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ETHANOL AND OTHER HOST-DERIVED VOLATILES AS ATTRACTANTS TO BEETLES THAT BORE INTO HARDWOODS[1]

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Abstract—Ethanol, methanol, acetone, and acetaldehyde—chemicals identified in the inner bark of living trees—were used to bait vane traps placed in crowns of oak trees in Connecticut. Ethanol-baited traps caught more cerambycid, scolytid, and clerid beetles than unbaited traps. Buprestidae were not attracted to ethanol. Acetaldehyde and acetone were not attractive to any family. A mixture of ethanol, methanol, and acetaldehyde was no more attractive than ethanol alone. The vane traps were very effective at catching Cerambycidae and Scolytidae, but ineffective compared to sticky panels at catching Buprestidae.

Key Words—Coleoptera, Buprestidae, Cerambycidae, Cleridae, Scolytidae, wood-boring beetles, bark beetles, ethanol, host attractants, hardwood tree insects.

INTRODUCTION

The concentration of ethanol in logs, sapwood, and bark was shown to increase markedly when these tissues were held under anoxic conditions (Cade et al., 1970; Moeck, 1970). The researchers also found that ethanol was an attractant to the ambrosia beetles, *Gnathotrichus sulcatus* LeConte and *Trypodendron lineatum* (Olivier). Ethanol has since been reported as an attractant to several scolytid species (Moeck, 1971; Roling and Kearby, 1975)

[1]Mention of a proprietary product or company name does not constitute endorsement by the USDA Forest Service.

and as a synergist for the aggregation pheromone of *Gnathotrichus* spp. (Borden et al., 1980).

There is circumstantial evidence that ethanol may be attractive to other insects. A major product of fermentation is ethanol. Fermenting baits have long been used to attract insects, particularly Lepidoptera, and have been reported to attract Elateridae and Cerambycidae (Champlain and Knull, 1932). The smell of ethanol from oaks that were declining or infested with two-lined chestnut borer, *Agrilus bilineatus* (Weber), was reported by Coté and Allen (1980).

Wood-boring beetles that attack oak trees following defoliation by gypsy moth caterpillars were of particular interest to us. We suspect that defoliation promotes anoxic conditions that favor production of ethanol. Tree defoliation results in reduced transpiration, which can lead to a marked increase in bole and stem hydration (Stephens et al., 1972). Reduced transpiration also results in higher soil moisture levels and thus prolongs anaerobic soil conditions during periods of high precipitation. Waterlogging of tree roots is known to lead to substantial increase in root ethanol levels (Coutts and Armstrong, 1976). Stem ethanol levels are strongly correlated with ethanol levels in roots (Crawford and Baines, 1977). Defoliation of oak seedlings has been shown to result in increased ethanol content of stems (Wargo, unpublished).

In this paper, we report on the potential of ethanol and other associated host-derived volatiles as baits to attract wood-boring beetles to traps. Vane and sticky-panel traps were tested in the crowns of trees where beetle attack is usually initiated. Our primary objective was to capture *Agrilus bilineatus* and other Buprestidae that attack living oak trees.

METHODS AND MATERIALS

Traps. Vane traps were fabricated from Plexiglas® and common laboratory plastic-ware (Figure 1). The vanes were 25 cm high by 20 cm wide. A 500-ml bottle was fitted to the funnel by drilling a hole through the bottle's lid and holding the lid onto the funnel stem with a neoprene gasket glued to the stem beneath the lid. The bottle served both to collect beetles and dispense test chemicals. Test chemicals also were placed in an inverted 220-ml plastic cup that had its lid glued to the trap top. Chemicals were dispensed from the cup through a capillary pipet onto a cotton wick.

Sticky panels were prepared by coating one side of 25- × 25-cm white paperboards with Tangle-Trap® (The Tanglefoot Company, Grand Rapids, Michigan). The paperboard was backed with fiberboard to provide rigidity. When the sticky panel was raised into the lower tree crown, it was positioned so the sticky white surface faced out, away from the bole of the tree.

