

## Efficacy of semiochemical-baited traps for detection of Scolytinae species (Coleoptera: Curculionidae) in the Russian Far East

JON D. SWEENEY<sup>1</sup>, PETER SILK<sup>1</sup>, VASILY GREBENNIKOV<sup>2</sup> and MICHAIL MANDELSHTAM<sup>3</sup>

<sup>1</sup>Natural Resources Canada, Canadian Forest Service – Atlantic Forestry Centre, PO Box 4000, Fredericton, NB, E3B 5P7, Canada; e-mails: [jon.sweeney@canada.ca](mailto:jon.sweeney@canada.ca), [peter.silk@canada.ca](mailto:peter.silk@canada.ca)

<sup>2</sup>Canadian Food Inspection Agency, Ottawa Plant Laboratory, 960 Carling Ave, K.W. Neatby Building, Ottawa, ON K1A 0Y9 Canada; e-mail: [vasily.grebennikov@inspection.gc.ca](mailto:vasily.grebennikov@inspection.gc.ca)

<sup>3</sup>Centre for Bioinformatics and Genome Research, Saint-Petersburg State Forest Technical University named after S.M. Kirov, Institutskii per. 5, 194021 Saint-Petersburg, Russia; e-mail: [michail@MM13666.spb.edu](mailto:michail@MM13666.spb.edu)

**Key words.** Coleoptera, Curculionidae, Scolytinae, semiochemicals, detection efficacy, Russian Far East

**Abstract.** Traps baited with plant volatiles and/or bark beetle pheromones have been used to survey for exotic and potentially invasive bark and wood-boring beetles in North America since the mid-1990s. Recent discoveries of sex and aggregation pheromones in the Cerambycidae offer means of improving detection rates of longhorn beetles, but little is known of their effects on detection of bark and ambrosia beetles in the subfamily Scolytinae. Our objectives were to determine the efficacy of host volatile trap lures for survey and detection of Scolytinae species and whether that efficacy was affected by the addition of longhorn beetle pheromones. More than 12,000 specimens and 36 species of Scolytinae were collected in two field trapping bioassays conducted in the Russian Far East in 2009 and 2010. The lure combination of spruce blend (a blend of racemic  $\alpha$ -pinene, (–)  $\beta$ -pinene, (+)-3-carene, (+)-limonene, and  $\alpha$ -terpinolene) and ethanol significantly increased detection rates and mean catches of *Hylastes brunneus* Erichson, *Hylastes obscurus* Chapuis, *Ips typographus* (L.), and *Dryocoetes striatus* Eggers compared with unbaited traps. The addition of the longhorn beetle pheromones, *E*-fusicumol, or *E*-fusicumol acetate, to traps baited with spruce blend and ethanol, slightly reduced mean catches of *D. striatus* but otherwise did not affect catch of any Scolytine species. Baiting traps with ethanol significantly increased mean catches of *Anisandrus apicalis* (Blandford), *Anisandrus dispar* (Fabr.), *Anisandrus maiche* (Kurenzov), *Xyleborinus attenuatus* (Blandford), *Xyleborinus saxesenii* (Ratzeburg), *Xylosandrus germanus* (Blandford), *Scolytoplatypus tycon* Blandford, and *Trypodendron lineatum* (Olivier). By themselves, the longhorn beetle pheromones, racemic hydroxyhexan-2-one and racemic hydroxyoctan-2-one, were not attractive to any Scolytine species. However, when added to ethanol-baited traps, hydroxyhexan-2-one lures significantly increased mean catch of *S. tycon*, hydroxyoctan-2-one lures significantly reduced mean catches of *A. maiche* and *X. attenuatus*, and lures of either hydroxyketone significantly reduced mean catch of *T. lineatum*. The lure treatments that detected the greatest number of species per sampling effort were spruce blend plus ethanol in 2009 (16 Scolytinae species and 13 species of Cerambycidae combined in an eight-trap sample) and hydroxyhexan-2-one plus ethanol in 2010 (20 Scolytinae species and 7 species of Cerambycidae combined in an eight-trap sample). Species accumulation curves did not reach an asymptote for any lure treatment, indicating that many species would go undetected in samples of 8–9 traps per site.

## INTRODUCTION

Species of bark and ambrosia beetles (Coleoptera: Curculionidae: Scolytinae) are readily carried in untreated solid-wood packaging used in the shipment of goods internationally and, as such, are frequently intercepted as exotic species in many countries (Haack, 2001, 2006; Brockerhoff et al., 2006). Several of these exotic bark and ambrosia beetles have become established in North America (LaBonte et al., 2005; Haack, 2006; Haack & Rabaglia, 2013), New Zealand (Brockerhoff et al., 2006), and Europe (Kirkendall & Faccoli, 2010), often outnumbering native Scolytinae in trapping surveys (Miller & Rabaglia, 2009; Gandhi et al., 2010), and some species have been particu-

larly destructive. For example, in the United States, the redbay ambrosia beetle, *Xyleborus glabratus* (Eichhoff), has killed thousands of red bay trees (Hanula et al., 2008), and the tea shot-hole borer, *Euwallacea fornicatus* Eichhoff, has been similarly destructive to avocado trees (Eskalen et al., 2012). *Xylosandrus germanus* (Blandford) is considered one of the most damaging pests of ornamental nurseries in the United States (Olivier & Mannion, 2001; Ranger et al., 2010), and the red turpentine beetle, *Dendroctonus valens* LeConte, has killed millions of *Pinus tabulaeformis* Carr. in northern China since its introduction in the early 1980s (Yan et al., 2005). Implementation of international phytosanitary measures such as ISPM 15

(FAO, IPPC 2013) that require treatment and certification of wood packaging material has reduced the percentage of shipments that contain live pests, but the sheer volume of international trade suggests that the continued introduction and establishment of new exotic bark and wood-boring insects is highly likely (Haack et al., 2014). Traps baited with host volatiles such as ethanol and  $\alpha$ -pinene, as well as pheromones of *Ips* spp., have been used for surveillance of exotic bark and wood-boring beetles in the United States and Canada for more than a decade (Rabaglia et al., 2008; Douglas et al., 2013) and have been reasonably successful at detecting exotic Scolytinae (8 among 18 exotic Scolytinae detected in survey traps between 1985 and 2005) but unsuccessful for species in the Cerambycidae or Buprestidae (0 of 7 species combined, for both families) (Haack 2006). Thus, there is room for improvement in trapping programs for surveillance and early detection of exotic bark and wood-boring beetles.

In the last decade or so, long-distance sex and aggregation pheromones have been identified in several species of longhorn beetles in the subfamilies Cerambycinae (Fettkötter et al., 1995; Allison et al., 2004; Lacey et al., 2004, 2007; Mitchell et al., 2015, Ray et al., 2015), Spondylidinae (Silk et al., 2007; Sweeney et al., 2010), Prioninae (Cervantes et al., 2006), Lamiinae (Fonseca et al., 2010, Pajares et al., 2010, 2014; Teale et al., 2011; Allison et al., 2012; Fierke et al., 2012) and Lepturinae (Ray et al., 2011, 2012), and use of racemic blends as well as pure enantiomers in traps has significantly increased the detection rate of several species of cerambycids (Hanks et al., 2007; Mitchell et al., 2011; Hanks & Miller, 2012, Hanks et al., 2012; Wong et al., 2012; Sweeney et al., 2014; Ray et al., 2015; Miller et al., 2015b). As a result, racemic blends of the cerambycinae pheromones, 3-hydroxyhexan-2-one and 3-hydroxyoctan-2-one, have been used in operational surveillance programs by the Canadian Food Inspection Agency from 2012–2014 (Troy Kimoto, pers. commun.).

Combining bark beetle pheromones and host volatiles on the same traps has synergized attraction of Scolytinae (Borden et al., 1980; Shore & Lindgren, 1996) as well as Cerambycidae (Billings, 1985; Allison et al., 2001, 2003, 2004; de Groot & Nott, 2004; Pajares et al., 2004; Ibeas et al., 2006; Costello et al., 2008; Miller et al., 2011, 2015a). Similarly, combination of longhorn beetle pheromones and host volatiles synergizes attraction of cerambycids (Nakamuta et al., 1997; Fettkötter et al., 2000; Reddy et al., 2005; Silk et al., 2007; Nehme et al., 2009; Sweeney et al., 2010, 2014; Pajares et al., 2010; Teale et al., 2011; Allison et al., 2012; Hanks et al., 2012; Macias-Samano et al., 2012; Miller et al., 2015b; Ryall et al., 2015; but see Pajares et al., 2010). In addition to increasing mean catch per trap and sensitivity of detecting several species of bark and wood-boring species, combining different pheromones and host volatiles on the same traps reduces survey costs by decreasing the number of traps required (Hanks et al., 2012; Noseworthy et al., 2012; Wong et al., 2012; Ras-sati et al., 2014). However, relatively little is known about the effects of combining longhorn beetle pheromones and

host volatiles on detection of Scolytinae. Noseworthy et al. (2012) reported that attraction of *Monarthrum scutellare* (LeConte) was synergized by the combination of racemic 3-hydroxyoctan-2-one and ethanol. Miller et al. (2015b) found that mean catches of *Hypothenemus rotundicollis* Wood & Bright and *Dryoxylon onoharaensum* (Murayama) in ethanol-baited traps increased and decreased, respectively, with the addition of racemic 3-hydroxyoctan-2-one, but that catches of other Scolytinae species were largely unaffected. Knowledge of the effects of such lure combinations on the detection of Cerambycidae and Scolytinae, whether they are positive, negative, or neutral, is necessary to optimize surveillance programs for exotic bark and wood-boring beetles.

The objectives of this study were to determine the relative efficacy of various combinations of host volatile and longhorn beetle pheromone lures for the survey and detection of Scolytinae species native to the Russian Far East and whether that efficacy was positively or negatively affected by the addition of longhorn beetle pheromones. This area shares similar climate and genera of trees and bark beetles with parts of northeastern China (= “Manchuria”) (Krestov, 2003) as well as northeastern North America and was therefore suitable for comparing the efficacy of lures for detecting species of Scolytinae that might be inadvertently introduced to North America. We predicted that the longhorn beetle pheromones would likely increase mean catches of some Scolytinae species, but would likely also decrease catches of other species. Data on the mean catch and rate of detection of Cerambycidae species in these experiments were reported earlier (Sweeney et al., 2014). In addition to presenting results on mean catch and detection rate of Scolytinae species, we also incorporate the data on longhorn species collected in the same site-years (Sweeney et al., 2014) to compare lure treatments for the mean combined number of Scolytinae and Cerambycidae species detected per sampling effort.

## METHODS

Two field-trapping bioassays were conducted in the Russian Far East, one from 30 May to 8 August 2009 and the other from 23 May to 21 July 2010, to compare a total of eight different semiochemical lure treatments for their efficacy in detecting species of bark and ambrosia beetles. Unbaited traps were included as controls in both years. The methods were described in Sweeney et al. (2014) and are summarized here for clarity.

### Trapping site

Both experiments were conducted in a relatively undisturbed mixed broadleaf–coniferous forest next to the properties of Sergey R. Shestakov, about 5 km south of the village of Anisimovka in Shkotovsky rayon, Primorsky Krai, Russia (43.1268°N, 132.7973°W; 450 m; Fig. 1 in Sweeney et al., 2014).

