Treating Panel Traps With a Fluoropolymer Enhances Their Efficiency in Capturing Cerambycid Beetles

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ABSTRACT The most effective traps for capturing cerambycids and other saproxylic beetles are intercept designs such as funnel traps and cross-vane panel traps. We have observed that adult cerambycids of many species often alight and walk upon panel traps, and few are actually captured. In an effort to improve trap capture and retention, researchers have treated intercept traps with Rain-X, a polysiloxane formulation that renders surfaces more slippery. Here, we summarize experiments that compared the efficacies of Rain-X and Fluon, a PTFE fluoropolymer dispersion, as surface treatments for panel traps that are deployed to capture cerambycid beetles, using untreated traps as controls. Fluon-treated traps captured on average >14× the total number of beetles, and many more cerambycid species, than were captured by Rain-X–treated or control traps. Beetles captured by Fluon-treated traps ranged in body length by 350%. They could not walk on vertical panels treated with Fluon but easily walked on those treated with Rain-X and on untreated traps. Moreover, a single Fluon treatment remained effective for the entire field season, even in inclement weather. We conclude that treating panel traps with Fluon greatly improves their efficiency in capturing cerambycid beetles. This increased efficacy will be particularly important when traps are deployed to detect very low-density populations, such as incursions of exotic species, or remnant communities of rare and endangered species. The influence of Fluon on trap efficiency may vary with product formulation and its source and also with climatic conditions.

KEY WORDS wood-boring insect, Cerambycidae, Fluon, pheromone, trap

A variety of traps have been designed specifically to catch cerambycids and other saproxylic beetles (Southwood and Henderson 2000), and among the most effective are intercept designs such as funnel traps and cross-vane panel traps (McIntosh et al. 2001, Morewood et al. 2002, Sweeney et al. 2004, Nehme et al. 2009). Intercept traps are used for monitoring the spread of exotic and invasive species of cerambycids (e.g., Sweeney et al. 2004), estimating population densities of threatened species (e.g., Buse et al. 2008), and identifying geographic patterns in biodiversity, ecology, and behavior (Jacobs et al. 2007, Wermelinger et al. 2007). Some researchers condition intercept traps with Rain-X (SOPUS Products, Houston, TX) to render their surfaces more slippery, with the goal of increasing trapping efficacy and retention of insects in traps (Czokajlo et al. 2003, de Groot and Nott 2003, Sweeney et al. 2004). Rain-X is a polysiloxane liquid that is marketed as a treatment for repelling water from glass, such as automobile windshields.

We have used cross-vane panel traps, conditioned with Rain-X, in our field research on volatile pheromones of cerambycid beetles for species that range in body size from ≈4 to 50 mm in length (Hanks et al. 2007; Lacey et al. 2004, 2008, 2009; Ray et al. 2009; J.D.B. et al., unpublished data). However, during the course of these studies, we have observed that adult cerambycids of many species are attracted to traps in great numbers but often alight and walk upon traps conditioned with Rain-X, and relatively few are actually captured (unpublished data). We therefore began to search for methods of improving the capture efficiency and retention of panel traps.

Here, we describe the results of experiments that tested the effect of the fluoropolymer Fluon PTFE (AGC Chemicals Americas, Inc., Exton, PA), applied as a surface conditioner, on the efficiency with which panel traps capture and retain cerambycid beetles. Fluon is available as an aqueous dispersion that dries to leave a slippery film. It commonly is applied to the upper walls of containers used to house insects in insectaries and to walls of behavioral arenas for studies of insect behavior, to prevent escape (Radinovsky and Krantz 1962, Suarez and Case 2002). To our knowledge, there has been little research to evaluate the effect of Fluon in enhancing the efficiency of insect traps for field research (but see Valles et al. 1991).

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Thus, we conditioned the panels and bases of pheromone-baited panel traps with Fluon or Rain-X, or left traps untreated, and compared the number of beetle species and individuals that they captured from a natural community of cerambycids. We also conducted studies to assess how trap conditioning influenced the mobility of beetles on trap surfaces and the likelihood that beetles would escape from traps.

Materials and Methods

Experiment 1 tested the effect of trap conditioning on numbers of beetles captured and was conducted at Allerton Park (Piatt County, IL), a University of Illinois Natural Area that is a 600-ha mixed hardwood forest, from 25 June to 27 July 2009. Weather during this period was poor, with 13 d of rain and a total rainfall of 13.1 cm (average ± SD maximum daily air temperature, 25.9 ± 3.1°C; wind speed at dusk, 10.9 ± 3.8 kph; www.wunderground.com). Inclement weather accounts for the reduced number of sample days in the data set.

