Field Attraction of the Stink Bug *Euschistus conspersus* (Hemiptera: Pentatomidae) to Synthetic Pheromone-Baited Host Plants

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ABSTRACT The attraction of the stink bug *Euschistus conspersus* Uhler to sources of the synthetic pheromone component methyl (2E,4Z)-decadienoate was investigated in a series of field experiments in native vegetation surrounding commercial apple orchards in Washington. In experiments with pheromone lures placed inside two different tube-type traps, stink bugs were attracted to the immediate area around traps in large numbers, but very few were caught in the traps. Pheromone lures attached directly to the host plant mullein, *Verbascum thapsus* L., demonstrated that these "baited" plants attracted significantly more *E. conspersus* than unbaited plants. Spring (reproductive) and summer (reproductively diapausing) *E. conspersus* adults, both males and females, were attracted to pheromone-baited plants. There was no significant difference in the number of male or female *E. conspersus* attracted to pheromone-baited traps or plants in any of the experiments, further characterizing methyl (2E,4Z)-decadienoate as an aggregation, and not a sex pheromone. Stink bug aggregations formed within 24–48 h of lure placement on mullein plants and remained constant until the lure was removed after which aggregations declined over 3–4 d to the level of unbaited plants. The implications of these studies for *E. conspersus* monitoring and management are discussed.

KEY WORDS *Euschistus conspersus*, Hemiptera, Pentatomidae, aggregation pheromone, trapping, orchard

STINK BUGS (PENTATOMIDAE) are recognized as pests of several economically important crops, including cotton (Toscano and Stern 1976), soybean (Daugherty et al. 1964), and a variety of tree fruits (Madsen 1950, Borden et al. 1952). In the fruit production areas of central Washington State, stink bugs have historically been regarded as sporadic, secondary pests (Beers et al. 1993), but they have become increasingly important as pest management for key orchard pests shifts away from the use of broad-spectrum insecticides. However, increased fruit injury from stink bugs has been reported not only from orchards where codling moth mating disruption was used but also in orchards where traditional insecticidal control was used (McGhee et al. 1996, Hilton 2000).

The most abundant stink bug species in central Washington, and the one implicated in most fruit damage in commercial orchards, is the stink bug *Euschistus conspersus* Uhler (McGhee 1997). It is native to North America and feeds on a variety of plants commonly found in riparian habitats or along orchard borders, including mullein (*Verbascum thapsus* L.), bitterbrush (*Purshia tridentata* (Pursh), red-osier dogwood (*Cornus stolonifera* Michx), and currant (*Rhus trilobata* Nutt.) (McGhee 1997). Although stink bug damage is often most severe along orchard borders, the reasons for stink bug migration into orchards from native veg-

etation remain unclear. Fruit damage begins in late summer and continues through the fall harvest period and is caused by stink bug adults entering the orchard to feed before overwintering. In cotton, stink bug damage has been suggested to occur in response to the senescence of native host plants (Toscano and Stern 1976), and host plant senescence may also be an important factor in Washington orchards. Because of the preharvest interval limitations of compounds that provide effective stink bug control, this late summer migration of stink bugs into orchards limits the chemical control options available to growers.

Stink bug management has proven extremely difficult in a variety of crops, including apple and pear. Among the primary deficiencies in the management of stink bugs, and true bugs in general, is the lack of reliable, effective monitoring techniques (McBrien and Millar 1999). Stink bugs are often found near traps (Aldrich et al. 1991) but tend not to enter traps in large numbers, or may enter and then leave (Zalom 1992). A method for monitoring stink bug densities in native habitats and on orchard borders during the early stages of immigration would represent a significant advance in the management of this pest complex.

Materials and Methods

Tests were conducted during 1999 and 2000 in Chelan County, WA. A component of the male-produced aggregation pheromone previously identified as having field activity for a variety of stink bug species, including *Euschistus conspersus* Uhler (Aldrich et al.