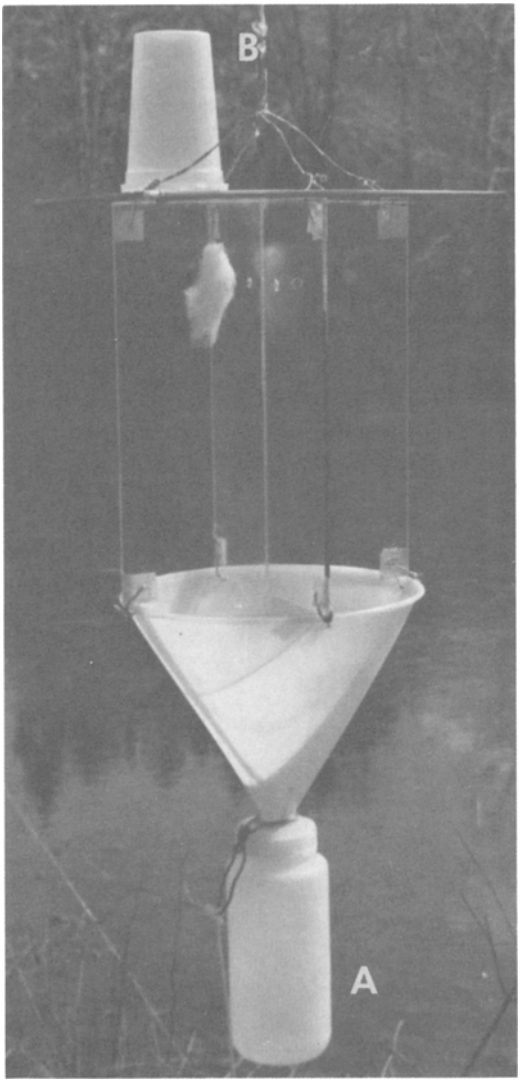

FIG. 1. Vane trap; A is the collecting bottle, which also dispensed treatment chemicals, and B is another dispenser used to release higher rates of chemicals.

TABLE 1. TEST SOLUTIONS[a] USED IN 1979 AND 1980

1979			1980
Treatment	Bottom container[b]	Top container	Treatment[c]
Control	water		Control (water)
Ethanol, low	50% ethanol		50% ethanol
Ethanol, med	50% ethanol	50% ethanol[e]	25% acetone
Ethanol, high	50% ethanol	50% ethanol[f]	25% acetaldehyde
Mixture	50% ethanol	50% ethanol +5% methanol +5% acetaldehyde[e]	bark extract[d] in water bark extract in 50% ethanol

[a]Percentages are v/v.
[b]Bottom containers also had 0.05% sodium hypochlorite aqueous bleach.
[c]Placed in bottom containers which also contained 0.05% Sodium Omidine® biostat.
[d]Equivalent to 1 g bark/10 ml final solution.
[e]Metered through 5-μl capillary.
[f]Metered through 10-μl capillary.

Test Solutions. Selection of test chemicals (Table 1) was based initially on Moeck's (1970) report that ethanol, acetaldehyde, and methanol were present in aged logs. A combination of these three chemicals as well as three levels of ethanol were tested in 1979. During 1979 we (unpublished) vacuum cold-trapped and chromatographed volatiles from inner bark of living trees. In addition to the chemicals reported by Moeck, we found acetone and therefore included it in our 1980 tests. An extract from freeze-dried red oak inner bark also was included in two treatments in 1980. This extract was prepared by grinding the bark to 0.5 mm, homogenizing the powder with water (0.2 g bark/ml), and then filtering. The extract was diluted 1:1 with water or ethanol before placement in the bottom container. Sodium Omidine® (Olin Corporation, Stamford, Connecticut) was added to the bark homogenates and to all other 1980 treatments to prevent fermentation and bacterial growth.

A low rate of ethanol was released by placing 100 ml of 50% ethanol in the catch (bottom) bottle. Higher rates were released by dispensing ethanol from both the catch bottle and top container. By metering top container ethanol through either a 5-μl or 10-μl capillary pipet, medium and high release rates, respectively, were obtained. Approximate ethanol release rates from traps held indoors at 21° C were determined by measuring weight loss and change in concentration. Ethanol loss from the bottom container was about 2 g/day. An additional 8 and 27 g/day were released from the capillaries in the medium and high ethanol treatments, respectively. Total ethanol release at the low, medium, and high rates was thus about 2, 10, and 29 g/day, respectively.