### Semiochemicals, lures, and release rates

Racemic (*E*)-fusicumol (>99% pure; GC/MS), hereafter referred to as “F”, was synthesized at the Atlantic Forestry Centre (AFC) by lithium aluminum hydride reduction of commercially available (*E*)-geranyl acetone (Aldrich Chemicals, Milwaukee, WI, USA; <0.5% *Z*-isomer), and the structure of the secondary alcohol verified by Electrospray Ionization mass spectrum, and

<sup>1</sup>H and <sup>13</sup>C Nuclear Magnetic Resonance (Silk et al., 2007). Racemic (*E*) fuscumol acetate, hereafter referred to as “FA”, was synthesized by treating racemic (*E*) fuscumol with acetic anhydride/pyridine/dimethyl aminopyridine. Release devices for F and FA were 0.2 ml thin-wall, clear, dome-capped polymerase chain reaction (PCR) sample tubes (Axygen Scientific Inc., Union City, CA, USA) containing ca. 15 mg of synthetic pheromone, with a 1 mm diam. hole drilled in the cap. Release rate of F was initially 800 µg/d, dropping to about 80 µg/d after 30 d at 23°C (determined by weight loss). The release rate of FA was not determined but assumed to be similar to that of fuscumol due to similarity in volatility. For traps baited with F or FA, we placed one lure per trap and replaced the lures after 4 weeks.

Racemic 3-hydroxyhexan-2-one and 3-hydroxyoctan-2-one (hereafter referred to as K6 and K8, respectively) were purchased commercially (Bedoukian Research Inc., Danbury, CT), verified as 99% pure by GC/MS at AFC, and loaded into release devices at Contech Inc. (Delta, BC). The release devices consisted of a piece of cellulose sponge (7.0 cm × 5.0 cm × 0.5 cm) inside a polyethylene pouch into which 1.4 g of either K6 or K8 was pipetted, and the pouch heat-sealed. The release rates, determined gravimetrically at 20°C, were 20 mg/d and 25 mg/d for K8 and K6, respectively, and these rates remained steady for more than 50 d. For traps baited with either K6 or K8, we placed two pouches per trap to obtain release rates of 40–50 mg/d and did not replace the lures.

Ultra-high release rate lures of spruce blend, also known as brown spruce longhorn beetle kairomone, hereafter referred to as “SB”, and ethanol, hereafter referred to as “E”, were purchased commercially (Contech Inc, Delta, BC). Release rates of SB (44% racemic  $\alpha$ -pinene, 19% (–)  $\beta$ -pinene, 10% (+)-3-carene, 18% (+)-limonene, and 9%  $\alpha$ -terpinolene) and E lures were about 2 g/d and 275 mg/d, respectively (Sweeney et al., 2006). Due to difficulties in shipping and receiving ethanol lures (considered dangerous goods) to Russia in 2010, we purchased empty ethanol release devices from Contech Inc. and filled them with locally purchased vodka (40% ethanol), sealing the top of the release device by folding the top of the sleeve over twice and pinching it with a strong paper clamp. This likely reduced the release rates of ethanol in 2010 to about half of that in 2009. The ethanol lures in 2010 may also have emitted trace amounts of compounds such as fusel oils, acetates, and acetic acid, as vodka often contains these impurities at concentrations ranging from 0.001 to 0.3% (Hu & Schaefer, 2010). We acknowledge that response of beetles to these lures may possibly have been affected by one or more of these trace compounds in the vodka but due to their very low concentrations relative to ethanol, we argue that any effects on beetle behavior were probably slight. For traps baited with E or SB, we placed one lure per trap and did not replace the lures.

### Experimental design

In experiment 1 (2009), we tested five lure combinations: (1) K6+E; (2) F+SB+E; (3) FA+SB+E; (4) SB+E; and (5) unbaited controls (C). In experiment 2 (2010), we tested six lure treatments: (1) E; (2) K6+E; (3) K8+E; (4) K6; (5) K8; and (6) unbaited controls (C). Our objectives were: (1) to compare the relative efficacy of each lure combination for detection of Scolytinae; (2) to determine the effects on Scolytinae detection of adding cerambycid pheromones to traps baited with plant volatiles, e.g., adding F or FA to traps baited with SB+E (experiment 1) or adding K6 or K8 to traps baited with ethanol (experiment 2).

Experiments were replicated in randomized complete block designs with eight replicates per treatment and 20–30 m spacing between traps and blocks. Black panel intercept traps (Alpha Scents, Inc., Portland OR) (Fig. 1 in Sweeney et al., 2014) were

suspended from rope tied between two trees so that the collecting cup was at least 30–60 cm above the ground and the trap was at least 1 m distant from each tree. Collecting cups were partially filled with 60% ethylene glycol in water. Traps were emptied every week for a total of 8–10 weeks, and captured insects sealed in Whirlpak bags with 96% ethanol labeled by date, lure treatment, and block, and stored at room temperature until sorting.

### Specimen identification, deposit, and taxonomy

All specimens of Scolytinae were identified to species, and pinned voucher specimens were deposited in the Canadian National Collection of Insects, Arachnids and Nematodes in Ottawa. Species’ names and classification were adopted following Knížek (2011).

### Data analysis

Because lure treatments differed between years, the data were analyzed separately for each experiment. For each species, a replicate was the total number of specimens captured per trap over the entire 8–10 week trapping period. A chi-square goodness-of-fit test was used to test whether the number of species detected differed among lure treatments. Cochran’s *Q* test for dichotomous data in randomized blocks (Zar, 1999) was used to test the null hypothesis that the proportion of traps that collected at least one specimen of that species was the same for all lure treatments ( $\alpha = 0.05$ ), i.e., a significant *Q* value indicated that lure treatments differed in efficacy of detection. Cochran’s *Q* was calculated only for species that were detected in at least four (2010 experiment) or five (2009 experiment) different trap blocks, such that the product of “a” (number of lure treatments) × “b” (number of blocks in which the species was detected in some but not all treatments) was 24 or greater (Zar, 1999). For species for which at least ten specimens were captured, data on the number of specimens per trap were first transformed by  $\log(y+1)$  and then subjected to ANOVA using the model: catch = block + lure treatment + error, using SAS PROC GLM (SAS Institute, 2002–2003). Residuals were checked for normality using Shapiro-Wilks test in SAS PROC Univariate. If residuals of the log-transformed data departed significantly from normality, the raw values were rank transformed and subjected to GLM (Friedman’s Test; Zar, 1999). For both log- and rank-transformed data, means were compared using the Ryan-Einot-Gabriel-Welsh multiple comparison test in SAS GLM.

The degree of similarity in species composition among lure treatments was determined by calculating the qualitative Sorensen index, which compares incidence of species, and the quantitative Morasita-Horn index (MH), which compares both incidence and abundance of species; both indices were calculated using EstimateS version 9 (Colwell, 2013). EstimateS was also used to calculate the mean number of species detected per number of trap samples using Coleman’s rarefaction. This was done to compare the number of species detected per sampling effort (i.e., number of traps) among each of the different lure treatments. We also used Coleman’s rarefaction to estimate the mean number of species detected per sampling effort for all binary combinations of lure treatments in each year, i.e., ten binary combinations of the five different lure treatments in 2009 (e.g., traps baited with K6+E combined with traps baited SB+E) and 15 binary combinations of the six different lure treatments in 2010. In other words, we wanted to see whether detection efficacy could be improved by using more than one kind of lure treatment at a site, e.g., if traps baited with K6+E attract a different set of species than traps baited with SB+E, then deploying four traps baited with K6+E plus four traps baited with SB+E may detect more species than eight traps baited with either K6+E or SB+E. Coleman’s rarefaction does not estimate true species richness but only the aver-

**Table 1.** Numbers of bark and ambrosia beetles (Curculionidae) collected in a mixed coniferous–broadleaf forest near Vladivostok, Russia, 30 May–8 August 2009, in black panel intercept traps baited with different semiochemical lures (K6 – racemic 3-hydroxyhexan-2-one; F – racemic *E*-fusicumol; FA – fusicumol acetate; E – ethanol, SB spruce blend [a mix of  $\alpha$ -pinene,  $\beta$ -pinene, 3-carene, limonene, and  $\alpha$ -terpinolene], C – unbaited control) ( $n = 8$  traps per lure treatment). Bold font indicates species for which lure treatments differed significantly in mean catch per trap (ANOVA,  $\alpha = 0.05$ ) or the proportion of traps that detected at least one specimen (Cochran's Q test, Zar, 1999) and also those lure(s) with the greatest mean catch or rate of detection.

Subfamily	Tribe	K6 + E	F + SB + E	FA + SB + E	SB + E	C	Total	Q	P
Platypodinae	Platypodini								
	<i>Platypus quercivorus</i> Murayama	0	2	0	1	0	3	–	–
Scolytinae	Hylastini								
	<b><i>Hylastes brunneus</i></b> Erichson	5	<b>1089</b>	<b>1023</b>	<b>957</b>	88	3162	14.3	<0.01
	<b><i>Hylastes obscurus</i></b> Chapuis	0	<b>186</b>	<b>152</b>	<b>215</b>	2	555	27.6	<0.001
	<i>Hylurgops longipillus</i> (Reitter)	0	1	0	0	0	1	–	–
	<i>Hylurgops palliatus</i> (Gyllenhal)*	1	0	0	0	0	1	–	–
	<i>Hylurgops transbaicalicus</i> Eggers	0	0	0	1	0	1	–	–
	Hylurgini								
	<i>Xylechinus pilosus</i> (Ratzeburg)	1	0	0	1	0	2	–	–
	Polygraphini								
	<i>Polygraphus proximus</i> Blandford	1	0	0	0	0	1	–	–
	Scolytini								
	<i>Scolytus claviger</i> Blandford	0	0	0	0	1	1	–	–
	Dryocoetini								
	<b><i>Dryocoetes striatus</i></b> Eggers (= <i>D. abietinus</i> Kono and Tamanuki)	0	2	3	<b>6</b>	0	11	13.1	<0.05
	<i>Dryocoetes hectographus</i> Reitter	2	0	0	0	3	5	8.0	NS
	<i>Dryocoetes orientalis</i> Kurenzov	0	2	0	1	0	3	–	–
	<i>Dryocoetes rugicollis</i> Eggers	0	0	0	1	0	1	–	–
	Crypturgini								
	<i>Crypturgus cf. cinereus</i> (Herbst)	0	2	0	1	1	4	–	–
	<i>Crypturgus hispidulus</i> Thomson	1	0	0	0	0	1	–	–
	<i>Crypturgus subcribrosus</i> Eggers	0	1	0	0	0	1	–	–
	Ipini								
	<b><i>Ips typographus</i></b> (Linnaeus)	16	<b>233</b>	<b>231</b>	<b>203</b>	3	686	16.3	<0.01
	Xyloterini								
	<i>Indocryphalus aceris</i> (Niisima)	0	0	0	1	1	2	–	–
	<i>Trypodendron lineatum</i> (Olivier) <sup>†</sup>	2	2	2	1	1	8	–	–
	<i>Trypodendron niponicum</i> Blandford	2	0	0	0	1	3	–	–
	Xyleborini								
	<b><i>Anisandrus apicalis</i></b> (Blandford)	<b>57</b>	4	1	1	0	63	18.5	<0.001
	<i>Anisandrus dispar</i> (Fabricius)* (= <i>A. aequalis</i> Reitter)	0	0	2	0	0	2	–	–
	<b><i>Anisandrus maiche</i></b> (Kurenzov)*	<b>241</b>	8	4	0	6	259	16.4	<0.01
	<i>Xyleborus seriatus</i> Blandford*	4	0	0	0	0	4	–	–
	Cryphalini								
	<i>Cryphalus piceus</i> Eggers	1	1	1	1	1	5	–	–
	<i>Eidophelus imitans</i> Eichhoff (= <i>E. elegans</i> Krivolutskaya)	0	1	1	1	0	3	–	–
	Scolytoplatypodini								
	<b><i>Scolytoplatypus tycon</i></b> Blandford	<b>1502</b>	32	24	15	36	1609	4.71	NS
No. species detected		14	15	11	16	12	27	3.78 <sup>1</sup>	NS
No. specimens captured		1836	1566	1435	1391	144	6397	1348 <sup>1</sup>	<0.001

<sup>1</sup> Chi-square goodness-of-fit test, where null hypothesis is equal frequency among lure treatments; <sup>†</sup> species is Holarctic; \* species adventive in North America ([http://www.barkbeetles.info/regional\\_chklist\\_condensed.php?user\\_geo=%28calc\\_canada%3D1%20OR%20calc\\_usa48%3D1%29&user\\_geo\\_title=Canada and U.S. \(continental N. America\)](http://www.barkbeetles.info/regional_chklist_condensed.php?user_geo=%28calc_canada%3D1%20OR%20calc_usa48%3D1%29&user_geo_title=Canada%20and%20U.S.%20(continent%20N.%20America))).

age number of species detected per 1, 2, ...,  $n$  samples (i.e., trap samples in our case) collected from a given area. In this sense, it provides a measure of how many traps are needed to detect most of the species liable to be detected with a given lure treatment, or conversely, the proportion of species that may go undetected when the number of traps per site is limited. The similarity indices and rarefaction curves were calculated for Scolytinae species, and also for total species of Scolytinae and Cerambycidae combined. The rarefaction curves for Cerambycidae species detected

in these trapping experiments were previously reported (Sweeney et al., 2014).