1991) was released from hollow polyethylene caps (No. 60975D-3; Kimble Glass, Vineland, NJ). Polyethylene caps were a two-piece design consisting of a hollow reservoir of ≈1-mL capacity and a plastic lid that snapped into place over the top of the reservoir. Each cap contained 0.5 ml of methyl (2E,4Z)-decadienoate (Bedoukian Research, Danbury, CT). The synthetic pheromone component was released under field conditions by diffusion through the plastic. Lures were aged at room temperature in a fumehood for 24–48 h before placing them in the field allowing any pheromone inadvertently splashed on the outside of the cap to dissipate. The lures were replaced at 2-wk intervals.

Release Rate Determination. Release rates of methyl (2E,4Z)-decadienoate from polyethylene caps were determined gravimetrically. Four polyethylene caps were each loaded with 1 ml of pheromone and were then weighed several hours later on that same day to provide a day 0 weight for each cap. Caps were then placed in a laboratory fume hood at ambient temperature (23°C). Caps were weighed again on days 1, 6, 8, 10, and 13 following the initial loading and weighing. Weight loss measurements were recalculated as micrograms of pheromone lost per hour. Weight loss was assumed to be due to the evaporation of pheromone from the dispenser.

Trap Test Experiment. The experiment was conducted from 15 July to 10 August 1999. Two sizes of clear plastic cylinder-type traps were used in this study. Similar traps have been tested by Aldrich et al. (1991) and James et al. (1996), for *Euschistus* spp., and *Biprorulus bibax* Breddin, respectively. The first trap was a clear plastic cylinder measuring 15 cm in length, with a 12 cm inside diameter, hence designated as the "large tube-trap." The second trap was also a clear plastic cylinder measuring 30 cm in length with an inside diameter of 10 cm, and was designated as the "small tube-trap." Both traps had wire mesh cone funnels at each end (2-mm mesh size), which narrowed to a 3-cm-diameter circular opening inside the tube. Both traps had a 5-mm hole drilled at the midpoint from which a wire was suspended holding the pheromone lure. Lures were held upright by the wire within the trap and did not make contact with any surface. Traps were attached to a mullein plant stem at or near ground level by using flexible wire in border areas immediately adjacent to orchards with a history of stink bug infestation. Traps were oriented horizontally on the mullein plant and placed a minimum of 20 m apart. No stink bugs were removed from plants to which the traps were attached before the start of the experiment, nor were insecticides applied to the area during the experiment. Twelve traps of each type were randomly placed along the orchard border, examined every 2 or 3 d, and rotated to new locations following each examination. Stink bugs found inside a trap were counted at each examination, removed, and taken to the laboratory where they were categorized by species, life stage (nymph or adult), and sex. Bugs that were near the trap but not inside, i.e., on the outside of the trap or elsewhere on the mullein plant attached to the trap, were counted as being "on the plant." These bugs were then removed and taken to the laboratory where they were categorized by species, life stage (nymph or adult), and sex.

Trap Plant Experiment. The lures used in this experiment were affixed directly to mullein at approximately the midpoint of the plants' height by using plastic-coated wire twist-ties. This experiment was conducted in spring and summer, to examine the response of both overwintering bugs during the spring that were reproductively active and those bugs present in late summer and fall that were in a reproductive diapause.

Spring Trials. Spring trials were conducted from 27 May to 22 June 1999 and from 5 May to 15 June 2000. Mullein plants used in this experiment were primarily small, fast-growing rosettes, from 15 to 40 cm in height. Individual mullein plants used were designated either as pheromone-baited or unbaited, and were separated by a minimum of 20 m and located adjacent to borders of commercial apple orchards in Douglas County, WA. Unbaited mullein plants were considered as controls. Fourteen paired mullein plants were used in the experiment in 1999, and 12 paired plants in 2000. All stink bugs were removed from plants before the beginning of the experiment. Plants were examined every 3–7 d. All *E. conspersus* were counted, sexed, and removed at each examination.

Summer Trials. Summer trials were conducted from 22 July to 9 August 1999 and from 20 July to 8 August 2000. *E. conspersus* populations at this time of year consisted of a mix of summer-generation nymphs and new adults, though the population was strongly adult-biased during most of the period, and numbers of nymphs found were extremely low. For this reason, and because the adults were our main area of focus, nymphal data were not included in the analysis. Mullein plants used in this study were located adjacent to a commercial apple orchard. At this point in the summer, plants had produced a large stalk and seed head with a total height of 1–1.5 m. Pheromone-baited or unbaited mullein plants were separated by a minimum of 20 m and all bugs were removed before the start of the experiment. Six pairs of plants were used in 1999, and 10 pairs in 2000. All *E. conspersus* were counted, sexed, and removed from each plant every 3 d. In both spring and summer tests stink bugs removed from plants were either taken to the laboratory or released outside the study area.