We used cross-vane panel traps (black corrugated plastic, 1.2 m in height by 0.3 m in width; model PT Intercept, APTIV, Portland, OR) that were modified to capture beetles alive by replacing the supplied collection basin with a plastic funnel that guided beetles into a plastic jar. The funnel and jar apparatus was constructed as follows: the spout of a ≈2-liter plastic funnel was cut to yield a 35-mm-diameter opening; a ≈7.5-cm-diameter hole was cut into the center of the threaded lid of an ≈2-liter plastic jar (P.E.T.; model 55-650C, General Bottle Supply Company, Los Angeles, CA). The funnel was glued into the lid such that the pointed end extended ≈3 cm inside the jar when the lid was screwed on. The funnel and jar apparatus was wired to the bottom of the panel trap. Traps were hung from L-shaped frames constructed of 1.5-cm i.d. polyvinyl chloride irrigation pipe (SCH40, JM Eagle, Los Angeles, CA) with a 1.5-m-long upright connected with a T-fitting to a 20-cm long arm having a loop of wire at the end from which the trap was suspended. The frame upright was mounted on a 1.5-m section of steel reinforcing bar (1.0 cm in diameter) that was driven part way into the ground.

We conditioned trap panels, the interior surfaces of their bases, and jar funnels with Fluon (Fisher Scientific, Pittsburgh, PA) or Rain-X. Untreated traps were used as controls. We applied Fluon with cotton pads, and it dried to a whitish, blotchy residue. Rain-X was applied from a spray bottle and spread evenly over the trap surface with a paper towel. Traps conditioned with Rain-X seemed shinier than control traps. We did not clean traps, or reapply conditioning materials, during the experiment.

All traps were baited with racemic 3-hydroxyhexan-2-one, synthesized from 1-hexyn-3-ol as described in Millar et al. (2009). The (*R*)-enantiomer of 3-hydroxyhexan-2-one is an important component, or the sole component, of aggregation pheromones for many cerambycid species in the subfamily Cerambycinae, and its attractiveness to beetles is generally unaffected by the presence of the (*S*)-enantiomer when the racemate is used as a trap lure (e.g., Hanks et al. 2007; Lacey et al. 2007, 2009). Pheromone lures consisted of clear polyethylene sachets (press-seal bags, Bagette model 14770, 5.1 by 7.6 cm, 0.05-mm wall thickness, Cousin Corp., Largo, FL) that were loaded with 50 mg of the racemic pheromone in 1 ml of 95% ethanol. Ethanol is an efficient carrier of the synthetic pheromone and has negligible if any activity alone at these volumes (e.g., Hanks et al. 2007). Lures lasted ≈5 d in the field. Control ("blank") lures consisted of sachets loaded with 1 ml of ethanol. The experiment included the following trap/lure treatments: Fluon/pheromone, Rain-X/pheromone, and control/pheromone traps (to test the conditioning effect), Fluon/blank traps (to compare with the Fluon/pheromone treatment to test the influence of the pheromone), and control/blank traps (to compare with the Fluon/blank treatment to test the influence of Fluon alone, and with the control/pheromone treatment to test the influence of pheromone lures in traps that are untreated). We did not include a Rain-X/blank treatment because our previous research already had confirmed that very few cerambycid beetles respond to such traps (e.g., Hanks et al. 2007).

Traps were set up in a linear transect through the woods, in three blocks that each contained one trap for each treatment (20 m apart, position assigned randomly), with blocks separated by at least 20 m. Traps were checked for beetles every 1–2 d, and captured beetles were returned to the laboratory for identification. We sexed beetles of the two best-represented species (see Results), *Neoclytus m. mucronatus* (F.) and *Xylotrechus colonus* (F.). A few beetles could not be sexed because they had been damaged in trap jars or escaped during handling. Trap treatments were rotated within blocks and lures were replaced every 5 d.