## RESULTS

Traps detected 27 Scolytinae species (6372 specimens) in 2009 (Table 1) and 28 Scolytinae species (5696 specimens) in 2010 (Table 2). Overall, 36 species of Scolytinae were detected, with 18 species common to both years. Six species accounted for 99% of specimens collected in 2009:

**Table 2.** Number of bark and ambrosia beetles (Curculionidae) collected in a mixed coniferous–broadleaf forest near Vladivostok, Russia, 23 May–21 July 2010, in black panel intercept traps baited with E (40% ethanol), K6 (racemic 3-hydroxyhexan-2-one), K8 (racemic 3-hydroxyoctan-2-one), K6 + E, K8 + E, or C (unbaited control), in a mixed wood ( $n = 8$  traps per lure treatment). Bold font indicates species for which lure treatments differed significantly in mean catch per trap (ANOVA,  $\alpha = 0.05$ ) or the proportion of traps that detected at least one specimen (Cochran's Q test, Zar, 1999) and also those lure(s) with the greatest mean catch or rate of detection.

Subfamily	E	K6 + E	K8 + E	K6	K8	C	Total	Q	P
Tribe									
Species									
Platypodinae									
Platypodini									
<i>Platypus quercivorus</i> Murayama	0	1	0	0	0	0	1	–	–
Scolytinae									
Hylastini									
<i>Hylastes obscurus</i> Chapuis	1	0	0	0	0	1	2	–	–
<i>Hylurgops longipillus</i> (Reitter)	0	0	0	0	0	1	1	–	–
<i>Hylurgops palliatus</i> (Gyllenhal)*	6	4	6	1	0	0	18	2.9	NS
<i>Hylurgops transbaicalicus</i> Eggers	0	1	0	0	0	0	1	–	–
Hylesinini									
<i>Hylesinus eos</i> Spessivtsev	0	1	0	0	0	0	1	–	–
Hylurgini									
<i>Tomiscus pilifer</i> (Spessivtsev)	1	1	0	2	14	1	19	1.1	NS
<i>Xylechinus pilosus</i> (Ratzeburg)	4	3	2	1	0	0	10	4.4	NS
Polygraphini									
<i>Polygraphus proximus</i> Blandford	0	0	0	0	1	1	2	–	–
Phloeotribini									
<i>Phloeotribus spinulosus</i> (Rey)	1	0	0	0	0	0	1	–	–
Dryocoetini									
<i>Dryocoetes striatus</i> Eggers (= <i>D. abietinus</i> Kono and Tamanuki)	10	10	2	0	2	3	27	10.4	NS
<i>Dryocoetes hectographus</i> Reitter	2	1	0	0	0	0	3	–	–
Crypturgini									
<i>Crypturgus tuberosus</i> Nijima	0	0	1	0	0	0	1	–	–
Ipini									
<i>Ips typographus</i> (Linnaeus)	0	1	0	2	4	0	7	–	–
Xyloterini									
<i>Indocryphalus aceris</i> (Niisima)	0	0	0	1	0	0	1	–	–
<i>Trypodendron laeve</i> (Eggers)	0	0	1	0	0	0	1	–	–
<b><i>Trypodendron lineatum</i></b> (Olivier) <sup>†</sup>	<b>21</b>	<b>3</b>	<b>1</b>	<b>0</b>	<b>1</b>	<b>1</b>	<b>27</b>	<b>15.2</b>	<b>&lt;0.05</b>
<i>Trypodendron niponicum</i> Blandford	0	1	2	0	0	0	3	7.0	NS
Xyleborini									
<b><i>Anisandrus apicalis</i></b> (Blandford)	<b>159</b>	<b>88</b>	<b>238</b>	3	2	1	491	30.6	<0.001
<b><i>Anisandrus dispar</i></b> (Fabricius)* (= <i>A. aequalis</i> Reitter)	<b>82</b>	<b>79</b>	<b>53</b>	33	3	3	253	21.7	<0.001
<b><i>Anisandrus maiche</i></b> (Kurenzov)*	<b>35</b>	<b>22</b>	9	0	0	1	67	25.8	<0.001
<i>Cyclorhipidon bodoanus</i> (Reitter)	2	3	1	0	0	0	6	8.6	NS
<b><i>Xyleborinus attenuatus</i></b> (Blandford)	<b>55</b>	<b>30</b>	10	11	2	1	109	16.7	<0.01
<b><i>Xyleborinus saxesenii</i></b> (Ratzeburg)*	<b>11</b>	<b>10</b>	<b>6</b>	0	0	0	27	24.0	<0.001
<b><i>Xylosandrus germanus</i></b> (Blandford)*	<b>60</b>	33	37	2	0	0	132	26.1	<0.001
Cryphalini									
<i>Cryphalus piceus</i> Eggers	0	0	0	0	2	0	2	–	–
<i>Procryphalus fraxini</i> (Berger)	0	1	0	0	0	0	1	–	–
Scolytoplatypodini									
<b><i>Scolytoplatypus tycon</i></b> Blandford	1670	<b>3269</b>	2012	30	10	84	7075	10.0	NS
No. species detected	16	20	15	10	10	11	28	5.43 <sup>1</sup>	NS
No. specimens captured	2120	3562	2381	86	42	98	8289	5696 <sup>1</sup>	<0.001

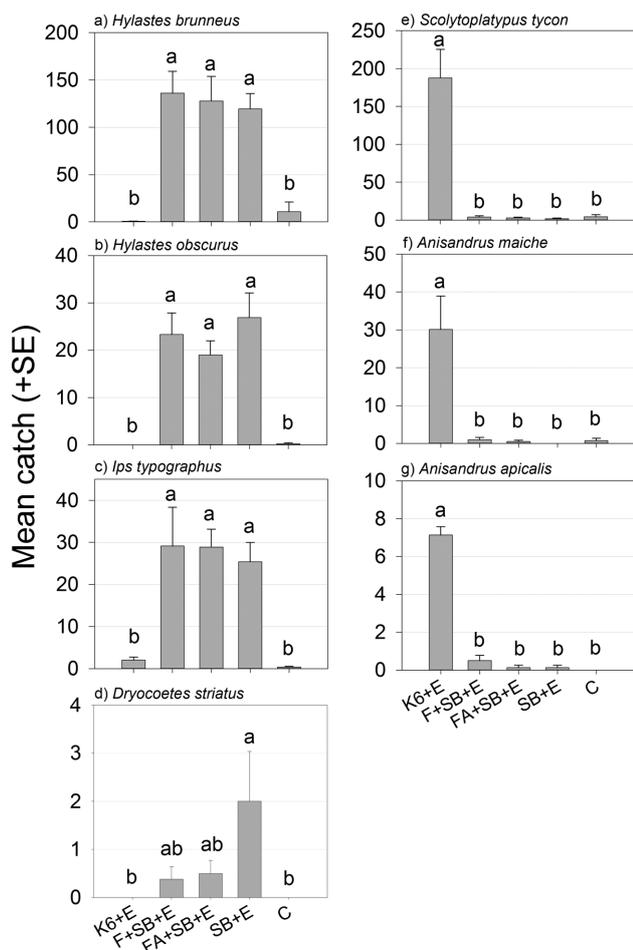
<sup>1</sup> Chi-square goodness-of-fit test, where null hypothesis was equal frequency of species or specimens among lure treatments; <sup>†</sup> species is Holarctic; \* species adventive in North America ([http://www.barkbeetles.info/regional\\_chklist\\_condensed.php?user\\_geo=%28calc\\_canada%3D1%20OR%20calc\\_usa48%3D1%29&user\\_geo\\_title=Canada and U.S. \(continental N. America\)](http://www.barkbeetles.info/regional_chklist_condensed.php?user_geo=%28calc_canada%3D1%20OR%20calc_usa48%3D1%29&user_geo_title=Canada%20and%20U.S.%20(continental%20N.%20America))).

*Hylastes brunneus* Erichson (49%), *Scolytoplatypus tycon* Blandford (25%), *Ips typographus* (L.) (11%), *Hylastes obscurus* Chapuis (9%), *Anisandrus maiche* (Kurenzov) (4%), and *Anisandrus apicalis* (Blandford) (1%) (Table 1). Similarly, six species accounted for 98% of specimens collected in 2010: *S. tycon* (85%), *A. apicalis* (6%), *Anisandrus dispar* (Fabr.) (3%), *Xylosandrus germanus* (Blandford) (1.6%), *Xyleborinus attenuatus* (Blandford) (1.3%), and *A. maiche* (0.8%) (Table 2). About 40% of species

were represented by only one or two specimens in both 2009 (11 of 27 species) and 2010 (12 of 28 species) (Tables 1, 2). The collection of *X. germanus* is a new species record for the Russian Continental Far East fauna; earlier records reported by Krivolutskaya (1996) were in error.

#### Mean catch per trap

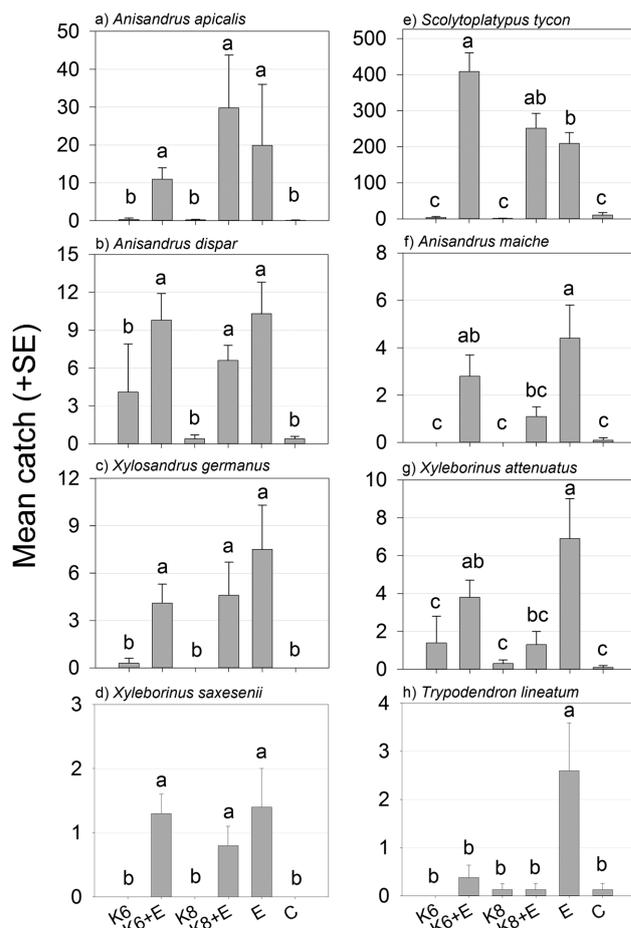
Lure treatment significantly affected mean catch per trap of seven species in 2009 (Fig. 1). The combination of



**Fig. 1 (a–g).** Mean catches of Scolytinae species in intercept traps baited with various semiochemical lures (K6 – racemic 3-hydroxyhexan-2-one; SB – spruce blend; E – ethanol; F – racemic fuscumol; and FA – fuscumol acetate), or left unbaited as controls (C) in the Russian Far East in 2009. Within each graph, means with different letters were significantly different (GLM or Friedmans test on ranks and Ryan-Einot-Gabriel-Welsh multiple range test ( $P < 0.05$ )).

