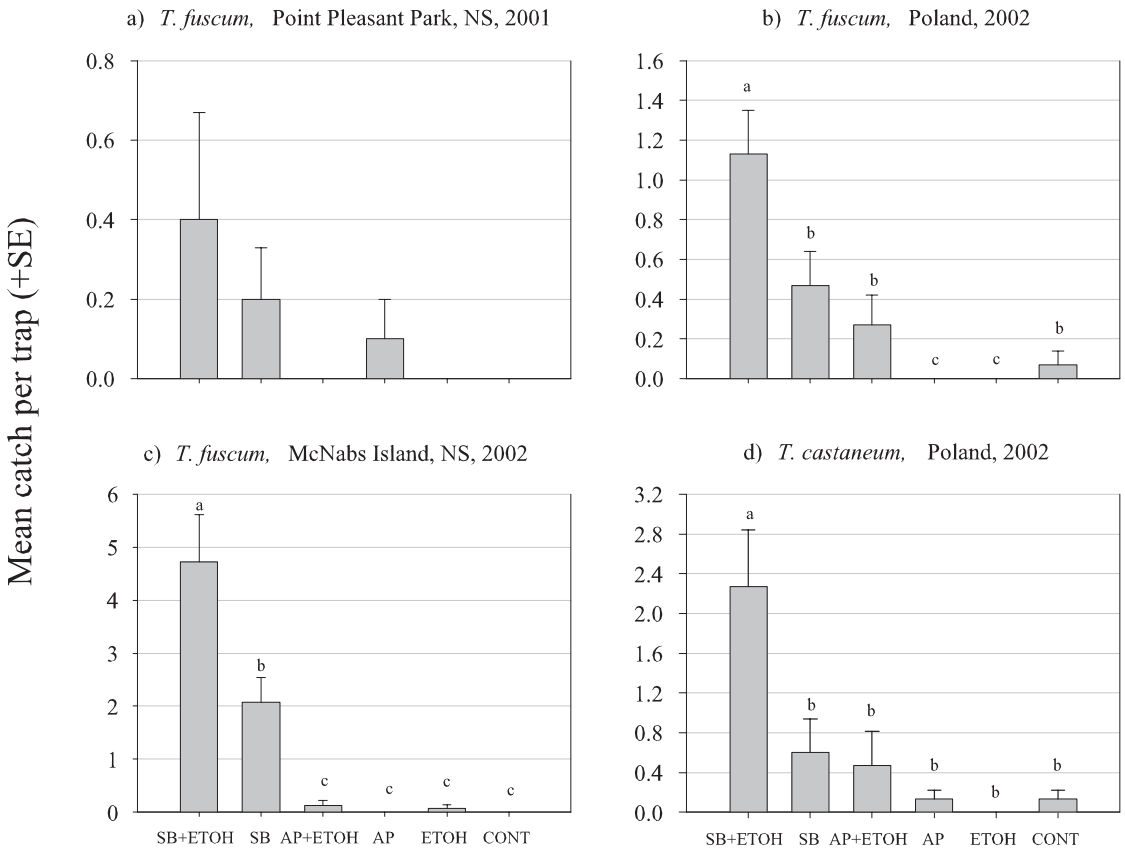


Fig. 3. Mean catch per trap ( $\pm$ SE) in traps baited with combinations of host volatile lures (SB, two spruce blend lures; ETOH, one ethanol lure; AP, one  $\alpha$ -pinene lure; CONT, unbaited) of: a) *T. fuscum* in Point Pleasant Park, NS, 2001; b) *T. fuscum* in Poland, 2002; c) *T. fuscum* on McNabs Island, NS, 2002; d) *T. castaneum* in Poland, 2002. Multiple funnel traps were used in 2001, and cross-vane pan traps were used in 2002. Within each graph, means with different letters were significantly different (ANOVA and REGW means comparison,  $P < 0.05$ ; analyses performed on data transformed by square root). Data for *T. fuscum* catch in Point Pleasant Park in 2001 (a) were not analyzed because of low overall catch.