These values do not represent release rates in the field, only relative differences between the treatments.

Experimental Area and Design. Tests were conducted in Madison, Connecticut, in a forest consisting predominantly of oak (*Quercus rubra* L., *Q. alba* L., and *Q. velutina* Lamar) with less than 15% red maple and hickory. Traps were placed 8–15 m from the forest floor in tree crowns. They were raised and lowered by a rope pulley for weekly collection of beetles and renewal of the test solutions. Tests were conducted for 11 weeks each year starting May 30 in 1979 and May 22 in 1980.

In 1979, there were five treatments arranged in five blocks with three replicates of each treatment per block. All traps were placed in red oak trees and were at least 15 m apart. In a separate area, a sticky panel was placed in the crown of each of 48 red oak trees. The capillary system used with the vane traps was fastened to 24 randomly selected panels and used to release 50% ethanol at a medium rate (8 g/day).

In 1980, 36 red oak and 36 white oak trees no closer than 10 m from one another were selected, and six trees of each species were assigned randomly one of six treatments (baits). The treatments were placed in vane traps, and an unbaited sticky panel was placed above each vane trap.

Statistical Analysis. In both years, catch numbers were summed for the 11-week period and transformed to $\sqrt{Y + 0.5}$ for analysis by ANOVA of treatment effects. With the 1980 data, effect of tree species was analyzed along with treatment effects. Comparisons between treatments were made at the 0.05 level using either Scheffe's multiple comparison test or the t test. Data presented are simple means.

RESULTS

1979 Tests. Vane traps containing ethanol caught more cerambycid, clerid, and scolytid beetles than traps containing the water control (Table 2). The three levels of ethanol release did not evoke a typical dosage response. The lowest dosage caught the most Scolytidae, but dosage had little effect on Cerambycidae and Cleridae capture. Traps with the mixture of ethanol, methanol, and acetaldehyde did not catch significantly more beetles of any family than traps with only ethanol released at the same medium rate.

Too few Buprestidae were caught in the vane traps to draw conclusions about the attractancy of ethanol to this family. In a separate test using sticky panels, greater numbers of Buprestidae were captured; however, no significant attraction to ethanol was found: panels baited with ethanol caught a mean of 3.3 Buprestidae/panel, whereas unbaited panels caught 2.7 Buprestidae/panel. In comparison, a mean of 43.0 Scolytidae were caught on ethanol-baited sticky panels, while unbaited panels caught 1.6 Scolytidae.

TABLE 2. MEAN NUMBER/TRAP OF BEETLES CAUGHT BETWEEN MAY 30 AND AUG. 13, 1979, IN VANE TRAPS WITH DIFFERENT BAIT SOLUTIONS

	Treatment[a]				
		Ethanol			
Family	Water	Low	Medium	High	Mixture
Buprestidae[b]	0.4a	0.3a	0.3a	0.4a	0.7a
Cerambycidae	5.6a	8.3b	11.3b	10.1b	10.1b
Cleridae	1.5a	5.0b	5.3b	5.5b	4.9b
Scolytidae	32.8a	223.7c	144.6b	159.9bc	148.6b

[a]See Table 1 for a full description of treatments.
[b]Row means followed by the same letter are not significantly different, $P < 0.05$, Scheffe's test.

1980 Tests. Vane traps baited with ethanol again caught more cerambycid, clerid, and scolytid beetles than control traps with water (Table 3). Neither acetone nor acetaldhyde was attractive to any of the families examined. Adding the bark extract had no significant effect on beetle catch; however, since the extract was equivalent to only 10 g of bark, the lack of significant effect could be due to insufficient potency.

Relative suitability of trap design for each of the four beetle families was examined by comparing capture rates of unbaited vane traps with capture rates of sticky-panel traps placed above the unbaited vane traps (Table 4). Fewer buprestid beetles were caught in vane traps than on sticky panels, whereas more scolytid and cerambycid beetles were captured in vane traps.