Recruitment/Dispersal of Aggregations. This experiment was conducted in late May through early June 2000 to determine how quickly stink bugs responded to sources of synthetic pheromone, and how quickly they dispersed once the source was removed. Ten pairs of mullein plants were used. Individual mullein plants were either pheromone-baited or unbaited, separated by a minimum of 20 m and located adjacent to borders of a commercial apple orchards. The lure was placed on the baited plants on day 1 and removed on day 7. The entire experiment lasted 16 d. The numbers of stink bugs on each plant were counted daily but were not removed or sexed to minimize
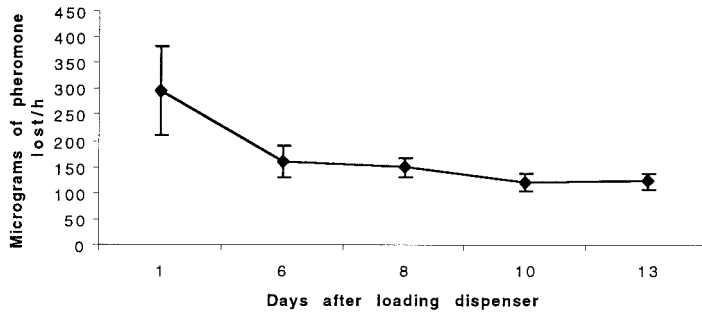
Fig. 1. Mean release rates (±SE) of polyethylene caps loaded with methyl (2E,4Z)-decadienoate, under laboratory conditions at constant temperature (23°C), $n = 4$.

disturbance. The lures were not rotated between plants but remained on the same plant throughout the experiment.

Statistical Analyses. Trap and plant capture data were transformed using log $(x + 1)$ to satisfy conditions of normality (Zar 1999). These data were analyzed using analysis of variance (ANOVA) and Fisher's protected least significant difference (LSD) test (SAS Institute 1995). Sex ratio data from trap plants were analyzed using a heterogeneity chi-square analysis to test whether the proportion of males captured differed significantly from 0.5 (Zar 1999).

Results

Release Rate Determination. Polyethylene caps had a release rate of pheromone on day 1 of 300 μg/h, but from day 6 through day 13 had a fairly constant release rate of $\approx$150 μg/h (Fig 1).

Trap Test Experiment. Neither trap type was effective in capturing or retaining stink bugs. Significantly more males, females, nymphs, and total stink bugs were found on the mullein plants to which the traps were attached (total *E. conspersus* [mean ± SE]: 4.28 ± 0.96), than inside the tube-traps themselves (total *E. conspersus:* 0.06 ± 0.02) ($P < 0.001$) (Table 1). In addition, plants associated with large tube-trap (5.94 ± 1.39) attracted significantly more stink bugs than plants associated with the small tube-trap (2.62 ± 0.62) ($P < 0.05$).

Trap Plant Experiment. Pheromone-baited mullein plants attracted significantly more *E. conspersus* than unbaited plants in both 1999 and 2000 experiments, during both spring and summer generations of each

year (Table 2). The sex ratio remained relatively constant at or near 50:50 in each phase of the experiment (Table 2).

Recruitment/Dispersal of Aggregations. Stink bugs in the field responded rapidly to the pheromone lure, reaching peak aggregation numbers on each plant within 24–48 h after lure placement. Removal of the lure resulted in a gradual decline of the aggregation over a period of 3–4 d, at which point numbers were similar to those of control plants (Fig 2).