SB+E significantly increased mean catches of *H. brunneus* ( $F_{4,28} = 17.5$ ;  $P < 0.0001$ ), *H. obscurus* ( $F_{4,28} = 24.9$ ;  $P < 0.0001$ ), *Ips typographus* (L.) ( $F_{4,28} = 61.6$ ;  $P < 0.0001$ ), and *Dryocoetes striatus* Eggers ( $F_{4,28} = 4.8$ ;  $P = 0.005$ ) compared with unbaited controls (Fig. 1a–d). The addition of the longhorn beetle pheromones F or FA to SB+E had little effect on catches of Scolytinae species, with the exception of *D. striatus*: mean catch in traps baited with SB+E was greater than that in unbaited traps whereas mean catch in traps baited with F+SB+E or FA+SB+E was not (Fig. 1d). Traps baited with K6+E captured significantly more *S. tycon* ( $F_{4,28} = 34.4$ ;  $P < 0.0001$ ), *A. maiche* ( $F_{4,28} = 39.0$ ;  $P < 0.0001$ ), and *A. apicalis* ( $F_{4,28} = 26.3$ ;  $P < 0.0001$ ) than did traps baited with any other lure treatment in 2009 (Fig. 1e–g).

Lure treatment significantly affected mean catch per trap of eight species in 2010, six of which were in the Xyleborini tribe [*A. apicalis* ( $F_{5,35} = 36.4$ ;  $P < 0.0001$ ), *A. dispar* ( $F_{5,35} = 16.6$ ;  $P < 0.0001$ ), *A. maiche* ( $F_{5,35} = 12.0$ ;  $P < 0.0001$ ), *X. germanus* ( $F_{5,35} = 12.5$ ;  $P < 0.0001$ ), *Xyleborinus saxesenii* (Ratzeburg) ( $F_{5,35} = 8.4$ ;  $P < 0.0001$ ), *X.*

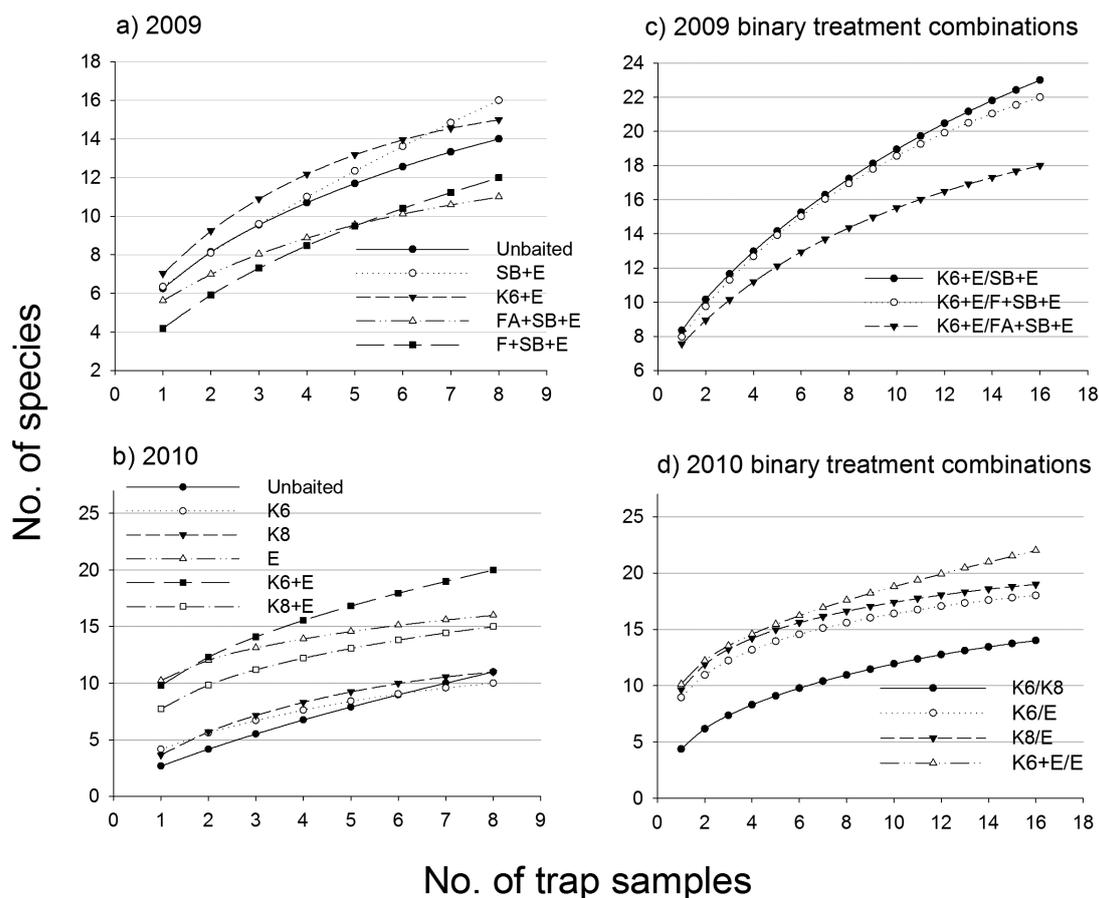


**Fig. 2 (a–h).** Mean catches of Scolytinae species in intercept traps baited with various semiochemical lures (K6 – racemic 3-hydroxyhexan-2-one; K8 – racemic 3-hydroxyoctan-2-one; E – ethanol; SB – spruce blend; F – racemic fuscumol; and FA – fuscumol acetate), or left unbaited as controls (C) in the Russian Far East in 2010. E lures contained 40% ethanol (vodka). Within each graph, means with different letters were significantly different (GLM or Friedmans test on ranks and Ryan-Einot-Gabriel-Welsh multiple range test ( $P < 0.05$ )).

*attenuatus* ( $F_{5,35} = 7.6$ ;  $P < 0.0001$ ); the remaining two were *S. tycon* ( $F_{5,35} = 41.3$ ;  $P < 0.0001$ ), and *Trypodendron lineatum* (Olivier) ( $F_{5,35} = 5.2$ ;  $P = 0.001$ ) (Fig. 2). For all eight species, there was a significant positive effect of ethanol on mean catch compared with unbaited controls, and no effect of either K6 or K8 by themselves (Figs 2a–h). Adding either K6 or K8 to ethanol-baited traps had no effect on mean catch of *A. apicalis*, *A. dispar*, *X. germanus*, or *X. saxesenii* (Figs 2a–d). However, the addition of K6 to ethanol-baited traps significantly increased mean catch of *S. tycon* (Fig. 2e), the addition of K8 to ethanol-baited traps significantly reduced mean catches of *A. maiche* and *X. attenuatus* (Figs 2f, g), and the addition of either K6 or K8 to ethanol-baited traps significantly reduced mean catch of *T. lineatum* (Fig. 2h).

#### Detection efficacy

Results in terms of detection rate were similar to those for mean catches in both years, i.e., the proportion of traps that captured at least one specimen differed significantly among treatments for all of the species for which mean



**Fig. 3.** Mean number of Scolytinae species detected per number of trap samples, estimated using Coleman's rarefaction, in the Russian Far East single lure treatments in a) 2009 and b) 2010, and in binary combinations of selected treatments in c) 2009 and d) 2010. K6 – racemic 3-hydroxyhexan-2-one; K8 – racemic 3-hydroxyoctan-2-one; E – ethanol; SB – spruce blend; F – racemic fuscumol; and FA – fuscumol acetate.

catch differed among treatments, with the exception of *S. tycon* (Tables 1, 2). Although mean catch of *S. tycon* was clearly greater in traps baited with K6+E than in most other lure treatments in both years, the species was also present in 50–75% of unbaited traps, albeit in much lower numbers.

#### Number of Scolytinae species detected per sampling effort

The total number of Scolytinae species detected (per eight replicate traps) varied among lure treatments, from 11 species in traps baited with FA+SB+E to 16 species in traps baited with SB+E in 2009 (Fig. 3a), and from 10 species in traps baited with K6 to 20 species in traps baited with K6+E in 2010 (Fig. 3b, Table 3). The addition of F or FA to traps baited with spruce blend and ethanol reduced the number of Scolytinae species detected per trap (Fig. 3a); in fact, traps baited with F+SB+E or FA+SB+E detected fewer species per trap than did unbaited traps. Conversely, the addition of K6 or K8 to ethanol-baited traps either increased the number of species detected or had little effect (Fig. 3b). However, although the number of specimens detected varied significantly among lure treatments in both 2009 and 2010, the number of species detected did not (Chi square goodness of fit tests,  $P < 0.05$ ) (Tables 1, 2). Species composition, as measured by Sorenson's qualitative index,

was least similar between traps baited with K6+E and traps baited with SB+E in 2009 and between traps baited with K6 and unbaited traps in 2010 (Table 3). The binary combination of different lure treatments that resulted in the greatest number of Scolytinae species detected (i.e., in a combined total of 16 traps) was the combination of traps baited with K6+E and traps baited with SB+E in 2009 (23 species detected) (Fig. 3c) and traps baited with K6+E plus unbaited traps in 2010 (23 species detected) (Fig. 3d, Table 3). In 2009, the binary treatment combination of traps baited with K6+E plus traps baited with SB+E performed only marginally better than traps baited with the best individual lure treatment combination (SB+E), detecting about 17 species compared with 16 species per eight traps. This was not true in 2010 when the best single lure treatment, K6+E, detected more Scolytinae species per trap than any binary treatment combination (Fig. 3b, d). None of the species accumulation curves appeared to reach an asymptote with the exception of perhaps traps baited with FA+SB+E (Fig. 3a) or K6 or K8 alone (Fig. 3b).

#### Number of combined Scolytinae and Cerambycidae species detected per sampling effort

When data on catch of Cerambycidae species were combined with those for Scolytinae, the relative differences among lure treatments in number of species detected was

**Table 3.** Number of species of Scolytinae captured in intercept traps baited with different semiochemical lure treatments or binary combinations of traps with different treatments, and the similarity in species composition between different lure treatments near Vladivostok, Russia, in 2009 and 2010. K6 – racemic 3-hydroxyhexan-2-one; K8 – racemic 3-hydroxyoctan-2-one; E – ethanol; SB – spruce blend; F – racemic fuscumol; FA – fuscumol acetate. Note: E lures contained 95% ethanol in 2009 and 40% ethanol (vodka) in 2010. For both the Sorenson index and Morasita-Horn index, a greater value indicates greater similarity in species composition and a value of 1.0 – same species composition. Indices were calculated using EstimateS 9 (Colwell, 2013).

