

2-Undecyloxy-1-ethanol in combination with other semiochemicals attracts three *Monochamus* species (Coleoptera: Cerambycidae) in British Columbia, Canada

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Abstract—Two species in the genus *Monochamus* Dejean (Coleoptera: Cerambycidae: Lamiinae) have recently been shown to have the same male-produced sex pheromone, 2-undecyloxy-1-ethanol (monochamol), suggesting that other congeners may share the same pheromone. We tested that hypothesis by conducting field bioassays of monochamol, in combination with bark-beetle pheromones and the host plant volatiles ethanol and α -pinene, in southern British Columbia, Canada. We captured 603 *Monochamus clamator* (LeConte), 63 *Monochamus obtusus* Casey, 245 *Monochamus scutellatus* (Say) (tribe Monochamini), and 42 *Acanthocinus princeps* (Walker) (tribe Acanthocinini). All three *Monochamus* species were significantly attracted to the combination of monochamol and host plant volatiles, whereas bark-beetle pheromones plus plant volatiles and plant volatiles alone were minimally attractive. Adding bark-beetle pheromones to the monochamol plus plant volatiles treatment synergised attraction of *M. clamator*, but not the other two *Monochamus* species. *Acanthocinus princeps* was most strongly attracted to the combination of bark-beetle pheromones and plant volatiles, and did not appear to be affected by the presence or absence of monochamol in baits. We conclude that monochamol is a likely pheromone component for the three *Monochamus* species, and that monochamol plus host plant volatiles is an effective attractant for these and perhaps other North American *Monochamus* species.

Résumé—On a démontré récemment que deux espèces du genre *Monochamus* Dejean (Coleoptera: Cerambycidae: Lamiinae) possédaient la même phéromone sexuelle mâle, le 2-undécyloxy-1-éthanol (monochamol), ce qui laisse croire que d'autres congénères pourraient aussi avoir cette même phéromone. Nous avons testé cette hypothèse par des bioessais de monochamol en nature en combinaison avec des phéromones de scolytes et des produits volatils de la plante-hôte, l'éthanol et l' α -pynène, dans le sud de la Colombie-Britannique, Canada. Nous avons capturé 603 *Monochamus clamator* (LeConte), 63 *Monochamus obtusus* Casey, 245 *Monochamus scutellatus* (Say) (tribu des Monochamini) et 42 *Acanthocinus princeps* (Walker) (tribu des Acanthocinini). Les trois espèces de *Monochamus* sont fortement attirées par la combinaison de monochamol et de produits volatils de la plante-hôte, alors que les phéromones de scolytes additionnées de produits volatils de la plante hôte et les produits volatils de la plante hôte seuls exercent très peu d'attraction. L'addition de phéromones de scolytes à la combinaison de monochamol et de produits volatils de la plante hôte a un effet synergique d'attraction chez *M. clamator*, mais non chez les deux autres espèces de *Monochamus*. *Acanthocinus princeps* est le plus fortement attiré par la combinaison de phéromones de scolytes et de produits volatils de plante et ne semble pas être affecté par la présence ou l'absence de monochamol dans les appâts. Nous concluons que le monochamol est vraisemblablement l'une des composantes de la phéromone des trois espèces de *Monochamus* et que la combinaison de monochamol et de produits volatils de la plante hôte a un pouvoir efficace d'attraction chez ces espèces et peut-être chez d'autres espèces nord-américaines de *Monochamus*.

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Until recently, little was known about the production and use of semiochemicals by cerambycid beetles for intraspecific and possibly interspecific communication (Allison *et al.* 2004). Historically, attractants used for trapping cerambycids have included volatiles associated with larval host plants, such as ethanol, turpentine, and α -pinene, or various fermented sugar baits (*e.g.*, see Champlain and Kirk 1932; Phillips *et al.* 1988). However, the situation has been changing rapidly over the past decade, with pheromones or related attractants identified for ~100 cerambycid species since 2004 (*e.g.*, Allison *et al.* 2004; Silk *et al.* 2007; Millar *et al.* 2009; Barbour *et al.* 2011).