Differences between trap treatments in the number of beetles captured per trap were tested with the nonparametric Friedman's test (PROC FREQ with CMH option; SAS Institute 2001) because assumptions of analysis of variance (ANOVA) were violated by heteroscedasticity (Sokal and Rohlf 1995). We include in that analysis only *N. m. mucronatus* and *X. colonus* because the numbers of beetles of the remaining species were insufficient to allow meaningful statistical comparison. We did not include a beetle species effect in the analysis because the two species responded to trap treatments in a similar manner (Table 1; species term in ANOVA, $P > 0.05$). We therefore combined the data for the two species, which improved the statistical power of the test of trap treatment on capture rate of cerambycine species in general. Date and block combinations that contained fewer than 10 beetles were eliminated from the analysis ($N = 13$ replicates remaining). Low numbers of captured beetles on some dates were attributable to unfavorable weather (e.g., rain, wind, cool temperatures). We tested differences between the preplanned pairs of treatment means (as defined above) with orthogonal contrasts (Sokal and Rohlf 1995; PROC

Table 1. Identity and number of cerambycine beetles captured with panel traps during experiments 1 and 2 according to trap and lure treatment[a]

Tribe	Species	Trap/lure treatment						
		Experiment 1					Experiment 2	
		Fluon/ pheromone	Rain-X/ pheromone	Control/ pheromone	Fluon/ blank	Control/ blank	Fluon/ pheromone	Rain-X/ pheromone
Elaphidiini	*Anelaphus parallelus* (Newman)	1						
Elaphidiini	*Anelaphus pumilus* (Newman)	4						
Elaphidiini	*Anelaphus villosus* (F.)	1					1	
Elaphidiini	*Elaphidion mucronatum* (Say)	4					1	
Elaphidiini	*Parelaphidion aspersum* (Haldeman)	4					2	
Elaphidiini	*Parelaphidion incertum* (Newman)	1						
Anaglyptini	*Cyrtophorus verrucosus* (Olivier)	2						
Clytini	*Neoclytus a. acuminatus* (F.)	6					3	1
Clytini	*Neoclytus m. mucronatus* (F.)	61M, 68F, 4U	5M, 2F	7M, 5F	1F		25M, 29F	5M
Clytini	*Sarosesthes fulminans* (F.)	1						
Clytini	*Xylotrechus colonus* (F.)	33M, 35F, 1U	1M, 5F	3M, 2F, 1U	1U		2M, 9F	1M
Tillomorphini	*Euderces picipes* (F.)	4						
Total no. species (tribes)		12 (4)	2 (1)	2 (1)	2 (1)	0	6 (2)	3 (1)

[a] Traps were conditioned with Fluon, Rain-X, or were untreated (control traps), and lures were loaded with synthetic pheromone in ethanol ("pheromone") or ethanol alone ("blank"). Sexes of beetles were determined only for the species *N. m. mucronatus* and *X. colonus* (F, female; M, male; U, unknown).

GLM contrast statement, SAS Institute 2001). We also used the Shannon–Wiener index (H' 160 ; Peet 1974, Hayek and Buzas 1997) to quantify the species diversity of cerambycines that were captured in the different treatments and tested differences in diversity between treatments with Student's t-test (Magurran 1988).

We used the data from experiment 1 to test whether the effect of Fluon conditioning on trap capture rate would change over the ≈1-mo period that traps were exposed to the elements. As mentioned, heavy rain fell on many days during the experiment, but traps were never retreated. For this analysis, we again combined data for *N. m. mucronatus* and *X. colonus.* We include only data for treatments with pheromone lures because few beetles were captured by traps with blank lures (see Results). We also averaged the data for the Rain-X/pheromone and control/pheromone treatments, by date and block, into a single "non-Fluon" treatment because Rain-X conditioning had no significant effect on trap capture rate (see Results). We tested the hypothesis that the percentage of the total number of beetles captured per day would decline over time for the Fluon/pheromone treatment as that conditioning treatment degraded. The linear relationship between this percentage and date was tested with regression analysis (PROC REG, SAS Institute 2001), and the hypothesis would be supported by a significant and negative relationship. Sample dates on which fewer than five beetles were captured were eliminated from the data set (12 dates remaining).

Experiment 2 was an independent field bioassay, at a different site, to compare more directly the efficiency of Fluon/pheromone and Rain-X/pheromone treatments (conditioned and baited as described above). The study site was the municipal Landscape Recycling Center in Urbana, IL (Champaign Co.), an 11-ha area where plant waste, including woody material, is recycled into mulch and compost. The Center is surrounded by a 54-ha natural area with tallgrass prairie and mixed hardwood forest habitats. On 22 June 2009, we set up a linear transect of five blocks of traps, each of which contained one Fluon/pheromone and one Rain-X/pheromone trap (20 m apart). Blocks were separated by at least 20 m, with trap treatments alternating down the transect. The bioassay was run until 23 July 2009 (weather conditions as described above), with beetles collected every 1–3 d, traps rotated within blocks and lures replaced every 5 d. We tested differences between treatments in species diversity of cerambycine beetles, and numbers of beetles captured (*N. m. mucronatus* and *X. colonus*, combined) as described above. The analysis included only date and block combinations that contained at least three beetles ($N = 10$ replicates; this threshold number of beetles was lower than in experiment 1 due to the lower population density at the study site).