Year	Lure 1	No. species detected	Lure 2	No. species detected	No. species shared	Total species detected	Sorenson	Morasita-Horn
2009	K6+E	14	SB+E	16	7	23	0.467	0.020
	K6+E	14	FA+SB+E	11	7	18	0.560	0.028
	K6+E	14	F+SB+E	15	7	22	0.483	0.034
	K6+E	14	Unbaited	12	8	18	0.615	0.376
	SB+E	16	FA+SB+E	11	9	18	0.667	0.996
	SB+E	16	F+SB+E	15	12	19	0.774	0.998
	SB+E	16	Unbaited	12	8	20	0.571	0.896
	FA+SB+E	11	F+SB+E	15	10	16	0.769	0.999
	FA+SB+E	11	Unbaited	12	7	16	0.609	0.904
2010	F+SB+E	15	Unbaited	12	8	19	0.593	0.907
	K6	10	K8	11	7	14	0.667	0.534
	K6	10	E	16	8	18	0.615	0.645
	K6	10	K6+E	20	9	21	0.600	0.584
	K6	10	K8+E	15	7	18	0.560	0.607
	K6	10	Unbaited	11	5	16	0.476	0.609
	K8	11	E	16	8	19	0.593	0.476
	K8	11	K6+E	20	9	22	0.581	0.428
	K8	11	K8+E	15	7	19	0.538	0.453
	K8	11	Unbaited	11	8	14	0.727	0.457
	E	16	K6+E	20	14	22	0.778	0.986
	E	16	K8+E	15	12	19	0.774	0.996
	E	16	Unbaited	11	9	18	0.667	0.992
	K6+E	20	K8+E	15	13	22	0.743	0.993
	K6+E	20	Unbaited	11	8	23	0.516	0.997
K8+E	15	Unbaited	11	7	19	0.538	0.993	

less than that observed for Scolytinae alone in 2009 (Fig. 4a vs. 3a) and, surprisingly, the performance of K6+E was about that same as ethanol alone in 2010 (Fig. 4b). The similarities in composition of Scolytinae and Cerambycidae species between different lure treatments were comparable to those for Scolytinae species (Table 4). In 2009, SB+E detected the most species of any lure treatment (29 species per eight traps) and detection efficacy was improved (to 33 species detected in eight traps) by using a combination of SB+E and K6+E (Fig. 4c). The latter two treatments also had one of the least similar species compositions of any binary treatment combination in 2009 (Table 4). However, in 2010, no combination of two lure treatments increased the number of species detected per trap over that detected with traps baited with the single lure treatment of K6+E (27 species in eight traps) (Fig. 4d).

## DISCUSSION

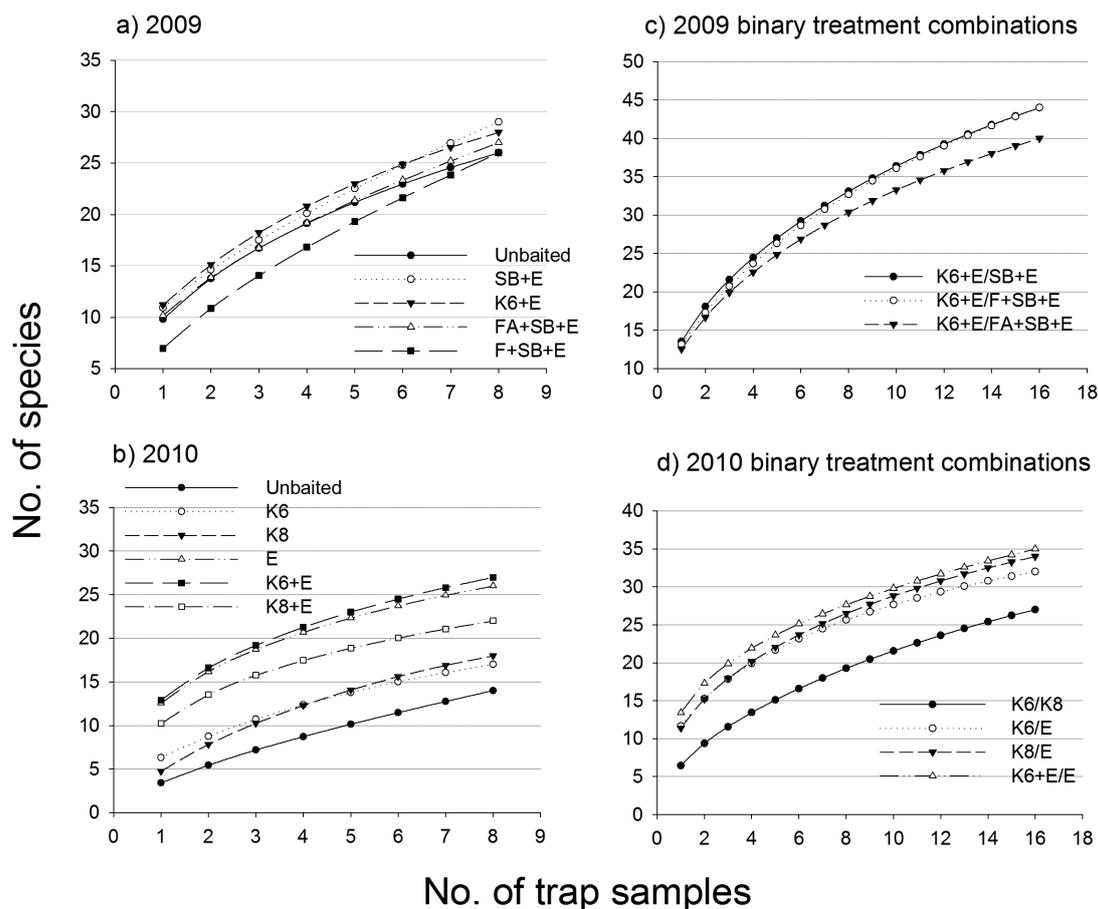
Our results demonstrate the efficacy of traps baited with ethanol and monoterpenes as survey tools for particular species of Scolytinae native to the Russian Far East, especially those in the tribe Xyleborini, but also suggest that many Scolytinae species may go undetected by such traps or be detected only by chance. A total of 116 species from 35 genera of Scolytinae are recorded from the Primorsk Territory (southernmost continental Province of the Russian Far East) (Krivolutskaja, 1996), and 58 species were collected in extensive surveys in the Lazo Nature Reserve (Mandelsham & Petrov, 2009), located at the

same latitude in Primorsk Territory as the present study site near Anisimovka. Thus, the detection of only 36 species of Scolytinae suggests that our traps and lures failed to detect about half of the species present at the site.

We also demonstrate that the addition of longhorn beetle pheromones to host volatile-baited traps can have both positive and negative effects on detection of Scolytinae species, depending on the pheromone–host volatile combination, and the particular beetle species.

In 2009, traps baited with a combination of ethanol and spruce (monoterpene) blend captured significant numbers of four bark beetle species that infest conifers: *H. brunneus*, *H. obscurus*, *D. striatus*, and *I. typographus*. Positive response to the combination of ethanol plus  $\alpha$ -pinene or a mix of monoterpenes has previously been reported for *H. brunneus* (Schroeder & Lindelöw, 1989; Lindelöw et al., 1993), *H. obscurus*, *D. striatus* (Lindelöw et al., 1993), *I. typographus* (Reddemann & Schopf, 1996) as well as other *Hylastes* spp. in eastern North America (Miller & Rabaglia, 2009).

In 2010, ethanol was significantly attractive to eight species in the tribes Xyloterini (*T. lineatum*), Xyleborini (*A. apicalis*, *A. dispar*, *A. maiche*, *X. attenuatus*, *X. saxesenii*, *X. germanus*), and Scolytoplatypodini (*S. tycon*). Attraction to ethanol has been previously shown for *A. dispar* (Schroeder & Lindelöw, 1989), *Anisandrus sayi* Hopkins (Ranger et al., 2011), *T. lineatum* (Moeck, 1970; Salom & McLean, 1990), *X. germanus* (Miller & Rabaglia, 2009; Ranger et al., 2010, 2011), *X. saxesenii* (Miller & Raba-



**Fig. 4.** Mean number of Scolytinae and Cerambycidae species detected per number of trap samples, estimated using Coleman's rarefaction, in the Russian Far East single lure treatments in a) 2009 and b) 2010, and in binary combinations of selected treatments in c) 2009 and d) 2010. K6 – racemic 3-hydroxyhexan-2-one; K8 – racemic 3-hydroxyoctan-2-one; E – ethanol; SB – spruce blend; F – racemic fuscumol; and FA – fuscumol acetate. Data for Cerambycidae catch from Sweeney et al. (2014).

glia, 2009), and *H. palliatus* (Schroeder, 1988; Schroeder & Lindelöw, 1989). To our knowledge, a significant positive response to ethanol-baited traps has not been reported previously for *A. apicalis*, *A. maiche*, *S. tycon* or *X. attenuatus*, although *A. maiche* has been detected in funnel traps baited with ethanol or ethanol plus  $\alpha$ -pinene in several states in the eastern U.S. as part of exotic bark beetle trapping surveys (Rabaglia et al., 2009; <http://www.barkbeetles.info/index.php>).

It is not possible to compare the relative performance of our lure treatments for consistency between years because the same set of lure treatments was not tested each year. However, testing a different set of lure treatments in each year allowed us to screen a greater total number of lure treatments for their efficacy at detecting Scolytinae in the Russian Far East, one of the main goals of this study. Furthermore, the inclusion of unbaited controls in each year provides a common baseline with which to compare lure treatments and for those species for which we infer mean catch was affected by lure treatment, the effect was highly significant ( $P < 0.0001$ ). Some differences between years were apparent in response to K6+E. *Anisandrus apicalis*, *A. maiche* and *S. tycon* responded positively to traps baited with K6+E in both years, whereas *A. dispar*, *X. germanus*, *X. attenuatus* and *X. saxesenii* responded positively

to K6+E in 2010 only. We can only speculate on possible reasons for these differences: (1) our use of vodka rather than 95% ethanol in 2010 may have affected response of some species, either due to the presence of impurities in the vodka, or to the lower concentration of ethanol (40% vs. 95%), or both; (2) activity level and or population densities of some species may have differed between years due to stochastic factors like weather.

The relatively low catches of *H. palliatus* in traps baited with ethanol or spruce blend plus ethanol were initially surprising because Schroeder (1988) trapped this species in relatively large numbers in Sweden in transparent flight barrier traps baited with ethanol or ethanol plus  $\alpha$ -pinene, and the first North American record of this species was from a trap baited with ethanol and  $\alpha$ -pinene (Rabaglia et al., 2008). Similarly, we collected very few specimens of *X. seriatus* in our traps even though this species has been collected in the hundreds in funnel traps baited with ethanol plus  $\alpha$ -pinene in Massachusetts (Hoebeke & Rabaglia, 2008, <http://www.barkbeetles.info/index.php>). It is possible that populations of these species were relatively low at our sites, or that attraction to ethanol or ethanol and  $\alpha$ -pinene was interrupted by the presence of longhorn beetle pheromones or additional monoterpenes in the spruce blend. However, it is more likely that the lower than ex-

**Table 4.** Number of species of Scolytinae and Cerambycidae captured in intercept traps baited with different semiochemical lure treatments or binary combinations of lure treatments, and the similarity in species composition between different lure treatments near Vladivostok, Russia, in 2009 and 2010. K6 – racemic 3-hydroxyhexan-2-one; K8 – racemic 3-hydroxyoctan-2-one; E – ethanol; SB – spruce blend; F – racemic fuscumol; FA – fuscumol acetate. Note: E lures contained 95% ethanol in 2009 and 40% ethanol (vodka) in 2010. For both the Sorenson index and Morasita-Horn index, a greater value indicates greater similarity in species composition and a value of 1.0 – same species composition. Indices were calculated using EstimateS 9 (Colwell 2013).