In addition, better and more specific baits have been developed for a few cerambycid species based on the observation that they are cross-attracted to bark-beetle semiochemicals. Cross-attraction could be adaptive for cerambycids because their larvae feed on larvae of bark beetles and also because bark-beetle pheromones could advertise a suitable host material (*e.g.*, Allison *et al.* 2003, 2004). For example, Miller *et al.* (2011) attracted large numbers of *Monochamus scutellatus* (Say), *Monochamus titillator* (Fabricius), and two other lamiine species, *Acanthocinus obsoletus* (Olivier) and *Acanthocinus nodosus* (Fabricius), in the southeastern United States, using a mixture of ethanol, α -pinene, ipsenol, and ipsdienol. In similar work in Spain, Ibeas *et al.* (2006) demonstrated that a mixture of α -pinene, ipsenol, and 2-methyl-3-buten-2-ol can be used as a practical management tool for *Monochamus galloprovincialis* (Olivier). This work was followed up by a search for possible pheromones for *M. galloprovincialis* by Pajares *et al.* (2010), who found that males produced 2-undecyloxy-1-ethanol (henceforth monochamol). This compound, in combination with host volatiles, was shown to attract beetles of both sexes under laboratory and field conditions, providing the first identification of a pheromone for beetles in the genus *Monochamus* Dejean (Pajares *et al.* 2010).

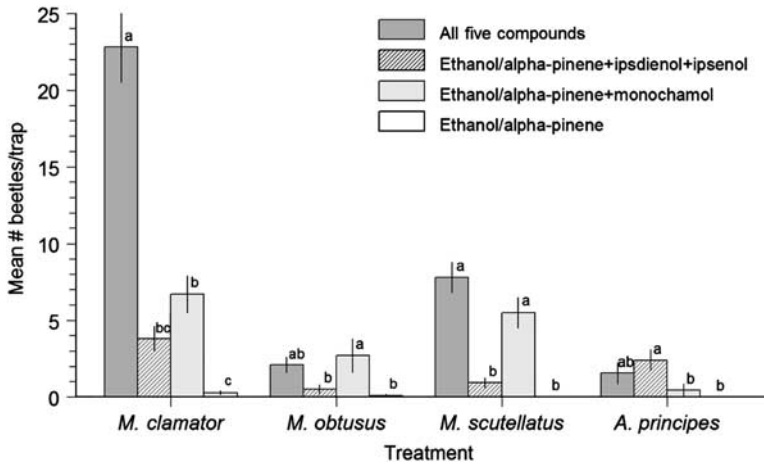
More recently, Teale *et al.* (2011) demonstrated that monochamol appeared to be the sole aggregation pheromone component for another *Monochamus* species, the Japanese pine sawyer, *Monochamus alternatus* Hope, with both sexes being attracted. The use of monochamol as a pheromone by two congeneric species is consistent with other recent studies that have shown that

pheromone structures often are highly conserved within the Cerambycidae, with species in the same genus, tribe, or subfamily frequently using the same pheromone components (*e.g.*, Hanks *et al.* 2007; Silk *et al.* 2007; Barbour *et al.* 2011; Mitchell *et al.* 2011). We therefore tested the hypothesis that monochamol is an attractant and possible pheromone component for other *Monochamus* species. Here, we report the results from field bioassays of monochamol in combination with blends of bark-beetle semiochemicals and host volatiles, conducted in a conifer forest in southern British Columbia, Canada.

The experiment was conducted in a forested area dominated by Ponderosa pine, *Pinus ponderosa* Lawson and Lawson (Pinaceae), ~3.5 km south of Princeton (49°25'49.99"N, 120°29'40.70"W), British Columbia, Canada. Trapping occurred from 6 August–26 September 2011, using multiple-funnel traps (Synergy Semiochemicals Corp., Burnaby, British Columbia, Canada). Monochamol (98% pure), ipsenol (93% pure), and ipsdienol (93% pure) were obtained from Bedoukian Research (Danbury, Connecticut, United States of America). The release devices, produced by Synergy Semiochemicals Corp., included plastic sachets for release of ethanol (10–20 mg/day, 15 ml load per lure), plastic bottles for release of α -pinene (100 mg/day, 15 ml per lure), and bubble caps for release of ipsenol (400 μ g/day, 100 mg per lure), ipsdienol (200 μ g/day, 100 mg per lure), and monochamol (0.7 mg/day, 95 mg per lure). Trap collection cups contained a killing agent (sections of Ortho[®] No-pest[®] strips; dichlorvos, The Scotts Miracle-Gro Company, Marysville, Ohio, United States of America). Treatments were as follows: ethanol + α -pinene (plant volatiles control); ethanol + α -pinene + monochamol; ethanol + α -pinene + ipsenol + ipsdienol; and the complete combination of all five components, ethanol + α -pinene + ipsenol + ipsdienol + monochamol.