$\alpha$ -pinene, with or without the addition of ethanol, was significantly attractive to *A. striatum*, but the spruce blend was not (Fig. 4a). Response of *S. buprestoides* was similar to *Tetropium* spp., with mean catch greatest in traps baited with spruce blend plus ethanol (Fig. 4b). *M. urussovii* was significantly attracted to spruce blend, but the addition of ethanol had no effect (Fig. 4c). By itself, ethanol was not attractive to any of the cerambycid species. None of the lures differed significantly from unbaited controls in trap catch of *A. tabacicolor* (Fig. 4d;  $F = 1.02$ ;  $df = 5,70$ ;  $P = 0.41$ ). Mean catch of *S. rubra* was not significantly affected by trap type ( $F = 0.35$ ;  $df = 2,45$ ;  $P = 0.71$ ) or lure ( $F = 0.69$ ;  $df = 1,45$ ;  $P = 0.41$ ). Block effects were significant for the catch of *A. tabacicolor* ( $F = 2.50$ ;  $df = 14,70$ ;  $P = 0.006$ ), *A. striatum* ( $F = 4.38$ ;  $df = 9,45$ ;  $P = 0.0004$ ), and *S. rubra* ( $F = 2.43$ ;  $df = 9,45$ ;  $P = 0.024$ ), but were insignificant ( $F = 0.78$ ;  $df = 14,70$ ;  $P = 0.68$ ) for the catch of *M. urussovii*. *S. buprestoides* was captured only in the old-growth blocks (11–15) at Bi-  
ałowicza, Poland.

## Discussion

*Tetropium fuscum* was significantly attracted to “spruce blend,” a synthetic blend of monoterpenes designed to simulate the relative concentrations of the main monoterpenes emitted from the cortex/sapwood of live *T. fuscum*-infested red spruce. Spruce blend was significantly more attractive to *T. fuscum* than racemic  $\alpha$ -pinene, suggesting that other monoterpenes, such as (-)- $\beta$ -pinene and (+)-3-carene, either alone or together with  $\alpha$ -pinene, play a role in host recognition by *T. fuscum*. Byers et al. (1985) showed that a three-component blend of (+)- $\alpha$ -pinene, (+)-3-carene, and terpinolene was as attractive to *Tomicus piniperda* L. as host logs, whereas single components were not. Similarly, Lindelöw et al. (1993) found that the scolytid beetles, *Hylastes cunicularius* Erichson, *H. brunneus* Erichson, and *Hylobius abietis* L., were attracted to spruce turpentine (composed mainly of  $\alpha$ -pinene,  $\beta$ -pinene, and 3-carene), but not to  $\alpha$ -pinene alone.