Year	Lure 1	No. species detected	Lure 2	No. species detected	No. species shared	Total species detected	Sorenson	Morasita-Horn
2009	K6+E	26	SB+E	29	11	44	0.400	0.020
	K6+E	26	FA+SB+E	27	13	40	0.491	0.028
	K6+E	26	F+SB+E	28	10	44	0.370	0.034
	K6+E	26	Unbaited	26	15	37	0.577	0.360
	SB+E	29	FA+SB+E	27	17	39	0.607	0.996
	SB+E	29	F+SB+E	28	20	37	0.702	0.997
	SB+E	29	Unbaited	26	15	40	0.545	0.888
	FA+SB+E	27	F+SB+E	28	18	37	0.655	0.996
	FA+SB+E	27	Unbaited	26	14	39	0.528	0.891
	F+SB+E	28	Unbaited	26	14	40	0.519	0.900
2010	K6	17	K8	18	8	27	0.457	0.402
	K6	17	E	26	11	32	0.512	0.456
	K6	17	K6+E	27	12	32	0.545	0.413
	K6	17	K8+E	22	9	30	0.462	0.428
	K6	17	Unbaited	14	6	25	0.387	0.439
	K8	18	E	26	10	34	0.455	0.424
	K8	18	K6+E	27	11	34	0.489	0.378
	K8	18	K8+E	22	8	32	0.400	0.403
	K8	18	Unbaited	14	9	23	0.563	0.419
	E	26	K6+E	27	18	35	0.679	0.987
	E	26	K8+E	22	14	34	0.583	0.997
	E	26	Unbaited	14	10	30	0.500	0.997
	K6+E	27	K8+E	22	15	34	0.612	0.993
	K6+E	27	Unbaited	14	8	33	0.390	0.990
	K8+E	22	Unbaited	14	8	28	0.444	0.990

pected catches are because we missed the main flight periods of these species. Our traps were out between late May and late July–early August; peak flights of *H. palliatus* occurred in late April (overwintered generation) and August (new generation) in Denmark (Subansenee, 1971), and those of *X. seriatus* occurred in mid-May in Massachusetts.

Lure treatment significantly affected beetle species composition in traps and likely reflected the volatiles emitted from suitable brood hosts (Schroeder & Lindelöw, 1989; Miller & Rabaglia, 2009; Ranger et al., 2011). Ethanol is found in the bark and sapwood of stressed trees (Kimmerer & Koslowski, 1982), stumps (Kelsey & Joseph, 1999) and logs (Kelsey, 1994), which provide suitable breeding material for many species of bark and ambrosia beetles, and thus likely acts as a host kairomone (Schroeder, 1988; Lindelöw et al., 1993; Raffa et al., 1993). Beetles that responded positively to traps baited with spruce blend plus ethanol, such as *Ips typographus* and *Hylastes* spp., likely did so because the lures simulated volatiles emitted from stressed or moribund conifers, preferred hosts of these species (Wood & Bright, 1992; Wermelinger, 2004; Lindgren & Raffa, 2013). The reduced catch of *A. dispar*, *A. maiche*, and *S. tycon* in traps baited with ethanol plus spruce monoterpenes vs. traps baited with ethanol plus racemic 3-hydroxyhexan-2-one was likely because the relatively high release rates of these monoterpenes are probably not typically emitted from suitable hosts; e.g., *Anisandrus maiche* and *A. dispar* feed mainly in broadleaf trees (Wood & Bright, 1992). Adding  $\alpha$ -pinene to traps baited with ethanol significantly reduced catches of *A. dispar*, *Anisandrus*

*sayi* Hopkins, *X. saxesenii* and *Dryoxylon onoharaensis* (Murayama) (Schroeder & Lindelöw, 1989; Miller & Rabaglia, 2009; Ranger et al., 2011). *Scolytoptatus tycon* is reported from both broadleaf and conifers, including *Picea* spp. (Wood & Bright, 1992); the negative effect of spruce monoterpenes on attraction of this species to ethanol was possibly due to their ultra-high release rates. Erbilgin et al. (2003) showed that high concentrations of  $\alpha$ -pinene inhibited response of *Ips pini* (Say) to its aggregation pheromone. Our results are similar to those of Miller & Rabaglia (2009) and Ranger et al. (2011) and support their conclusion that detection surveys for bark and ambrosia beetle species should use traps baited with ethanol alone as well as traps baited with ethanol plus  $\alpha$ -pinene.

Adding longhorn beetle pheromones to traps baited with ethanol or spruce blend and ethanol had negative, positive, or neutral effects on catch of Scolytinae, depending on the pheromone and beetle species. By itself, neither K6 nor K8 significantly affected trap catch of Scolytinae species. However, the combination of K6+E detected the most species of Scolytinae and Scolytinae plus Cerambycidae of any lure treatment in 2010, suggesting it would increase detection efficacy compared with traps baited with E alone. Moreover, the addition of K6 to ethanol-baited traps synergized attraction of *S. tycon*, significantly increasing mean catch twofold and >100-fold compared with traps baited with ethanol or K6, respectively, but reduced catch of *T. lineatum*. On the other hand, adding K8 to ethanol-baited traps significantly reduced catches of *A. maiche*, *X. attenuatus*, and *T. lineatum*, and adding either F or FA to traps

baited with SB+E caused a slight reduction in catches of *D. striatus* and reduced the total number of Scolytinae species detected by 4–5 species (25–30%). A negative effect on catch of *T. lineatum* may actually be a benefit in terms of processing of catch as this species is Holarctic and thus not a target species in exotic bark and wood-boring beetle surveys traps in North America, but is often captured in large numbers in ethanol-baited traps (Sweeney et al., unpubl. data). The addition of K8 to traps baited with ethanol significantly increased catches of *M. scutellare* (Noseworthy et al., 2012) and *Hypothenemus rotundicollis* Wood & Bright (Miller et al., 2015b) and reduced catches of *Dryoxylon onoharaensum* (Murayama) (Miller et al., 2015b). Positive response of *S. tycon* to a pheromone that is emitted by many species of longhorn beetles in the subfamily Cerambycinae suggests that *S. tycon* perceives it as a kairomone indicative of a suitable host for colonization. Many species of Cerambycidae infest stressed or moribund hosts (Linsley, 1961; Solomon, 1995; Hanks, 1999) like those colonized by many species of bark and ambrosia beetles (Furniss & Carolin, 1980). The negative responses of *A. maiche*, *X. attenuatus* and *T. lineatum* to the combination of K8+E suggest it is perceived as an unsuitable host cue, perhaps indicating a host already occupied by longhorn beetles that could compete for space or resources. Overall, our results suggest that combining K6 and E on a single trap increased the number of species of Scolytinae and Cerambycidae detected, thereby reducing costs without significantly reducing detection efficacy. In a study comparing various trap and lure combinations in Italian ports and surrounding areas, Rassati et al. (2014) similarly found that traps baited with multi-lure combinations were more efficient at detecting species of bark and wood-boring beetles than were traps baited with single lures. However, our study also shows that some multiple lure combinations (e.g., K8+E) reduce the attraction of certain species, e.g., *A. maiche*, *X. attenuatus*, and *T. lineatum*. Thus, knowledge of how different target species respond to different lure combinations must be taken into consideration when designing operational surveys. It was also apparent from our data that many of the Scolytinae species that we detected were not significantly attracted to any of the lure treatments in 2009 (20/27 species) or 2010 (20/28 species). Furthermore, as pointed out by Miller et al. (2015b), although we can compare the relative efficacy of traps and lures for detection of a given species, we do not have independent data on population densities of any species at our experimental sites. Thus we do not know the relationship between mean catch and population density for any species and, therefore, have no measure of how sensitive a trap-lure is in terms of detecting a low density population of an exotic beetle that may recently have established in a new range. Future research should address this question, especially for high risk target species.

**ACKNOWLEDGEMENTS.** We thank Natural Resources Canada, Canadian Forest Service Forest Invasive Alien Species program and A. Hopkin (Sault Ste. Marie, ON), the Canadian Food Inspection Agency and T. Kimoto (Vancouver, BC), the USDA Ani-

mal Plant Health Inspection Service, V. Mastro and J. Francese (Buzzards Bay, MA) for support and funding. A.S. Lelej and S.R. Shestakov (Vladivostok, Russia) assisted with the fieldwork logistics. C. Hughes and J. Price (Fredericton, NB, Canada) and T. Kimoto and E. Kovacs (Vancouver, BC, Canada) provided technical and logistical support. J. Allison (Sault Ste. Marie, ON, Canada), L. Humble (NRCan, CFS-PFC, Victoria, BC, Canada), B. Rabaglia (USDA Forest Service Arlington, VA), and T. Kimoto (Canadian Food Inspection Agency) are thanked for providing helpful comments on an earlier version of this manuscript, and C. Simpson is thanked for editorial review and corrections.

## REFERENCES

- ALLISON J.D., BORDEN J.H., MCINTOSH R.L., DE GROOT P. & GRIES G. 2001: Kairomonal response by four *Monochamus* species (Coleoptera: Cerambycidae) to bark beetle pheromones. — *J. Chem. Ecol.* **27**: 633–646.
- ALLISON J.D., MOREWOOD W.D., BORDEN J.H., HEIN K.E. & WILSON I.M. 2003: Differential and bio-activity of *Ips* and *Dendroctonus* (Coleoptera: Scolytidae) pheromone components for *Monochamus clamator* and *M. scutellatus* (Coleoptera: Cerambycidae). — *Environ. Entomol.* **32**: 23–30.
- ALLISON J.D., BORDEN J.H. & SEYBOLD S.J. 2004: A review of the chemical ecology of the Cerambycidae (Coleoptera). — *Chemoecology* **14**: 123–150.
- ALLISON J.D., MCKENNEY J.L., MILLAR J.G., MCELFRISH J.S., MITCHELL R.F. & HANKS L.M. 2012: Response of the Woodborers *Monochamus carolinensis* and *Monochamus titillator* (Coleoptera: Cerambycidae) to known Cerambycid pheromones in the presence and absence of the host plant volatile  $\alpha$ -pinene. — *Environ. Entomol.* **41**: 1587–1596.
- BILLINGS R.F. 1985: Southern pine bark beetles and associated insects. Effects of rapidly-released host volatiles on response to aggregation pheromones. — *Z. Angew. Entomol.* **99**: 483–491.
- BORDEN J.H., LINDGREN B.S. & CHONG L. 1980: Ethanol and alpha-pinene as synergists for the aggregation pheromones of two *Gnathotrichus* species. — *Can. J. Forest Res.* **10**: 290–292.
- BROCKERHOFF E.G., BAIN J., KIMBERLEY M. & KNÍŽEK M. 2006: Interception frequency of exotic bark and ambrosia beetles (Coleoptera: Scolytinae) and relationship with establishment in New Zealand and worldwide. — *Can. J. For. Res.* **36**: 289–298.
- CERVANTES D.E., HANKS L.M., LACEY E.S. & BARBOUR J.D. 2006: First documentation of a volatile sex pheromone in a longhorned beetle (Coleoptera: Cerambycidae) of the primitive subfamily Prioninae. — *Ann. Entomol. Soc. Am.* **99**: 718–722.
- COLWELL R.K. 2013: *EstimateS: Statistical Estimation of Species Richness and Shared Species from Samples. Ver. 9. User's Guide and Application.* Available at: <http://purl.oclc.org/estimates> (accessed February 2015).
- COSTELLO S.L., NEGRÓN J.F. & JACOBI W.R. 2008: Traps and attractants for wood-boring insects in ponderosa pine stands in the Black Hills, South Dakota. — *J. Econ. Entomol.* **101**: 409–420.
- DE GROOT P. & NOTT R.W. 2004: Response of the whitespotted sawyer beetle, *Monochamus s. scutellatus*, and associated woodborers to pheromones of some *Ips* and *Dendroctonus* bark beetles. — *J. Appl. Entomol.* **128**: 483–487.
- DOUGLAS H., BOUCHARD P., ANDERSON R.S., DE TONNANCOUR P., VIGNEAULT R. & WEBSTER R.P. 2013: New Curculionioidea (Coleoptera) records for Canada. — *Zookeys* **309**: 13–48.
- ERBILGIN N., POWELL J.S. & RAFFA K. 2003: Effect of varying monoterpene concentrations on the response of *Ips pini* (Coleoptera: Scolytidae) to its aggregation pheromone: Implica-