TABLE 3. MEAN NUMBER/TRAP OF BEETLES CAUGHT BETWEEN MAY 21 AND AUG. 6, 1980, IN VANE TRAPS CONTAINING DIFFERENT BAIT SOLUTIONS

	Treatment[a]					
Family	Water	Ethanol	Acetone	Acetaldehyde	Bark water	Bark ethanol
Buprestidae[b]	0.67a	0.50a	0.50a	0.42a	0.75a	0.67a
Cerambycidae	0.83a	6.58b	1.83a	1.50a	1.33a	4.67b
Cleridae	0.75a	3.58b	1.33a	1.17a	1.08a	2.58b
Scolytidae	5.67a	114.92b	5.08a	2.17a	2.83a	148.67b

[a]See Table 1 for a full description of treatments.
[b]Means in a row followed by the same letter are not significantly different, $P < 0.05$, Scheffe's test.

TABLE 4. COMPARISON OF VANE TRAPS AND STICKY PANELS USING ONLY CONTROL TRAPS

Family	Mean number captured/trap	
	Vane	Sticky
Buprestidae	0.71	4.98*[a]
Cerambycidae	0.92	0.33*
Cleridae	1.08	1.13 ns
Scolytidae	4.38	2.50*

[a]Asterisk indicates significant difference by paired t test ($N = 24$, $P < 0.05$).

Equal numbers of Cleridae were caught with both traps. Based on area of catching surface, the vane traps would be expected to capture two or three times (two times if the side of the vane trap towards the tree is considered a noncatching surface) as many beetles as the sticky traps.

Sticky panels were placed above the vane traps primarily to monitor possible effects of tree species and tree condition. Beetle capture on sticky panels, however, did not prove to be independent of trap treatment. Sticky panels above ethanol-baited vane traps caught significantly more Scolytidae than those above control traps (224 vs. 60, respectively), and more Cleridae (46 vs. 27, respectively). Buprestidae were caught in near equal numbers (93 vs. 98, respectively) on sticky panels above traps with ethanol compared to sticky panels above water treatments. Very few Cerambycidae were caught on sticky panels regardless of vane trap treatment, 6 vs. 8 on sticky panels above ethanol treated traps and control traps, respectively. The acetone and acetaldehyde treatments in vane traps did not have any signficant influence on numbers of beetles caught on panels.

Tree species had little effect on either vane trap or sticky panel catch of three of the four families. Preference for tree species probably operates at the species rather than the family level. The scolytid beetle caught in greatest number, *Xyleborus dispar* (F.), was caught less frequently in vane traps placed on red oak than in traps placed on white oak, a ratio of 0.6:1, respectively. Differences in preference between *Q. alba* and *Q. rubra* by other species of Scolytidae or by any species of Buprestidae, Cleridae, or Cerambycidae were not detected.

DISCUSSION

Based on the work of Roling and Kearby (1975), who caught over 25 scolytid species in window-pane traps baited with 50% ethanol, we expected to find ethanol attractive to Scolytidae associated with oak forests. However,

Roling and Kearby did not include non-ethanol-baited traps in these tests; hence, it is difficult to gauge the actual attractancy of the ethanol. We found that ethanol-baited traps caught from 5 to 50 times as many Scolytidae as unbaited traps. All of the scolytid species caught in high numbers showed a statistically significant attraction to ethanol. *Xyleborus dispar* (F.) accounted for nearly half the specimens recorded, while *Xyleborinus saxeseni* (Ratzeburg), *Monarthrum mali* (Fitch), and *Pseudopityophthorus minutissimus* (Zimmermann) each accounted for 4–11%. Only female *X. dispar* were captured (males are flightless and do not leave the larval feeding gallery). With *M. mali* and *P. minutissimus*, males predominated. Moeck (1971) also caught *X. dispar* (=*Anisandrus pyri*), which is thought to attack only hardwoods, in great abundance in ethanol-baited traps placed in a Douglas-fir stand in British Columbia, Canada. It may be that ethanol is not only strongly attractive to this beetle but also effective at considerable distance.

Our lowest ethanol release rate, 2 g/day, was more attractive to Scolytidae than higher rates. Moeck (1970) evaporated ethanol from 450-cm pans and found that the lowest concentrations tested, 0.1–0.4%, captured more of the ambrosia beetle, *T. lineatum*, than concentrations of 2–30%. In aged logs that were attractive to the beetles, Moeck (1971) found ethanol concentrations of 0.02 M (<0.1%). It is possible that ethanol release rates lower than those we tested would be more attractive.

