Instant Symposium

Multicolored Asian Lady Beetles in Agriculture and Urban Environments

Jeffrey Hahn and Joseph Kovach, Organizers

The multicolored Asian lady beetle, *Harmonia axyridis* Pallas, has recently become a very important insect species in agriculture and urban environments. After a series of unsuccessful releases of *H. axyridis,* an established population was found in Louisiana in 1988. From there these lady beetles spread into the eastern and northern areas of the United States. They have become major pests in urban areas because they enter structures, often in large numbers, to overwinter. As *H. axyridis* numbers increase, there is growing concern of negative impacts they may have on lady beetle species already present as well as nontarget insects. In agriculture, *H. axyridis* has become a significant biological control agent for some pest aphid species, such as soybean aphid, *Aphis glycines* Matsumura. But at the same time, it has also become an important pest in apples, grapes, and other fruit. *H. axyridis* has the potential to be a medically important insect as there are documented cases of *H. axyridis* as a human allergen.

It was with such diverse impacts in mind that a multicolored Asian lady beetle symposium was organized to bring together in one place the current information and research about the multicolored Asian lady beetles' history, life history, genetics, physiology, behavior, and pest management.

Impact of Multicolored Asian Lady Beetle as a Biological Control Agent

Douglas A. Landis, Tyler B. Fox, and Alejandro C. Costamagna

The multicolored Asian ladybeetle, *Harmonia axyridis* Pallas (Coleoptera; Coccinellidae), has become a well-known nuisance insect in North America (see other symposium summaries in this issue). Despite these negative aspects, *H. axyridis* also plays a beneficial role by suppressing pests in a variety of cropping systems (Koch 2003). The recent arrival of the soybean aphid, *Aphis glycines* Matsumura (Homoptera: Aphididae) into North American soybean production systems has created a situation in which the positive and negative aspects of this insect are highlighted. Here we discuss some recent studies exploring the role of *H. axyridis* in biocontrol of soybean aphid.

The soybean aphid is a major new invasive pest of soybean (*Glycine max* L.) in North America. First discovered in July 2000 in Wisconsin and adjoining states, it is currently distributed in 21 U.S. states and parts of Canada. In 2003, more than 42 million acres of soybean in the North Central United States were infested, and more than 7 million acres were treated with insecticides to control *A. glycines* (Landis et al. 2003). Populations exceeding 24,000 aphids per plant and 40% losses in seed yield have been reported (DiFonzo and Hines 2002). *Aphis glycines* overwinters on plants in the genus *Rhamnus* (buckthorn), with summer generations occurring on soybean. The exotic invasive shrub *Rhamnus cathartica* appears to be the key overwintering host for *A. glycines* in Michigan. Fall migration to *R. cathartica* by *A. glycines* gynopare and production of oviparae and overwintering eggs in the field has been observed with subsequent production of fundatrices and alate viviparous females and migration to soybean the following spring (Ragsdale et al. 2004). Alates arrive in soybean in early- to mid-June, soon after crop emergence (Fox 2002).

Natural enemies play a key role in suppressing soybean aphid populations (Fox et al. 2004). In China, where soybean aphid outbreaks are rare, coccinellids are among the most common natural enemies; however, soybean aphid colonies also typically experience parasitism rates of 40% (G. Heimpel, University of Minnesota personal observation). In the United States, 22 predator taxa are reported to attack soybean aphid, with generalist predators including *Harmonia axyridis, Coccinella septempunctata,* and *Orius insidiosus* dominating the natural enemy community (Fox and Landis 2003, Rutledge et al. 2004). The arrival of the soybean aphid in North America has created a vast new prey base for *H. axyridis* in soybean, a habitat formerly devoid of aphid prey. In soybean aphid outbreak years, soybean fields support large numbers of *H. axyridis* that can subsequently cause problems for homeowners and fruit producers.

Fig. 1. Multicolored Asian lady beetle (*Harmonia axyridis* Pallas) attacking soybean aphid (*Aphis glycines* Matsumura) (Photo: D. A. Landis).