We combined data from experiments 1 and 2 to maximize the statistical power for testing the hypothesis that adult female and male beetles (*N. m. mucronatus* and *X. colonus*) are influenced differently by trap treatments. We used data only for traps that were baited with pheromone lures, and tested differences between treatments in sex ratios of beetles with the G goodness-of-fit test (Sokal and Rohlf 1995; sex ratio of beetles in Fluon treatments used to calculate the "expected" number of each sex for Rain-X and control treatments). The hypothesis would be supported if trap treatments differed significantly in beetle sex ratio. Statistical power of the test was limited by the relatively small number of beetles captured by Rain-X and control traps (see Results).

The large number of beetles that were captured by Fluon/pheromone traps (see Results) raised a new hypothesis: Traps with Fluon act as sinks during bioassays, removing beetles from the habitat that otherwise eventually would have been captured by Rain-X/pheromone or control/pheromone traps. Experiment 3 tested this hypothesis with an independent bioassay at Allerton Park from 31 July to 7 August 2009 (average maximum air temperatures, 25.5 ± 1.2°C; wind speed at dusk, 7.9 ± 3.1 kph; rain on 3 d, total precipitation, 2.0 cm). More specifically, the experiment was designed to test the secondary hypothesis that Rain-X/pheromone traps would capture fewer beetles when they were in proximity to Fluon/pheromone traps. Our experimental treatments were sets of two traps that were 3 m apart: 1) a Rain-X/pheromone trap neighboring a Fluon/pheromone trap and 2) two neighboring Rain-X/pheromone traps. For the latter sets, we randomly designated one of the Rain-X traps as the "study" trap (i.e., the trap that would be influenced by its neighbor). The Rain-X traps that neighbored Fluon traps were the study traps within those sets. Sets of traps were positioned in a linear transect, with two sets (one of each combination of treatments) constituting a block (sets separated by 20 m), and with five such blocks that were separated by at least 20 m. Beetles were collected every 1–2 d. Differences between treatments in the number of adult *N. m. mucronatus* and *X. colonus* that were captured by Rain-X study traps were tested by ANOVA (data were homoscedastic) blocked by day and trap block. All data were included in the analysis because at least 10 beetles were captured on every sample date. Our secondary hypothesis would be supported if Rain-X study traps that neighbored another Rain-X trap captured more beetles than Rain-X traps that neighbored a Fluon trap.

Experiment 4 was a laboratory study of the influence of Rain-X and Fluon conditioning on the mobility of beetles on traps. Test animals were adult *Megacyllene robiniae* (Förster), a diurnal species that we had collected from inflorescences of goldenrod (*Solidago* species) 4 d earlier. Beetles were housed in the laboratory in an aluminum screen cage and provided 10% sucrose solution and fresh inflorescences of goldenrod as food. We used the funnel-shaped bases of the panel traps for this study, conditioning one with Fluon (as described above), another with Rain-X, and leaving a third untreated (control). We included a fourth trap base, from a trap that was conditioned with Fluon and left in the field from June through mid-September, so that we could determine whether exposure to the elements would alter the effect of Fluon on beetle mobility. Trap bases were positioned, tapered end down, on a laboratory bench with the opening flush against the bench. Thus, beetles could be released individually at the bottom and attempt to escape by walking up the side. We allowed each beetle 2 min to reach the rim by walking (all beetles walked rather than attempting to fly), and videotaped each trial. We tested ten beetles (both sexes, but chosen arbitrarily for each trial) per treatment, using each beetle only once. Differences between treatments in the percentage of beetles that escaped were tested with the *G* goodness-of-fit test. The experiment was conducted from 1300 to 1500 hours on 15 September 2009 under laboratory conditions (≈20°C, ≈50% RH, and a photoperiod of ≈12:12 [L:D] h).