Discussion

This study demonstrates that the stink bug aggregation pheromone, methyl (2E,4Z)-decadienoate, attracts adults of *E. conspersus* in the field. Both spring and summer adults were attracted to mullein plants baited with the aggregation pheromone. However, when the lures were placed in traps *E. conspersus* adults did not enter or did not remain in traps, though large numbers were found on the mullein plant to which the trap was attached. The larger numbers of bugs captured on plants associated with the larger tube trap may be a product of the higher-diameter opening and an associated increased volume of airflow, allowing for greater volumes of pheromone-permeated air to be distributed in the vicinity of the trap opening. This correlation of trap opening size and catch has been noted in captures in pheromone-baited traps for corn earworm, *Helicoverpa zea* (Boddie) (Gauthier et al. 1991, Lopez et al. 1994), and the tobacco budworm, *Heliothis virescens* (F.) (Hartstack et al. 1979, Lopez et al. 1994). The reluctance of *E. conspersus* adults to enter traps (although they were

Table 1. Mean ± SE total number of *E. conspersus* per trap or trap-plant per day using methyl (2E,4Z)-decadienoate released from polyethylene caps, 1999

Monitoring unit	Mean (SE) no. of *E. conspersus* captured/d			
	Females	Males	Nymphs	Total
Small tube-trap	0.0a	0.0a	0.0a	0.0a
Small trap plant	1.17 (0.28)b	0.91 (0.23)ab	0.54 (0.15)ab	2.62 (0.62)b
Large tube-trap	0.08 (0.03)a	0.0a	0.03 (0.01)a	0.11 (0.03)a
Large trap plant	2.40 (0.53)b	1.96 (0.52)b	1.55 (0.41)b	5.94 (1.39)c

Means within each column followed by the same letter are not significantly different ($P \leq 0.05$) with the Fisher's protected LSD test.

Table 2. Mean (± SE) total number of stink bugs/trap-plant with methyl (2*E*,4*Z*)-decadienoate released from polyethylene caps, including sex ratio of stink bugs collected

Monitoring Unit	Season/Yr	Trapping interval, d	*E. conspersus*		
			Mean total/d ± SE	Ratio (P:C)	% Males[a]
Pheromone	Spring/99	27	4.7 ± 1.5a		50.0
Control	Spring/99	27	1.0 ± 0.4b	4.7	50.4
Pheromone	Summer/99	19	8.5 ± 2.2a		49.0
Control	Summer/99	19	2.2 ± 0.7b	3.9	54.4
Pheromone	Spring/00	41	12.2 ± 2.0a		53.1
Control	Spring/00	41	5.4 ± 1.9b	2.3	46.5
Pheromone	Summer/00	20	11.1 ± 3.2a		54.5
Control	Summer/00	20	4.2 ± 1.3b	2.6	48.5

Means within each column and season/yr followed by the same letter are not significantly different ($P \leq 0.05$) using the Fishers' protected LSD test.

[a] There was no significant departure from a 50:50 sex ratio on any of the trap plants (chi-square test for heterogeneity, $P \leq 0.05$).

attracted to the vicinity of the trap) is puzzling and worthy of further study.

The low capture rates are not unprecedented in stink bug trapping studies and may be due in part to the behavior of stink bugs exposed to unnaturally high levels of aggregation pheromone components. In a study investigating field activity of the aggregation pheromone of the spined citrus bug, *Biprorulus bibax* Breddin, James et al. (1996) noted the presence of high numbers of bugs around the pheromone-baited funnel traps, but reported consistently low trap catches. This observation led James et al. (1996) to hypothesize that the release rate was too high to attract the *B. bibax* to point sources, and high levels of pheromone in the air surrounding the lure were sufficient to aggregate and/or cause arrestment of responders. Although not documented in stink bugs, arrestment is a documented response in other insects when exposed to unnaturally high pheromone concentrations (Cardé and Hagaman 1979, Charlton et al. 1993).

Another possible factor limiting trapping efficiency is the importance of nonchemical cues in stink bug communication. Visual, tactile, and vibrational cues have been demonstrated to be important components in stink bug communication for a number of species, including *Nezara viridula* L. (Ota and Çokl 1991, Ryan and Walter 1992); *Halyomorpha mista* Uhler (Kawada and Kitamura 1983); and *Thyanta pallidovirens* Stal (Wang and Millar 1997); as well as the species in our study, *E. conspersus* (Alcock 1971). The importance of nonolfactory cues represents a major challenge in situations where the object is to mimic attractive conspecifics as closely as possible in an attempt to lure insects to enter an unnatural environment, such as a trap.