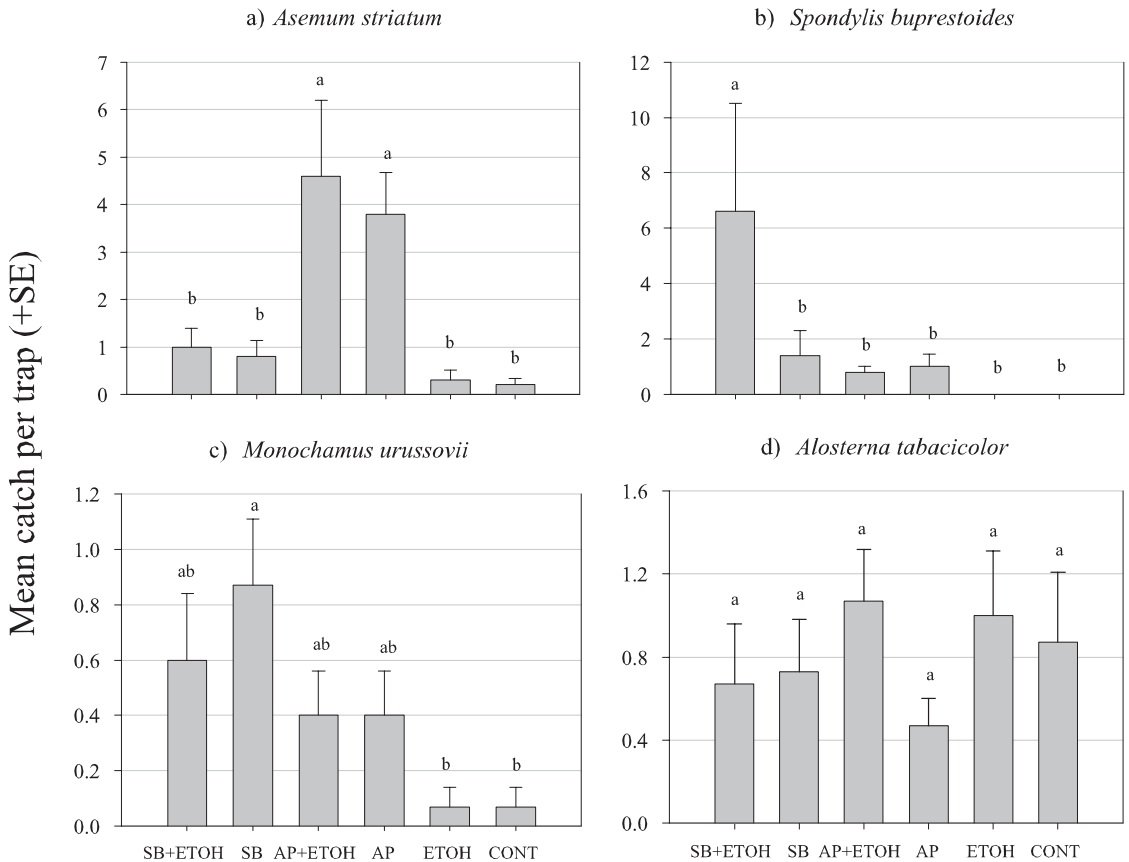


Fig. 4. Mean catch per trap ( $\pm$ SE) of cerambycid species in traps baited with combinations of host volatile lures (SB, two spruce blend lures; ETOH, one ethanol lure; AP, one  $\alpha$ -pinene lure; CONT, unbaited) in multiple funnel traps, Point Pleasant Park, 2001 (a) and in cross-vane pan traps, Białowieża, Poland, in 2002 (b–d). (a) *Asemum striatum* L.; (b) *Spondylis buprestoides* L.; (c) *Monochamus urussovii* (Fischer); and (d) *Alosterna tabacicolor* (DeGeer). Within each graph, means with different letters were significantly different (ANOVA and REGW means comparison,  $P < 0.05$ ; analyses performed on data transformed by square root).

Conifers emit a variety of monoterpenes and sesquiterpenes, and their relative concentrations vary with the tissue sampled (Persson et al. 1993, Latta et al. 2000), time of season (Wallin and Raffa 1999), time of day (Peñuelas and Llusià 1999), temperature (Peñuelas and Llusià 1999), fungal infections (Klepzig et al. 1991), and exposure to drought stress (Hodges and Lorio 1975), pollutants (Kimmerer and Kozłowski 1982), defoliators (Wallin and Raffa 1999), and other factors. Changes in amounts and proportions of terpenes are associated with the formation of traumatic resin ducts in the cambium zone of conifers responding to attack by stem borers and microbial pathogens (Alfaro 1995, Seybold et al. 2000, Alfaro et al. 2002, Fäldt et al. 2003). Lieutier et al. (1989) observed large increases in total concentration of phloem monoterpenes in *P. pinaster* Aiton and *P. sylvestris* inoculated with *T. piniperda* and the associated fungus *Lep-tographium wingfieldii* Morelet, but found no qualitative differences in monoterpene composition between induced and preformed resin. Both *T. fuscum* and *T. castaneum* infest freshly felled or live spruce trees

(*Picea* spp.) that have usually been weakened by fungal infection, insect infestation, or abiotic factors, such as lightning or drought (Juutinen 1955), and likely respond to volatile composition and increased volatile concentrations associated with such trees when searching for hosts.