- tions for pest management and ecology of bark beetles. — *Agric. For. Entomol.* **5**: 269–274.
- ESKALEN A., GONZALEZ A., WANG D.H., TWIZEYIMANA M., MAYORQUIN J.S. & LYNCH S.C. 2012: First report of a *Fusarium* sp. and its vector tea shot hole borer (*Euwallacea fornicatus*) causing *Fusarium* dieback on avocado in California. — *Plant Dis.* **96**: 1070–1070.
- FAO IPPC 2013: *Regulation of Wood Packaging Material in International Trade. International Standards for Phytosanitary Measures 15. International Plant Protection Convention of the Food and Agricultural Organization.* Available at: <https://www.ippc.int/publications/regulation-wood-packaging-material-international-trade-0>
- FETTKÖTHER R., DETTNER K., SCHRÖDER F., MEYER H., FRANKE W. & NOLDT U. 1995: The male pheromone of the old house borer *Hylotrupes bajulus* (L.) (Coleoptera: Cerambycidae): identification and female response. — *Experientia* **51**: 270–277.
- FETTKÖTHER R., REDDY G.V.P., NOLDT U. & DETTNER K. 2000: Effect of host and larval frass volatiles on behavioral response of the old house borer *Hylotrupes bajulus* (L.) (Coleoptera: Cerambycidae), in a wind tunnel bioassay. — *Chemoecology* **10**: 1–10.
- FIERKE M.K., SKABEIKIS D.D., MILLAR J.G., TEALE S.A., MCEL-FRESH J.S. & HANKS L.M. 2012: Identification of a male-produced aggregation pheromone for *Monochamus scutellatus* and an attractant for the congener *Monochamus notatus* (Coleoptera: Cerambycidae). — *J. Econ. Entomol.* **105**: 2029–2034.
- FONSECA M.G., VIDAL D.M. & ZARBIN P.H.G. 2010: Male-produced sex pheromone of the cerambycid beetle *Hedypathes betulinus*: chemical identification and biological activity. — *J. Chem. Ecol.* **36**: 1132–1139.
- FURNISS R.L. & CAROLIN V.M. 1980: *Western Forest Insects*. U.S. Dept. Agriculture – Forest Service, Misc. Pub. 1339. 654 pp.
- GANDHI K.J.K., COGNATO A.I., LIGHTLE D.M., MOSLEY B.J., NIELSEN D.G. & HERMS D.A. 2010: Species composition, seasonal activity, and semiochemical response of native and exotic bark and ambrosia beetles (Coleoptera: Curculionidae: Scolytinae) in northeastern Ohio. — *J. Econ. Entomol.* **103**: 1187–1195.
- HAACK R.A. 2001: Intercepted Scolytidae (Coleoptera) at U.S. ports of entry: 1985–2000. — *Integr. Pest Manag. Rev.* **6**: 253–282.
- HAACK R.A. 2006: Exotic bark- and wood-boring Coleoptera in the United States: recent establishments and interceptions. — *Can. J. For. Res.* **36**: 269–288.
- HAACK R.A. & RABAGLIA R.J. 2013: Exotic bark and ambrosia beetles in the USA: Potential and current invaders. In Peña J. (ed.): *Potential Invasive Pests of Agricultural Crops*. CAB International, Wallingford, pp. 48–74.
- HAACK R.A., BRITTON K.O., BROCKERHOFF E.G., CAVEY J.F., GARRETT L.J., KIMBERLEY M., LOWENSTEIN F., NUDING A., OLSON L.J., TURNER J. & VASILAKY K.N. 2014: Effectiveness of the International Phytosanitary Standard ISPM No. 15 on reducing wood borer infestation rates in wood packing material entering the United States. — *PLoS ONE* **9**(5): e96611.
- HANKS L.M. 1999: Influence of the larval host plant on reproductive strategies of cerambycid beetles. — *Annu. Rev. Entomol.* **44**: 483–505.
- HANKS L.M. & MILLAR J.G. 2012: Field bioassays of cerambycid pheromones reveal widespread parsimony of pheromone structures, enhancement by host plant volatiles, and antagonism by components from heterospecifics. — *Chemoecology* **23**: 21–34.
- HANKS L.M., MILLAR J.G., MOREIRA J.A., BARBOUR J.D., LACEY E.S., MCEL-FRESH J.S., REUTER F.R. & RAY A.M. 2007: Using generic pheromone lures to expedite identification of aggregation pheromones for the cerambycid beetles *Xylotrechus nauticus*, *Phymatodes lecontei*, and *Neoclytus modestus modestus*. — *J. Chem. Ecol.* **33**: 889–907.
- HANKS L.M., MILLAR J.G., MONGOLD-DIERS J.A., WONG J.C.H., MEIER L.R., REAGEL P.F. & MITCHELL R.F. 2012: Using blends of cerambycid beetle pheromones and host plant volatiles to simultaneously attract a diversity of cerambycid species. — *Can. J. For. Res.* **42**: 1050–1059.
- HANULA J.L., MAYFIELD III A.E., FRAEDRICH S.W. & RABAGLIA R.J. 2008: Biology and host associations of redbay ambrosia beetle (Coleoptera: Curculionidae: Scolytinae), exotic vector of laurel wilt killing redbay trees in the southeastern United States. — *J. Econ. Entomol.* **101**: 1276–1286.
- HOEBEKE E.R. & RABAGLIA R.J. 2008: *Xyleborus seriatus* Blandford (Coleoptera: Curculionidae: Scolytinae), an Asian ambrosia beetle new to North America. — *Proc. Entomol. Soc. Wash.* **110**: 470–476.
- HU N. & SCHAEFFER D.W. 2010: Effect of impurity compounds on ethanol hydration. — *J. Mol. Liq.* **155**: 29–36.
- IBEAS F., GALLEGO D., DÍEZ J. & PAJARES J.A. 2006: An operative kairomonal lure for managing pine sawyer beetle *Monochamus galloprovincialis* (Coleoptera: Cerambycidae). — *J. Appl. Entomol.* **131**: 13–20.
- KELSEY R.G. 1994: Ethanol synthesis in Douglas-fir logs felled in November, January, and March and its relationship to ambrosia beetle attack. — *Can. J. For. Res.* **24**: 2096–2104.
- KELSEY R.G. & JOSEPH G. 1999: Ethanol and water in *Pseudotsuga menziesii* and *Pinus ponderosa* stumps. — *J. Chem. Ecol.* **25**: 2779–2792.
- KIMMERER T.W. & KOZLOWSKI T.T. 1982: Ethylene, ethane, acetaldehyde, and ethanol production by plants under stress. — *Plant Physiol.* **69**: 840–847.
- KIRKENDALL L.R. & FACCOLI M. 2010: Bark beetles and pinhole borers (Curculionidae, Scolytinae, Platypodinae) alien to Europe. — *ZooKeys* **56**: 227–251.
- KNÍŽEK M. 2011: Scolytinae. In Löbl I. & Smetana A. (eds): *Catalogue of Palaearctic Coleoptera. Vol. 7.* Apollo Books, Stenstrup, pp. 204–251.
- KRESTOV P.V. 2003: Chapter 5. Forest vegetation of easternmost Russia (Russian Far East). In Kolbek J., Šrútek M. & Box E.O. (eds): *Forest Vegetation of Northeast Asia*. Kluwer Academic Publishers, Dordrecht, pp. 93–180.
- KRIVOLUTSKAYA G.O. 1996: Sem. Scolytidae – Koroedy [Fam. Scolytidae – Bark beetles]. In Lehr P.A. (ed.): *Opredelitel' nasekomykh Dal'nego Vostoka Rossii v shesti tomakh. [Key to the Insects of the Russian Far East.] Vol. 3: Zhestkokrylye, ili zhuki, Ch. 3.* Dal'nauka, Vladivostok, pp. 312–373 [in Russian].
- LABONTE J.R., MUDGE A.D. & JOHNSON K.J.R. 2005: Nonindigenous woodboring Coleoptera (Cerambycidae, Curculionidae: Scolytinae) new to Oregon and Washington, 1999–2002: consequences of the intracontinental movement of raw wood products and solid wood packing materials. — *Proc. Entomol. Soc. Wash.* **107**: 554–564.
- LACEY E.S., GINZEL M.D., MILLAR J.G. & HANKS L.M. 2004: Male-produced aggregation pheromone of the cerambycid beetle *Neoclytus acuminatus acuminatus*. — *J. Chem. Ecol.* **30**: 1493–1507.
- LACEY E.S., MOREIRA J.A., MILLAR J.G., RAY A.M. & HANKS L.M. 2007: Male-produced aggregation pheromone of the longhorned beetle *Neoclytus mucronatus mucronatus*. — *Entomol. Exp. Appl.* **122**: 171–179.
- LINDELÖW A., EIDMANN H.H. & NORDENHEIM H. 1993: Response on the ground of bark beetle and weevil species colonizing co-