Another possibility is that these traps have design flaws that make it too easy for bugs to leave traps, as
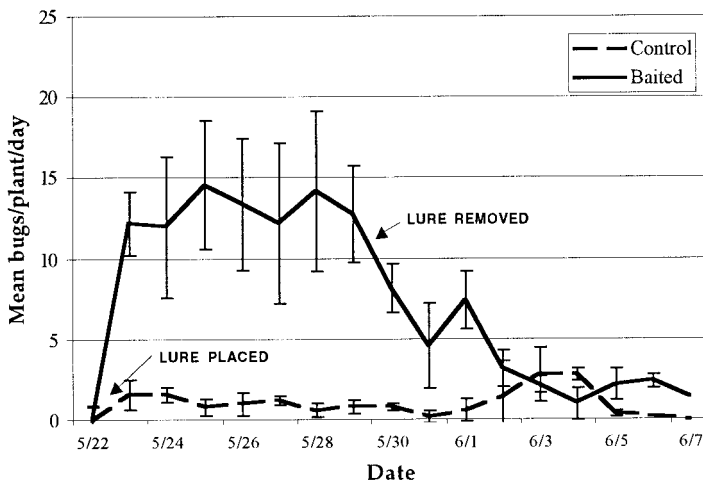

Fig. 2. Mean numbers of *E. conspersus* (±SE) attracted to pheromone-baited (methyl 2*E*,4*Z*-decadienoate) or unbaited mullein showing bugs/plant. All plants had all stink bugs removed at outset, with lures removed from baited plants after 7 d, as indicated, *n* = 10.

the ability of traps to retain bugs was not specifically examined. Trap orientation (i.e., higher, lower in canopy, orientation with respect to wind) was not examined and may play a role in mediating attraction or retention of stink bugs in traps.

The experiments described herein were conducted with field populations of adults that were either reproductively active (spring) or in reproductive diapause (summer). Ovaries and testes of *E. conspersus* adults are small and undeveloped from late summer through fall in north central Washington (C.H.K. and J.F.B., unpublished data), a state we consider to be a reproductive diapause. No mating or egg-laying is seen among newly eclosed *E. conspersus* adults from early July onward in our study area, and a winter cold period appears to be necessary to trigger reproductive maturity in this region, because mating begins in the spring shortly after emergence (Alcock 1971, McGhee 1997; C.H.K. and J.F.B., unpublished data). Although this insect does have two reproductively active generations in some parts of its range, including California (Borden et al. 1952), environmental conditions in Washington support only one reproductively active generation (Alcock 1971). Our summer experiments clearly show that despite being in a state of reproductive diapause, *E. conspersus* adults were strongly attracted to synthetic sources of the aggregation pheromone until the fall. This observation raises questions about the ultimate function of the aggregation pheromone. If *E. conspersus* adults are not yet reproductively active the pheromone may be playing a role in aggregating them in the fall to optimum overwintering sites (James 1990), thus increasing survivorship during the overwintering period and ensuring proximity to mates once the overwintering period ends. Our results showing a strong level of attraction of overwintering *E. conspersus* to pheromone-baited mullein are contrary to those of Aldrich et al. (1991), who reported that two congeners of *E. conspersus, E. tristigmus* and *E. politus,* were relatively unresponsive to methyl (2*E*,4*Z*)-decadienoate in the spring.

Although trapping experiments with the aggregation pheromone to monitor *E. conspersus* in areas adjacent to orchards were discouraging, the concept of combining the aggregation pheromone with a trap-plant shows promise. It may be possible to use the mullein plant as a preliminary monitoring site to indicate when *E. conspersus* adults begin to move to orchards in late summer and early fall and to assess their relative density. The season-long attraction of *E. conspersus* to methyl (2*E*,4*Z*)-decadienoate opens several new possibilities for pest management. For example, combining the aggregation pheromone with host plants such as mullein grown in large stands could serve as trap crops to either lure *E. conspersus* away from orchards thus reducing crop injury. It also may be possible to use these attractive trap crops as focus points for *E. conspersus* in spray programs designed to reduce stink bug densities, thus reducing the overall risk to the orchardist, while avoiding the need for widespread insecticide sprays.

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