Experiment 5 further evaluated the influence of trap conditioning on mobility of beetles, but more specifically on their ability to escape from trap jars (often a significant problem with intercept traps that lack a killing agent; Morewood et al. 2002, de Groot and Nott 2003, Sweeney et al. 2006). We conditioned the interior surfaces of trap jars and their funnel attachments (see trap design, above) with Fluon or Rain-X, or left them untreated (controls; three jars per treatment). Jars were positioned arbitrarily on the floor of a polyethylene camping tent (≈2 m square by 1.5 m in height) in the backyard of a private residence in Urbana, IL (Champaign Co.) during 13–16 September 2009 (maximum air temperatures, 27–29°C; partly cloudy). We again used adult *M. robiniae* for this experiment, but different individuals than were used in experiment 4. We placed six beetles (three of each sex) into each jar and allowed them 48 hr to escape (the maximum time that beetles are held in traps jars during field bioassays), and the experiment was repeated once. We recorded the number of beetles remaining in jars after 48 h. Differences between treatments in the percentage of beetles that escaped were tested with the *G* goodness-of-fit test.

Results and Discussion

During experiment 1, we captured 263 beetles of 12 cerambycine species over the 32-d period (Table 1). The most numerous species were *N. m. mucronatus* (58% of total) and *X. colonus* (31%), males of which produce pheromones that include (*R*)-3-hydroxyhexan-2-one as a component (Lacey et al. 2007, 2009). These two species are endemic to North America, the larvae are polyphagous on species of hardwood trees, and the adults are active between April and October in the area of our studies (Lingafelter 2007; personal observations).

Trap treatments differed dramatically in the number of *N. m. mucronatus* and *X. colonus* that were captured (Fig. 1; Friedman's $Q_{4,49} = 27.8$; $P < 0.0001$), with the mean for Fluon/pheromone traps being at least 14 times greater than the means for the other treatments. Several beetles that we observed arriving at Fluon/pheromone traps immediately fell into the trap jar after striking the panels, apparently unable to alight on and cling to the conditioned surfaces. The mean for the Fluon/pheromone treatment was significantly larger than that for the Rain-X/pheromone and control/pheromone, and from the mean for the Fluon/blank treatments (orthogonal contrasts for all comparisons: $F_{1,52} > 460$; $P < 0.0001$), confirming that conditioning pheromone-baited panel traps with Fluon greatly increased the number of beetles that they captured. There was no significant difference between the means for Rain-X/pheromone and con-

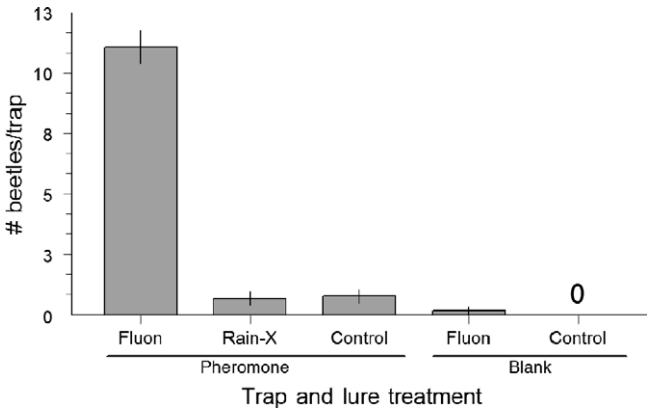

Fig. 1. Mean ± SEM number of beetles of the species *N. m. mucronatus* and *X. colonus* (combined) that were captured in experiment 1 by traps that were conditioned with Fluon, Rain-X, or that were untreated (control), and baited either with lures that were loaded with synthetic pheromone diluted in ethanol ("pheromone") or lures containing only ethanol ("blank"). Statistically significant differences between treatments (orthogonal contrasts: $F_{1,52} > 460$; $P < 0.0001$): Fluon/pheromone versus Rain-X/pheromone, control/pheromone, and Fluon/blank. Treatment means not significantly different (orthogonal contrasts: $P > 0.1$): Rain-X/pheromone versus control/pheromone, control/pheromone versus control/blank, Fluon/blank versus control/blank.

trol/pheromone treatments ($F_{1,52} = 0.1$; $P = 0.76$), indicating that Rain-X had no effect on trap efficiency, as reported in an earlier publication (Sweeney et al. 2004; but see Czokaljo et al. 2003; de Groot and Nott 2003). The mean for the Fluon/blank treatment was not significantly different than that for the control/blank treatment ($F_{1,52} = 2.5$; $P = 0.13$), confirming that beetles were not attracted to unbaited traps conditioned with Fluon. Finally, control/pheromone traps did not capture significantly more beetles than control/blank traps ($F_{1,52} = 2.38$; $P = 0.13$), suggesting that a very large percentage of beetles that were attracted to control traps by pheromones had managed to escape. This last finding was disappointing, because for many years we have relied on panel traps that were untreated, or conditioned with Rain-X, in our bioassays for identifying pheromones of cerambycine species (Hanks et al. 2007; Lacey et al. 2004, 2008, 2009; Ray et al. 2009). Consequently, we achieved statistical significance between pheromone treatments in some of those studies only by using large numbers of replicates.