Neither *T. fuscum* nor *T. castaneum* were attracted to racemic  $\alpha$ -pinene or ethanol, released at rates of  $\approx 150$  and  $50$  mg/d, respectively. Even the combination of  $\alpha$ -pinene plus ethanol, found to be highly attractive to the cerambycid *Xylotrechus longitarsis* Casey (Morewood et al. 2002a) and many scolytids such as *Hylobius abietis* (Tilles et al. 1986) and *Hy-lurgops palliatus* (Gyllenhal) (Schroeder 1988), was not attractive to either *Tetropium* species. Our results contrast with those of Weslien and Schroeder (1999), who captured significantly more *T. castaneum* in traps baited with a combination of 3:97 (+):(-)- $\alpha$ -pinene and ethanol than in unbaited traps. However, many things may have accounted for the different results: Weslien and Schroeder (1999) used 3:97 (+):(-)- $\alpha$ -pinene and ethanol at release rates of  $\approx 50$  and 2,000

mg/d, respectively, compared with our use of racemic  $\alpha$ -pinene and ethanol at release rates of  $\approx 150$  and 50 mg/d, respectively. Also, Weslien and Schroeder (1999) suspended both baited and unbaited traps beside an *I. typographus*-infested spruce bolt, so attraction may have been because of the combination of  $\alpha$ -pinene and ethanol with other spruce volatiles, *I. typographus* pheromones, or both. Kairomonal response to *Ips* aggregation pheromones, in combination with  $\alpha$ -pinene and ethanol, has been shown for *Monochamus clamator* (LeConte) and *M. scutellatus scutellatus* (Say) (Allison et al. 2003). McIntosh et al. (2001) trapped an average of  $\approx 12$  *Tetropium* spp./trap in Alberta in cross-vane traps (similar to the traps that we used) baited with 5:95 (+):(-)- $\alpha$ -pinene and ethanol lures with release rates of  $\approx 2.2$  and 1.8 g/d (determined at 30°C), respectively, but, unfortunately, did not include unbaited controls for comparison of attraction.

The addition of an ethanol lure to traps baited with spruce blend lures synergized attraction of both *T. fuscum* and *T. castaneum*. Ethanol is an attractant for ambrosia beetles (Moeck 1970, Liu and McLean 1989, Salom and McLean 1990, Byers 1992), as well as some species of clerid (Schroeder 2003) and cerambycid beetles (Montgomery and Wargo 1983) and other bark- and wood-boring beetles (Lindelöw et al. 1993). However, by itself, ethanol was not attractive to any cerambycid species in our trapping experiments. Ethanol synergizes attraction of many species of bark- and wood-boring beetles when released in combination with host monoterpenes (Ikeda et al. 1980, Fatzinger 1985, Tilles et al. 1986, Vité et al. 1986, Phillips et al. 1988, Schroeder 1988, Schroeder and Lindelöw 1989, Klepzig et al. 1991, Lindelöw et al. 1993, Joseph et al. 2001, Morewood et al. 2002a). Conversely, high release rates of ethanol have been shown to decrease attraction to monoterpenes of some species, e.g., *T. piniperda* (Schroeder 1988). Ethanol is produced in small amounts in the cambium of healthy trees during periods of rapid growth (Harry and Kimmerer 1991, MacDonald and Kimmerer 1991) but is usually found in higher concentrations in the bark and sapwood of diseased trees (Gara et al. 1993), stressed conifers (Kimmerer and Kozlowski 1982), stumps (Kelsey and Joseph 1999), and logs (Kelsey 1994). Because ethanol production is increased in many woody plants as a result of stress (Kimmerer and Kozlowski 1982), it is not surprising that it boosted attraction of *T. fuscum* and *T. castaneum*, species that tend to favor stressed, less vigorous trees (Juutinen 1955, O'Leary et al. 2003).