Although the Cerambycidae as a family showed attraction to ethanol, the response was not uniform at the species level. Two species, *Aegoschema modesta* Gyllenhal and *Graphisurus fasciatus* (De Geer), were clearly not attracted to ethanol. *Analeptura lineda* (Say), *Clytus ruricola* (Olivier), *Elaphididionides villosus* (Fab.), and *Urgleptes querci* (Fitch) are examples of species strongly attracted to ethanol. We could not discern any relationship between ecology or habits of the cerambycid species caught and attractancy to ethanol. Species that infest wood dead a year or more, as well as those that attack "freshly dead" wood, were attracted to ethanol. However, very low numbers of cerambycid species that attack living trees were caught.

All species of Cleridae caught in sufficient numbers to make statistical tests showed significant attraction to ethanol. These species are: *Cymatodera bicolor* Say, *Enoclerus nigripes* (Say), *Neorthopleura thoracia* (Say), *Phyllobaenus pallipenis* (Say), *Phylogistostermus dislocatus* (Say), and *Placopterus thoracius* (Olivier). Clerid beetles are predators of scolytid, cerambycid, and buprestid beetles, as well as other insects feeding in woody tissue. Ethanol odor likely is used by clerids as an aid in locating prey. It is unfortunate that Cleridae are attracted to ethanol in the sense that these beneficial predators will be caught along with bark- and wood-boring beetles in traps baited with ethanol. Use of specialized traps such as the Scandinavian "drain pipe" that have small holes through which Scolytidae crawl will not entirely exclude

Cleridae. The most abundant clerid beetle in our catches, *P. dislocatus*, is smaller in diameter than the most abundant scolytid beetle, *X. dispar*.

Buprestidae were not attracted to ethanol. Over 65% of the buprestid beetles caught were *Agrilus bilineatus* and *Chrysobothris sexsignata* (Say) with 14 species comprising the remainder. Neither of the two most abundant species considered individually showed attraction to ethanol. Lack of evidence for ethanol attractancy must be tempered because vane traps were very inefficient at catching buprestids, and only limited testing of ethanol was done with sticky panels.

No beetles were attracted to acetone or acetaldehyde. Both of these compounds can be formed in plants by oxidative metabolism of ethanol (Cossins, 1978). Acetone was found by Billings et al. (1976) in fresh ponderosa pine resin, and its loss from resin samples exposed to air was accompanied by a decline in scolytid beetle response to the pheromone-resin complex. They did not establish whether it was acetone or some other highly volatile nonterpene constituent that influenced resin attractiveness. Moeck (1970) found acetaldehyde present in anaerobically treated bark, but the chemical did not prove attractive to *T. lineatum* in olfactometer tests. Evidence regarding the attractiveness of low-molecular-weight volatiles other than ethanol is not conclusive, and they should not be overlooked in future studies.

Initially we theorized that ethanol was produced by trees under stress and consequently was used as a host location cue by beetles such as *A. bilineatus* that attack trees in the initial stages of decline. The beetles attracted to ethanol are those associated with trees that have actually reached the dead stage. It appears that production of ethanol in response to stress would be fairly rapid. Graham (1968) found that peak attractancy of woody tissues to *T. lineatum* occurred at between 20–28 hr of anaerobic processing. Crawford and Baines (1977) found that ethanol levels in the flood intolerant *Picea sitchensis* Carr. increased from 0.5 to 6 μmol/g fresh weight of root in 24 hr.

It is possible that ethanol may also be invoked by beetle infestation. The two families that were attracted strongly to ethanol also tend to seek out beetle-infested wood, the Cleridae in search of prey and the Scolytidae to form aggregations. For the latter, ethanol acts synergistically with aggregation pheromones (Pitman et al., 1975; Borden et al., 1980). Although we did not make ethanol measurements of beetle-infested tissue, we did often note, as did Coté and Allen (1980), a pronounced smell of ethanol from infested tissue. If high levels of ethanol are present in infested wood, it may be produced by microorganisms and decomposition processes connected with beetle activity. Microorganisms associated with bark beetles produce several related alcohols, ketones, and acetates (Brand et al., 1977). Ethanol, in particular, is produced in the initial stages of microorganism growth and thus could serve as a cue by which clerids and scolytids locate recently infested tissue.

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