The 10 remaining species of cerambycines that were captured during experiment 1 were all caught in Fluon/pheromone traps (Table 1), including four species that have male-produced pheromones that contain (*R*)-3-hydroxyhexan-2-one, or structurally-related compounds: *Neoclytus a. acuminatus* (F.), *Sarosesthes fulminans* (F.), *Anelaphus pumilus* (Newman), and *Cyrtophorus verrucosus* (Olivier) (Lacey et al. 2004, 2009; unpublished data). Too few specimens of these species were captured to allow a robust statistical test of treatments (Table 1). Nevertheless, it is highly improbable that all 29 beetles of those species would have been captured by Fluon/pheromone traps by mere chance. In fact, a goodness-of-fit test that combined the data for just those 10 species was highly significant (*G*-test, $P < 0.0001$), confirming that the Fluon/pheromone traps captured a greater number of cerambycine beetles, in general, than traps in the other treatments. Therefore, it is not surprising that species diversity of cerambycines was significantly greater for Fluon/pheromone traps (Shannon-Wiener $H' = 1.14$) than for Rain-X/pheromone and control/pheromone traps ($H' = 0.69$, 0.64, respectively; *t*-tests, $P < 0.05$). Beetles that were captured by traps conditioned with Fluon ranged in size (elytron length) by ≈350%, from 4.0 mm for a *Euderces picipes* (F.) to 14.5 mm for a *Parelaphidion aspersum* (Haldeman) (standard deviation, 1.5). Attraction of all twelve species to the racemic synthetic pheromone provides further evidence of widespread response of cerambycine species to (*R*)-3-hydroxyhexan-2-one and related compounds (Hanks et al. 2007, Lacey et al. 2009, Millar et al. 2009).

The hypothesis that the efficacy of Fluon-conditioned traps would degrade over time was not supported: the percentage of all beetles that were captured by Fluon traps was not significantly correlated with sample date (regression analysis $F_{1,11} = 0.5$; $P = 0.50$). The percentage of beetles that were in Fluon traps, averaged across sample dates, was 92.5 ± 6.7 (SD). In fact, traps with Fluon consistently captured >90% of beetles from 8 to 27 July, approximately the last half of the experiment. The durability of Fluon conditioning was further indicated by the great numbers of beetles captured by Fluon traps in field bioassays that were conducted later in 2009 and that used the same traps as in the present studies, but without retreatment (unpublished data). We conclude from these data that a single treatment of panel traps with Fluon is sufficient to render them highly effective in capturing beetles throughout an entire season, at least under the climatic conditions of central Illinois.

In experiment 2, which compared only the Fluon/pheromone and Rain-X/pheromone treatments at a

different study site, we captured 79 cerambycid beetles of six species over the 26-d period (Table 1). *Neoclytus m. mucronatus* represented 75% of the total and *X. colonus* represented 15%. Fluon traps captured ≈6 times as many beetles as did traps in the Rain-X treatment (means 3.7 ± 0.62 and 0.60 ± 0.22, respectively; significantly different) (Friedman's $Q_{1,19}$ = 10.1; $P = 0.0015$). There also were smaller numbers of four other cerambycine species (10% of the total), and all but one of those beetles were in the Fluon/pheromone traps (Table 1).

There was no support for the hypothesis that trap treatments would influence adult female and male beetles differently: trap treatments did not differ significantly in the sex ratios of adults that were captured in experiments 1 and 2 (all *G*-tests, $P > 0.05$). Pheromone-baited Fluon, Rain-X, and control traps captured female *N. m. mucronatus* in ratios of 55, 33, and 42%, respectively, and female *X. colonus* in ratios of 59, 60, and 60%, respectively. We cannot extend these sex ratio data to speculate on differences between the sexes in the probability of their being captured by panel traps because we do not know the operational sex ratio of the wild population from which they had been sampled.

Experiment 3 did not support the hypothesis that Fluon traps act as sinks during bioassays, removing beetles from the habitat that otherwise eventually would have been captured by traps in the other treatments. We captured 54 cerambycid beetles, of which *N. m. mucronatus* and *X. colonus* accounted for all but two. Traps conditioned with Rain-X captured very small numbers of beetles whether they neighbored a trap treated with Fluon or another Rain-X trap: means 0.15 ± 0.1 and 0.1 ± 0.1 beetles per trap, respectively (not significantly different, ANOVA $F_{8,39} = 0.4$; $P = 0.91$). Fluon traps, however, captured 3.6 ± 0.31 beetles per trap during the study (not compared statistically with other treatments). We therefore conclude that traps conditioned with Fluon did not interfere with traps with Rain-X, and low numbers of beetles in the Rain-X treatments of experiments 1 and 2 were entirely due to the inherent inefficiency of those traps.