Four traps were set up in linear transects in each of six blocks (15 m between traps and blocks) and treatments were assigned randomly to traps for a split-plot design with two factors (Steele and Torrie 1980): treatment (4 levels) and date (3 levels), with a total of six blocks (replicates), respectively. Treatments were re-randomised within blocks three times during the experiment. Insects were collected weekly and captured

Fig. 1. Mean (± 1 SE) number of beetles captured per trap with respect to composition of the lure for three *Monochamus* and one *Acanthocinus* species. Means significantly different for *Monochamus clamator*, *Monochamus obtusus*, *Monochamus scutellatus*, and *Acanthocinus princeps*: Friedman's $Q_{3,72} = 45.7$, $P < 0.0001$; $Q_{3,40} = 14.3$, $P = 0.0025$; $Q_{3,68} = 42.7$, $P < 0.0001$; and $Q_{3,36} = 12.9$, $P = 0.005$, respectively. Means with the same letters within species are not significantly different (REGWQ means-separation test) at $P < 0.05$.



insects were not sexed. Cerambycidae classification used in this paper follows Lingafelter (2007).

Differences between treatment means, blocked by site, date, and block, were tested separately for each species using the nonparametric Friedman's Test (PROC FREQ, option CMH; SAS Institute 2001). Differences between pairs of means were tested with the REGWQ means-separation test, which controls for maximum experiment-wise error rates (PROC GLM; SAS Institute 2001). Replicates with fewer than two beetles were dropped from analyses to optimise sample sizes.

Voucher specimens have been deposited in the Spencer Entomological Collection at the Beaty Biodiversity Museum, Vancouver, British Columbia, Canada.

During the course of the experiment, we captured a total of 953 cerambycid beetles of two genera in the subfamily Lamiinae, including 603 *Monochamus clamator* (LeConte), 63 *Monochamus obtusus* Casey, 245 *M. scutellatus* (tribe Monochamini), and 42 *Acanthocinus princeps* (Walker) (Tribe Acanthocinini). Seventeen *Xylotrechus longitarsis* Casey (subfamily Cerambycinae) also were captured (too few for statistical analysis).

For all three *Monochamus* species, traps baited with the combination of monochamol and the host

plant volatiles caught significantly more beetles than plant volatiles controls (Fig. 1), whereas the bark-beetle pheromones plus plant volatile treatment was not significantly different than host volatiles controls. The same plant volatiles were found to synergise monochamol for the congener *Monochamus carolinensis* (Olivier) during a concurrent study run in Illinois, United States of America (Hanks *et al.* 2012). The combination of all five compounds (ethanol, α -pinene, ipsdienol, ipsenol, and monochamol) attracted three times more *M. clamator* than the plant volatiles + monochamol treatment (Fig. 1), but the bark-beetle pheromones did not enhance attraction of the other two *Monochamus* species. The fact that the bark-beetle pheromones did not significantly increase attraction of *M. scutellatus* was inconsistent with the results of earlier studies that had reported that the same compounds greatly increased attraction of both *M. scutellatus* and *M. clamator* when combined with ethanol and α -pinene (Allison *et al.* 2001; Miller *et al.* 2011).

Acanthocinus princeps showed a different pattern in its response to the treatments, with the greatest numbers being attracted to the plant volatiles plus bark-beetle pheromones treatment (Fig. 1). There was no indication that attraction

of this species was affected by monochamol. Synergism between ethanol, α -pinene, and these bark-beetle pheromones has been reported for congeneric species (Miller *et al.* 2011). The lack of attraction of *A. princeps* to monochamol was consistent with the results of previous field studies in which only *Monochamus* species, and no other lamiinae species, were attracted to that compound (Pajares *et al.* 2010; Teale *et al.* 2011).

Relatively few of the lamiinae beetles were attracted to traps baited with plant volatiles, despite *Monochamus* species being reported to be strongly attracted to ethanol and α -pinene (e.g., Miller 2006; Costello *et al.* 2008). In our studies, the apparent lack of response to plant volatiles that others had shown to attract *Monochamus* spp. may have been due to competition among traps, such that those baited with both monochamol and plant volatiles drew beetles away from traps baited with plant volatiles alone (e.g., Hanks *et al.* 2012).

In summary, our data strongly supports the hypothesis that monochamol is a common pheromone component shared among *Monochamus* species. The marked increase in trapping efficiency with baits containing blends of monochamol with host volatiles, coupled with the fact that the pheromone is relatively inexpensive to produce, suggests such baits could be rapidly incorporated into generic surveillance programmes for *Monochamus* spp.

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