We did not fully characterize the array of sesquiterpenes emitted from the cortex/sapwood of red spruce because the identity of many components could not be confirmed, and their relative concentration varied greatly from tree to tree. However, we acknowledge that some of these sesquiterpenes may be behaviorally active and should perhaps be investigated for their potential role as kairomones for *T. fuscum* and other wood-boring species. Longifolene, emitted by some of the red spruce we sampled, was the

second most dominant sesquiterpene in turpentine extracted from *P. sylvestris* (Kula et al. 1996), whereas carophyllene was one of the most abundant sesquiterpenes emitted by Mediterranean *Pinus* and *Quercus* species (Llusià and Peñuelas 1998). Strong response to certain sesquiterpenes has been measured in olfactory receptor neurons of the pine weevil, *Hylobius abietis* L. (Wibe et al. 1997). Very little is known about the response of longhorned beetles to sesquiterpenes, but Sakai and Yamasaki (1990) reported that a particular ratio of a sesquiterpene, (+)-juniperol, and a diterpene, (+)-pimaral, induced flight response and attraction of *Monochamus alternatus* Hope in the laboratory.

Response to the volatile lures varied among the other cerambycid species. Some species were attracted to volatiles reported to be associated with their preferred hosts or host condition, whereas others were not. *Tetropium cinnamopterum* infests wind-felled and freshly cut logs (Drooz 1985), which are known to produce ethanol (Kelsey 1994), and was very common in red spruce bait logs on McNabs Island in 2001, along with *T. fuscum* (J. S., unpublished data). However, very few specimens of *T. cinnamopterum* were captured in traps baited with spruce blend or spruce blend plus ethanol. Trap catch is only an index of attraction, because trapping efficacy may vary among species, but it should still provide a reliable relative measure of attraction to different volatiles within a species and among species of similar size, flight ability, and response to visual stimuli. All of our traps mimicked the shape and silhouette of a tree trunk, a factor that has been suggested as an important close-range host-finding cue for many species of bark- and wood-boring species (Tilden et al. 1983, Chénier and Philogène 1989a, Wyatt et al. 1997, de Groot and Nott 2001, Morewood et al. 2002b). Gardiner (1957) observed that *T. cinnamopterum* was attracted in much larger numbers to smoke (from burning pine chips and coniferous foliage) than to turpentine baits. The results suggest that our lure treatments did not simulate the volatiles emitted from freshly felled spruce, or at least not the particular compounds or relative concentrations of volatiles that *T. cinnamopterum* responds to when searching for hosts. Results for *A. striatum* were similar to those reported by Chénier and Philogène (1989b):  $\alpha$ -pinene was significantly attractive, but the addition of other monoterpenes or ethanol had little effect. *S. buprestoides*, however, did not respond to  $\alpha$ -pinene or spruce blend alone but was attracted to a combination of spruce blend and ethanol. This contrasts with results of Ikeda et al. (1980), who found that *S. buprestoides* was attracted to a monoterpene blend, with or without ethanol. Racemic  $\alpha$ -pinene was as attractive as the spruce blend to *M. urussovii*, but only spruce blend-baited traps differed significantly from unbaited controls in mean catch; the addition of ethanol to either  $\alpha$ -pinene or spruce blend did not increase attraction. Response of other *Monochamus* spp. to monoterpenes and ethanol varies: ethanol did not increase the attraction of *M. carolinensis* (Olivier) to turpentine (Phillips et al. 1988) but

significantly increased attraction of *M. alternatus* (Ikeda et al. 1980), *M. scutellatus scutellatus* (Say) (Chénier and Philogène 1989b), and *M. titillator* (F.) (Phillips et al. 1988) to monoterpenes. Neither *S. rubra* nor *A. tabacicolor* were attracted to spruce blend or combinations of monoterpenes and ethanol.