- nifer stumps and roots to terpenes and ethanol. — *J. Chem. Ecol.* **19**: 1393–1403.
- LINDGREN B.S. & RAFFA K.F. 2013: Evolution of tree killing in bark beetles (Coleoptera: Curculionidae): trade-offs between the maddening crowds and a sticky situation. — *Can. Entomol.* **145**: 471–495.
- LINSLEY E.G. 1961: *The Cerambycidae of North America. Part I. Introduction*. Univ. California Publ. Entomol. 18, Berkeley, CA, pp. 1–97.
- MACIAS-SAMANO J.E., WALKERCHUK D., MILLAR J.G. & HANKS L.M. 2012: 2-Undecyloxy-1-ethanol in combination with other semiochemicals attracts three *Monochamus* species (Coleoptera: Cerambycidae) in British Columbia, Canada. — *Can. Entomol.* **144**: 821–825.
- MANDELSHTAM M.YU. & PETROV A.V. 2009: Family Scolytidae – bark beetles. In Storozhenko S.Yu. (ed.): *Insects of Lazovsky Nature Reserve*. Dal'nauka, Vladivostok, pp. 206–209 [in Russian].
- MILLER D.R. & RABAGLIA R.J. 2009: Ethanol and (-)-alpha-pinene: attractant kairomones for bark and ambrosia beetles in the southeastern US. — *J. Chem. Ecol.* **35**: 435–448.
- MILLER D.R., ASARO C., CROWE C.M. & DUERR D.A. 2011: Bark beetle pheromones and pine volatiles: Attractant kairomone lure blend for longhorn beetles (Cerambycidae) in pine stands of the southeastern United States. — *J. Econ. Entomol.* **104**: 1243–1257.
- MILLER D.R., CROWE C.M., DODDS K.J., GALLIGAN L.D., DE GROOT P., HOEBEKE E.R., MAYFIELD E.A., POLAND T.M., RAFFA K.F. & SWEENEY J.D. 2015a: Ipsenol, ipsdienol, ethanol and  $\alpha$ -pinene: Trap lure blend for Cerambycidae and Buprestidae (Coleoptera) in pine forests of eastern North America. — *J. Econ. Entomol.* **108**: 1837–1851.
- MILLER D.R., CROWE C.M., MAYO P.D., SILK P.J. & SWEENEY J.D. 2015b: Responses of Cerambycidae and other insects to traps baited with ethanol, 2,3-hexanediol and 3,2-hydroxyketone lures in North-Central Georgia. — *J. Econ. Entomol.* **108**: 2354–2365.
- MITCHELL R.F., GRAHAM E.E., WONG J.C.H., REAGEL P.F., STRIMAN B.L., HUGHES G.P., PASCHEN M.A., GINZEL M.D., MILLAR J.G. & HANKS L.M. 2011: Fuscumol and fuscumol acetate are general attractants for many species of Cerambycid beetles in the subfamily Lamiinae. — *Entomol. Exp. Appl.* **141**: 71–77.
- MITCHELL R.F., REAGEL P.F., WONG J.C.H., MEIR L.R., SILVA W.D., MONGOLD-DIERS J., MILLAR J.G. & HANKS L.M. 2015: Cerambycid beetle species with similar pheromones are segregated by phenology and minor pheromone components. — *J. Chem. Ecol.* **41**: 431–440.
- MOECK H.A. 1970: Ethanol as the primary attractant for the ambrosia beetle *Trypodendron lineatum* (Coleoptera: Scolytidae). — *Can. Entomol.* **102**: 985–995.
- NAKAMUTA K., LEAL W.S., NAKASHIMA T., TOKORO M., ONO M. & NAKANISHI M. 1997: Increase of trap catches by a combination of male sex pheromones and floral attractant in longhorn beetle, *Anaglyptus subfasciatus*. — *J. Chem. Ecol.* **23**: 1635–1640.
- NEHME M.E., KEENA M.A., ZHANG A., BAKER T.C. & HOOVER K. 2009: Attraction of *Anoplophora glabripennis* to male-produced pheromone and plant volatiles. — *Environ. Entomol.* **38**: 1745–1755.
- NOSEWORTHY M.K., HUMBLE L.M., SWEENEY J., SILK P.J. & MAYO P. 2012: Attraction of *Monarthrum scutellare* (Coleoptera: Curculionidae: Scolytinae) to hydroxy ketones and host volatiles. — *Can. J. For. Res.* **42**: 1851–1857.
- OLIVER J. & MANNION C.M. 2001: Ambrosia beetle (Coleoptera: Scolytidae) species attacking chestnut and captured in ethanol-baited traps in middle Tennessee. — *Environ. Entomol.* **30**: 909–918.
- PAJARES J.A., IBEAS F., DIEZ J.J. & GALLEGO D. 2004: Attractive responses by *Monochamus galloprovincialis* (Col., Cerambycidae) to host and bark beetle semiochemicals. — *J. Appl. Entomol.* **128**: 633–638.
- PAJARES J.A., ÁLVAREZ G., IBEAS F., GALLEGO D., HALL D.R. & FARMAN D.I. 2010: Identification and field activity of a male-produced aggregation pheromone in the pine sawyer beetle, *Monochamus galloprovincialis*. — *J. Chem. Ecol.* **36**: 570–583.
- PAJARES J.A., ÁLVAREZ G., HALL D.R., DOUGLAS P., CENTENO F., IBARRA L., SCHROEDER M., TEALE S.A., WANG Z., YAN S., MILLAR J.G. & HANKS L.M. 2013: 2-(Undecyloxy)-ethanol is a major component of the male-produced aggregation pheromone of *Monochamus sutor*. — *Entomol. Exp. Appl.* **149**: 118–127.
- RABAGLIA R., DUERR D., ACCIAVATTI R. & RAGENOVICH I. 2008: *Early Detection and Rapid Response for Non-native Bark and Ambrosia Beetles*. US Dept. Agriculture, Forest Service, Forest Health Protection, Washington, D.C., 12 pp.
- RABAGLIA R.J., VANDENBERG N.J. & ACCIAVATTI R.E. 2009: First records of *Anisandrus maiche* Stark (Coleoptera: Curculionidae: Scolytinae) from North America. — *Zootaxa* **2137**: 23–28.
- RAFFA K.F., PHILLIPS T.W. & SALOM S.M. 1993: Strategies and mechanisms of host colonization by bark beetles. In Schowalter T. & Filip G. (eds): *Beetle-Pathogen Interactions in Conifer Forests*. Academic Press, San Diego, CA, pp. 102–128.
- RANGER C.M., REDING M.E., PERSAD A.B. & HERMS D.A. 2010: Ability of stress-related volatiles to attract and induce attacks of *Xylosandrus germanus* and other ambrosia beetles. — *Agric. For. Entomol.* **12**: 177–185.
- RANGER C.M., REDING M.E., GANDHI K.J.K., OLIVER J.B., SCHULTZ P.B., CAÑAS L. & HERMS D.A. 2011: Species-dependent influence of (-)- $\alpha$ -pinene on attraction of ambrosia beetles (Coleoptera: Curculionidae: Scolytinae) to ethanol-baited traps in nursery agroecosystems. — *J. Econ. Entomol.* **104**: 674–679.
- RASSATI D., TOFFOLO E.D., ROQUES A., BATTISTI A. & FACCOLI M. 2014: Trapping wood boring beetles in Italian ports: a pilot study. — *J. Pest Sci.* **87**: 61–69.
- RAY A.M., ŽUNIĆ A., ALTEN R.L., McELFRESH J.S., HANKS L.M. & MILLAR J.G. 2011: cis-Vaccenyl acetate, a female-produced sex pheromone component of *Ortholeptura valida*, a longhorn beetle in the subfamily Lepturinae. — *J. Chem. Ecol.* **37**: 173–178.
- RAY A.M., SWIFT I.P., McELFRESH J.S., ALTEN R.L. & MILLAR J.G. 2012: (R)-desmolactone, a female-produced sex pheromone component of the cerambycid beetle *Desmocerus californicus californicus* (subfamily Lepturinae). — *J. Chem. Ecol.* **38**: 137–157.
- RAY A.M., MILLAR J.G., MOREIRA J.A., McELFRESH J.S., MITCHELL R.F., BARBOUR J.D. & HANKS L.M. 2015: North American species of cerambycid beetles in the genus *Neoclytus* share a common hydroxyhexanone-hexanediol pheromone structural motif. — *J. Econ. Entomol.* **108**: 1860–1868.
- REDDEMANN J. & SCHOPF R. 1996: The importance of monoterpenes in the aggregation of the spruce bark beetle *Ips typographus* (Coleoptera: Scolytidae: Ipsinae). — *Entomol. Gener.* **21**: 69–80.
- REDDY G.V.P., FETTKÖTHER R., NOLDT U. & DEITNER K. 2005: Enhancement of attraction and trap catches of the old-house borer, *Hylotrupes bajulus* (Coleoptera: Cerambycidae), by combination of male sex pheromone and monoterpenes. — *Pest Manag. Sci.* **61**: 699–704.
- RYALL K., SILK P., WEBSTER R.P., GUTOWSKI J.M., MENG Q., LI Y., GAO W., FIDGEN J., KIMOTO T., SCARR T., MASTRO V. & SWEENEY

- J.D. 2015: Further evidence that monochamol is attractive to *Monochamus* spp., with attraction synergized by host plant volatiles and bark beetle pheromones. — *Can. Entomol.* **147**: 564–579.
- SALOM S.M. & MCLEAN J.A. 1990: Flight and landing behavior of *Trypodendron lineatum* (Coleoptera: Scolytidae) in response to different semiochemicals. — *J. Chem. Ecol.* **16**: 2589–2604.
- SAS INSTITUTE 2002–2003: *Proprietary Software Release 9.1*. SAS Institute Inc., Cary, NC.
- SCHROEDER L.M. 1988: Attraction of the bark beetle *Tomicus piniperda* and some other bark- and wood-living beetles to the host volatiles  $\alpha$ -pinene and ethanol. — *Entomol. Exp. Appl.* **46**: 203–210.
- SCHROEDER L.M. & LINDELÖW A. 1989: Attraction of scolytids and associated beetles by different absolute amounts and proportions of alpha-pinene and ethanol. — *J. Chem. Ecol.* **15**: 807–817.
- SHORE T.L. & LINDGREN B.S. 1996: Effect of ethanol and  $\alpha$ -pinene on response of ambrosia beetle, *Trypodendron lineatum*, to lineatin-baited funnel and drainpipe traps. — *J. Chem. Ecol.* **22**: 2187–2196.
- SILK P.J., SWEENEY J., WU J., PRICE J., GUTOWSKI J.M. & KETTEL E. 2007: Evidence for a male produced pheromone in *Tetropium fuscum* (F.) and *Tetropium cinnamopterum* (Kirby) (Coleoptera: Cerambycidae). — *Naturwissenschaften* **94**: 697–701.
- SOLOMON J.D. 1995: *Guide to Insect Borers in North American Broadleaf Trees and Shrubs*. U.S. Dept. Agric. Forest Service, Agric. Handbook 706, Washington, D.C, 735 pp.
- SUBANSENEE W. 1971: Flight period and emergence in Denmark of the adult bark beetle *Hylurgops palliatus* Gyll. (Coleoptera, Scolytidae). — *Copenh. R. Vet. Agric. Univ. Yearbook* **1971**: 114–123.
- SWEENEY J.D., GUTOWSKI J.M., PRICE J. & DE GROOT P. 2006: Effect of semiochemical release rate, killing agent, and trap design on detection of *Tetropium fuscum* (F.) and other longhorn beetles (Coleoptera: Cerambycidae). — *Environ. Entomol.* **35**: 645–654.
- SWEENEY J.D., SILK P.J., GUTOWSKI J.M., WU J., LEMAY M.A., MAYO P.D. & MAGEE D.I. 2010: Effect of chirality, release rate, and host volatiles on response of *Tetropium fuscum* (F.), *Tetropium cinnamopterum* (Kirby), and *Tetropium castaneum* (L.) (Coleoptera: Cerambycidae) to the aggregation pheromone, fuscumol. — *J. Chem. Ecol.* **36**: 1309–1321.
- SWEENEY J.D., SILK P.J. & GREBENNIKOV V. 2014: Efficacy of semiochemical-baited traps for detection of longhorn beetles (Coleoptera: Cerambycidae) in the Russian Far East. — *Eur. J. Entomol.* **111**: 397–406.
- TEALE S.A., WICKHAM J.D., ZHANG F., SU J., CHEN Y., XIAO W., HANKS L.M. & MILLAR J.G. 2011: A male-produced aggregation pheromone of *Monochamus alternatus* (Coleoptera: Cerambycidae), a major vector of pine wood nematode. — *J. Econ. Entomol.* **104**: 1592–1598.
- WERMELINGER B. 2004: Ecology and management of the spruce bark beetle *Ips typographus* – a review of recent research. — *For. Ecol. Manag.* **202**: 67–82.
- WOOD S.L. & BRIGHT D.E. 1992: A catalog of Scolytidae and Platypodidae (Coleoptera), Part 2: Taxonomic index. — *Great Basin Nat. Mem.* **13**: 1–1553.
- WONG J.C.H., MITCHELL R.F., STRIMAN B., MILLAR J.G. & HANKS L.M. 2012: Blending synthetic pheromones of cerambycid beetles to develop trap lures that simultaneously attract multiple species. — *J. Econ. Entomol.* **105**: 906–915.
- YAN Z., SUN J., DON O. & ZHANG Z. 2005: The red turpentine beetle, *Dendroctonus valens* LeConte (Scolytidae): an exotic invasive pest of pine in China. — *Biodiver. Conserv.* **14**: 1735–1760.
- ZAR J.H. 1999: *Biostatistical Analysis, 4th ed.* Prentice Hall, Upper Saddle River, NJ, 663 pp.

Received September 18, 2015; revised and accepted December 2, 2015  
Published online January 11, 2016