In experiment 4, none of the adult *M. robiniae* escaped from trap bases treated with Fluon, including the trap base that had been in the field during summer and fall. However, 100% of beetles escaped from trap bases that were treated with Rain-X, or untreated trap bases (treatments significantly different, *G*-test, $P < 0.0001$) and did so within 5.8 ± 0.8 and 6.0 ± 0.5 s (mean ± SD), respectively. The probability of escape in all control treatments was obviously independent of the sex and body size of beetles.

In experiment 5, only 17 ± 8.4% of the adult *M. robiniae* escaped from trap jars (and attached funnels) that were treated with Fluon within 48 h, whereas more than four times as many escaped from jars conditioned with Rain-X and control jars (69 ± 2.7 and 81 ± 8.9%, respectively; treatments significantly different, *G*-test, $P < 0.0001$). Percentages for the Rain-X and control jars were not significantly different from one another (*G*-test, $P > 0.05$). Beetles escaped from the Rain-X and control jars by crawling, but the few that escaped from the Fluon jars apparently did so by flying. Across treatments, 57% of males and 54% of females escaped, and the treatments did not differ in the proportion of females versus males that escaped (ratios not significantly different, *G*-test $P < 0.0001$).

In summary, our experiments clearly demonstrate that conditioning panel traps with Fluon greatly enhances their efficiency in capturing cerambycid beetles, both by preventing them from clinging to trap surfaces when they land (such that they immediately drop into the collection jar) and by minimizing escape from collecting jars. Moreover, the Fluon treatment is quite durable, even in inclement weather, and conditioned traps capture beetles of a fairly broad range of body sizes. Nevertheless, it is unlikely that conditioning surfaces of traps with Fluon would influence capture rates of very large species (e.g., *Prionus* species; Rodstein et al. 2009). We conclude that conditioning with Fluon will significantly enhance the efficacy, and thus the sensitivity of sentinel traps deployed to detect incursions of a diversity of exotic cerambycid species, or for monitoring threatened species, at very low population densities. Fluon also is likely to improve trap efficiency for other types of saproxylic beetles, but is less likely to affect trapping efficacy of insects that are more agile in flight, such as moths. Further research will be necessary to determine how the efficiency of traps is affected when they are conditioned with different formulations of Fluon, and traps are exposed to different climatic conditions.

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References Cited

Buse, J., T. Ranius, and T. Assmann. 2008. An endangered longhorn beetle associated with old oaks and its possible role as an ecosystem engineer. Conserv. Biol. 22: 329–337.

Czokajlo, D., J. McLaughlin, L. I. Abu Ayyash, S. Teale, J. Wickham, J. Warren, R. Hoffman, B. Aukema, K. Raffa, and P. Kirsch. 2003. Intercept™ panel trap (INT PT) effective in management of forest Coleoptera, pp. 125–126. *In* M. L. McManus and A. M. Liebhold (eds.), Proceedings, IUFRO Conference: Ecology, survey and management of forest insects, 1–5 September 2002, Kraków, Poland, General Technical Report NE-311, U.S. Dep. Agric. Forest Service, Newtown Square, PA.

de Groot, P., and R. W. Nott. 2003. Response of *Monochamus* (Col., Cerambycidae) and some Buprestidae to flight intercept traps. J. Appl. Entomol. 127: 548–552.

Hanks, L. M., J. G. Millar, J. A. Moreira, J. D. Barbour, E. S. Lacey, J. S. McElfresh, F. R. Reuter, and A. M. Ray. 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.

Hayek, L. C., and M. A. Buzas. 1997. Surveying natural populations. Columbia University Press, New York.

Jacobs, J. M., J. R. Spence, and D. W. Langor. 2007. Influence of boreal forest succession and dead wood qualities on saproxylic beetles. Agric. For. Entomol. 9: 3–16.

Lacey, E. S., M. D. Ginzel, J. G. Millar, and L. M. Hanks. 2004. Male-produced aggregation pheromone of the cerambycid beetle *Neoclytus acuminatus acuminatus.* J. Chem. Ecol. 30: 1493–1507.