All of the cerambycid species that we trapped in relatively large numbers infest conifers of varying condition, from live weakened trees (e.g., *T. fuscum*, *M. urussovii*) to fresh stumps (e.g., *A. striatum*, *S. buprestoides*) to old, decayed stumps and logs (e.g., *S. rubra*) (Cherepanov 1988, Sama 2002). *A. striatum* is a holarctic species that infests stumps and the basal portion of recently dead or dying conifers, including *Abies*, *Larix*, *Picea*, *Pinus*, and *Pseudotsuga menziesii* (Mirb.) (Furniss and Carolin 1977, Hayes and Tickell 1984, Drooz 1985, Cherepanov 1988, Sama 2002). Fresh pine stumps also serve as hosts for *S. buprestoides* (Jakaitis and Valenta 1976) and *T. castaneum* (Sama 2002), and in Asia, both species may colonize the same host along with *A. striatum* (Cherepanov 1988). *M. urussovii* breeds in dying, recently cut, or windfelled *Abies*, *Pinus*, and other trees (Isaev et al. 1988), and vectors a blue-stain fungus, *Leptographium sibiricum* (Jacobs et al. 2000). It is somewhat surprising that ethanol did not synergize attraction of *A. striatum* or *M. urussovii* to monoterpenes, because both species breed in hosts (e.g., stumps or weakened trees) that reportedly have elevated ethanol concentrations. However, ethanol concentrations were much lower in the roots compared with the above-ground portion of pine stumps (Kelsey and Joseph 1999), and *A. striatum* was found to be more abundant below than above the soil in *P. sylvestris* stumps (Hayes and Tickell 1984). *M. urussovii* feeds as an adult on the bark of young, growing shoots in the crowns of *Abies sibirica* Ldb. (Isaev et al. 1988) and *P. abies* (Gutowski 1995), which likely emit relatively little ethanol (Kelsey 2001). We tested only one release rate of ethanol. The quantities of ethanol produced by logs and stumps vary greatly and are strongly influenced by tree species and surrounding environmental conditions (Kelsey 2001). It is possible that the relative concentrations of ethanol to monoterpenes in our experiments did not simulate hosts preferred by *A. striatum* or *M. urussovii* or simply that neither species responds to ethanol when searching for hosts. Lack of attraction of *S. rubra* and *A. tabacicolor* to our monoterpene lures is not surprising because both species breed in hosts that likely emit lower monoterpene concentrations than stressed or freshly felled conifers. *S. rubra* breeds in long dead, decaying conifers (Sama 2002) and *A. tabacicolor* breeds in the bark and wood of dead, decaying portions of living broadleaf trees (Gutowski 1986).

None of the three trap designs tested caught significantly more *Tetropium* spp. than the others. McIntosh et al. (2001) trapped significantly fewer numbers of *Tetropium* spp. and two other cerambycid species in multiple funnel traps than in cross-vane pan traps. Fewer cerambycids were trapped in multiple funnel traps than in sticky stove pipe traps (Chénier and Philogène 1989a) or cross-vane traps (Morewood et al.

2002b); in both cases, the authors attributed the difference to the funnel column's weaker visual stimulus because of its less regular or narrower vertical silhouette.

We recommend that surveys for *T. fuscum* and *T. castaneum* use traps baited with spruce blend plus ethanol lures because this will significantly increase the probability of detecting *T. fuscum* where it is present compared with baiting with spruce blend alone. Either the cross-vane pan trap or the IPM Intercept trap would be suitable designs for *Tetropium* trapping surveys. Future research will test whether mean catch of *T. fuscum* is increased with high release rate lures of spruce blend and ethanol and will test the correlation between mean catch and population levels of *T. fuscum*.

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**Appendix 1. List of Cerambycidae captured in host volatile-baited traps in Point Pleasant Park and McNabs Island, Halifax, Nova Scotia, in 2001 and 2002**

Subfamily and species	Number of specimens
<b>Spondylidinae</b>	
<i>Arhopalus foveicollis</i> (Haldeman)	1
<i>Asemum striatum</i> L.	162
<i>Tetropium fuscum</i> (F.)	274
<i>Tetropium cinnamopterum</i> Kirby	33
<i>Tetropium schwarzi</i> Casey	1
<b>Cerambycinae</b>	
<i>Microclytus compressicollis</i> (Lap. de Cast.l & Gory)	4
<i>Phymatodes dimidiatus</i> (Kirby)	11
<i>Pronocera collaris collaris</i> (Kirby)	1
<i>Xylotrechus colonus</i> (F.)	1
<i>Xylotrechus undulatus</i> (Say)	34
<b>Lepturinae</b>	
<i>Acmaeops proteus proteus</i> (Kirby)	11
<i>Anastrangalia sanguinea</i> (LeConte)	8
<i>Anthophylax attenuatus</i> (Haldeman)	69
<i>Anthophylax viridis</i> LeConte	6
<i>Brachyleptura champlaini</i> Casey	1
<i>Evodinus monticola monticola</i> (Randall)	25
<i>Judolia m. montivagans</i> (Couper)	1
<i>Leptura subhamata</i> Randall	5
<i>Lepturoopsis biforis</i> (Newman)	1
<i>Pidonia ruficollis</i> (Say)	8
<i>Pygoleptura nigrella nigrella</i> (Say)	2
<i>Rhagium inquisitor</i> L.	17
<i>Sachalinobia rugipennis rugipennis</i> (Newman)	1
<i>Stictoleptura canadensis canadensis</i> (Olivier)	40
<i>Strangalepta abbreviata</i> (Gemar)	46
<i>Strophiona nitens</i> (Forster)	1
<i>Trachysida aspera brevifrons</i> (Howden)	14
<i>Trachysida mutabilis</i> (Newman)	1
<b>Lamiinae</b>	
<i>Acanthocinus pusillus</i> Kirby	2
<i>Monochamus notatus</i> (Drury)	6
<i>Monochamus scutellatus scutellatus</i> (Say)	17
<i>Pogonocherus penicillatus</i> LeConte	21
<i>Urographis fasciatus</i> (DeGeer)	1

**Appendix 2. List of Cerambycidae captured in host volatile-baited traps in Develier and Mont Crosin, Switzerland (S), and near Bialowieza, Poland (P), in 2002**

Subfamily and species	Location	Number of specimens
<b>Spondylidinae</b>		
<i>Arhopalus rusticus</i> L.	P	1
<i>Spondylis buprestoides</i> L.	P	56
<i>Tetropium castaneum</i> L.	P/S	55/27
<i>Tetropium fuscum</i> (F.)	P/S	30/1
<b>Cerambycinae</b>		
<i>Callidium coriaceum</i> (Paykull)	P	1
<i>Clytus lama</i> Mulsant	S	1
<i>Molorchus minor</i> L.	P/S	1/1
<i>Obrium brunneum</i> (F.)	P	1
<i>Phymatodes testaceus</i> L.	P	1
<b>Lepturinae</b>		
<i>Acmaeops septentrionis</i> (Thomson)	P	1
<i>Alosterna tabacicolor</i> (DeGeer)	P/S	77/2
<i>Anastrangalia dubia</i> (Scopoli)	S	4
<i>Anastrangalia reji</i> (Heyden)	P	1
<i>Anastrangalia sanguinolenta</i> L.	P	1
<i>Anoplodera sexguttata</i> (F.)	P	3
<i>Brachyleptura maculicornis</i> (DeGeer)	P	1
<i>Cortodera femorata</i> (F.)	P	6
<i>Dinoptera collaris</i> L.	P	5
<i>Leptura mimica</i> Bates	P	1
<i>Oxymirus cursor</i> L.	P/S	12/9
<i>Pachytodes cerambyciformis</i> (Schrank)	P	2
<i>Rhagium bifasciatum</i>	S	8
<i>Rhagium inquisitor</i> L.	P	2
<i>Rhagium mordax</i> (DeGeer)	P/S	1/2
<i>Rutpela maculata</i> Poda	P/S	1/6
<i>Stenurella melanura</i> L.	P/S	2/1
<i>Stictoleptura rubra</i> L.	S	225
<b>Lamiinae</b>		
<i>Agapanthia villosoviridescens</i> (DeGeer)	P	2
<i>Leiopus nebulosus</i> L.	P	7
<i>Monochamus saltuarius</i> (Gebler)	P	2
<i>Monochamus sutor</i> L.	P	1
<i>Monochamus urussovii</i> (Fischer)	P	56
<i>Pogonocherus decoratus</i> Fairmaire	P	1
<i>Pogonocherus fasciculatus</i> (DeGeer)	P	6
<i>Pogonocherus hispidus</i> L.	P	1