Lacey, E. S., J. A. Moreira, J. G. Millar, A. M. Ray, and L. M. Hanks. 2007. Male-produced aggregation pheromone of the cerambycid beetle *Neoclytus mucronatus mucronatus.* Entomol Exp. Appl. 122: 171–179.

Lacey, E. S., J. A. Moreira, J. G. Millar, and L. M. Hanks. 2008. A male-produced aggregation pheromone blend consisting of alkanediols, terpenoids, and an aromatic alcohol from the cerambycid beetle *Megacyllene caryae.* J. Chem. Ecol. 34: 408–417.

Lacey, E. S., J. G. Millar, J. A. Moreira, and L. M. Hanks. 2009. Male-produced aggregation pheromones of the cerambycid beetles *Xylotrechus colonus* and *Sarosesthes fulminans.* J. Chem. Ecol. 35: 733–740.

Lingafelter, S. W. 2007. Illustrated key to the longhorned wood-boring beetles of the eastern United States. Coleopterists Society, North Potomac, MD.

Magurran, A. E. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, NJ.

McIntosh, R. L., P. J. Katinic, J. D. Allison, J. H. Borden, and D. L. Downey. 2001. Comparative efficacy of five types of trap for woodborers in the Cerambycidae, Buprestidae and Siricidae. Agric. For. Entomol. 3: 113–120.

Millar, J. G., L. M. Hanks, J. A. Moreira, J. D. Barbour, and E. S. Lacey. 2009. Pheromone chemistry of cerambycid beetles, pp. 52–79. *In* K. Nakamura and J. G. Millar (eds.), Chemical ecology of wood-boring insects. Forestry and Forest Products Research Institute, Ibaraki, Japan.

Morewood, W. D., K. E. Hein, P. J. Katinic, and J. H. Borden. 2002. An improved trap for large wood-boring insects, with special reference to *Monochamus scutellatus* (Coleoptera: Cerambycidae). Can. J. For. Res. 32: 519–525.

Nehme, M. E., M. A. Keena, A. Zhang, T. C. Baker, and K. Hoover. 2009. Attraction of *Anoplophora glabripennis* to male-produced pheromone and plant volatiles. Environ. Entomol. 38: 1745–1755.

Peet, R. K. 1974. The measurement of species diversity. Annu. Rev. Ecol. Syst. 5: 285–307.

Radinovsky, S., and G. W. Krantz. 1962. The use of Fluon to prevent the escape of stored-product insects from glass containers. J. Econ. Entomol. 55: 815–816.

Ray, A. M., J. G. Millar, J. S. McElfresh, I. P. Swift, J. D. Barbour, and L. M. Hanks. 2009. Male-produced aggregation pheromone of the cerambycid beetle *Rosalia funebris.* J. Chem. Ecol. 35: 96–103.

Rodstein, J., J. S. McElfresh, J. D. Barbour, A. M. Ray, L. M. Hanks, and J. G. Millar. 2009. Identification and synthesis of a female-produced sex pheromone for the cerambycid beetle *Prionus californicus.* J. Chem. Ecol. 35: 590–600.

SAS Institute. 2001. SAS/STAT user's guide for personal computers, release 8.01. SAS Institute, Cary, NC.

Sokal, R. R., and F. J. Rohlf. 1995. Biometry, 3rd ed. W. H. Freeman, New York.

Southwood, T.R.E., and P. A. Henderson. 2000. Ecological methods, 3rd ed. Blackwell, Oxford, United Kingdom.

Suarez, A. V., and T. J. Case. 2002. Bottom-up effects on persistence of a specialist predator: ant invasions and horned lizards. Ecol. Appl. 12: 291–298.

Sweeney, J., J. M. Gutowski, J. Price, and P. de Groot. 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., P. de Groot, L. Macdonald, S. Smith, C. Cocquempot, M. Kenis, and J. M. Gutowski. 2004. Host volatile attractants and traps for detection of *Tetropium fuscum* (F.), *Tetropium castaneum* L., and other longhorned beetles (Coleoptera: Cerambycidae). Environ. Entomol. 33: 844–854.

Valles, S. M., J. L. Capinera, and P.E.A. Teal. 1991. Evaluation of pheromone trap design, height, and efficiency for capture of male *Diaphania nitidalis* (Lepidoptera: Pyralidae) in a field cage. Environ. Entomol. 20: 1274–1278.

Wermelinger, B., P. F. Flückiger, M. K. Obrist, and P. Duelli. 2007. Horizontal and vertical distribution of saproxylic beetles (Col., Buprestidae, Cerambycidae, Scolytinae) across sections of forest edges. J. Appl. Entomol. 131: 104–114.

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