In 2001-2003, we conducted a series of predator exclusion trials to examine the influence of predation on soybean aphid populations. In early season trials in 2001-2002, we used clip cages to protect establishing aphids from predation for 24 h (Fox and Landis, unpublished); for midseason trials, we used 1-m^3 field cages to investigate predator impacts on aphid population growth over 7 days (Fox et al., in press). In 2004, *H. axyridis* constituted 66% of the early season predator community, with all predators combining to reduce aphid density by 26-56% over exclusion cages. However, in 2002, *H. axyridis* emerged before aphids were present, and adults did not remain in soybean. In midseason trials, *H. axyridis* had recolonized fields and constituted 57% of the total predator community in 2001, contributing to a 54% reduction in aphid abundance. In 2002 and 2003, predator reduction of aphid density was very high (>90 in both years). In 2002, *H. axyridis* was the second most abundant predator, constituting 25% of the community; whereas in 2003, it only represented 10%.

These studies suggest that *H. axyridis* is a variable but important part of the natural enemy community of soybean aphid. The overall predator community appears quite important in suppressing *A. glycines*, causing a 21-56% reduction in early season aphid establishment and a 54-95% reduction in midseason aphid population growth.

In 2003, a study in Michigan investigated the relative strength of top-down (natural enemies) versus bottom-up (plant effects) regulation of soybean aphid. Plant quality was varied using three agronomic treatments with aphid and predator populations sampled in each plot weekly throughout the summer. Aphid populations were 3- to 7-fold greater in the predator exclusion versus the sham or no-cage treatments, indicating a strong top-down effect, while the bottom-up signal was relatively weak and inconsistent. The natural enemy community in these trials primarily comprised *H. axyridis, C. septempunctata,* and *O. insidiosus* (ACC and DAL, unpublished data).

Overall, predator communities appear to exert consistent top-down suppression of *A. glycines* in Michigan; however, this is not always sufficient to prevent aphid outbreaks. Adult *H. axyridis* foraging in soybean in the early season appear to be important in reducing establishment of *A. glycines* and the rate at which colonies expand. If aphid densities increase to where they stimulate *H. axyridis* oviposition, the feeding of *H. axyridis* larvae appears to be an important factor in causing population crashes. There is a need to further understand the role of *H. axyridis* in suppression of the soybean aphid. In particular, the potential for *H. axyridis* to act as an intraguild predator, disrupting biocontrol by native or introduced parasitoids, should be investigated.

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Nontarget Effects of the Multicolored Asian Lady Beetle (Coleoptera: Coccinellidae): Case Study with the Monarch Butterfly (Lepidoptera: Nymphalidae)

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Exotic organisms often have adverse ecological effects in the habitats they invade. The multicolored Asian lady beetle, *Harmonia axyridis* (Pallas), is no exception. After the initial detection of *H. axyridis* in the southeastern United States, this exotic coccinellid rapidly expanded its range to cover much of the continental United States and southern Canada (Koch 2003). The voracious, generalist feeding behaviors of *H. axyridis* make it particularly likely to have adverse effects on insects that are not considered pests (which we classify as nontarget species).

Koch (2003) reviewed the known nontarget prey of *H. axyridis*. Most studies on nontarget impacts of *H. axyridis* have focused on intraguild interactions, primarily predation on various developmental stages of other coccinellid species such as *Adalia bipunctata* (L.), *Adonia variegata* (Goeze), *Coleomegilla maculata* (DeGeer), *Coccinella septempunctata* L., *C. s. brucki* Mulsant, *Cycloneda sanguinea* L., *Propylea japonica* (Thunberg), and *P. quatuordecimpunctata* (L.). In addition to coccinellids, *Chrysoperla carnea* Stephens has been documented as an intraguild prey of *H. axyridis*. A paucity of literature exists on predation by *H. axyridis* on nontarget insects outside the guild of generalist predators. However, through the use of laboratory and field studies, Koch et al. (2003) identified *H. axyridis* as a potential hazard to monarch butterflies, *Danaus plexippus* (L.).

To more thoroughly evaluate the risk of *H. axyridis* having an adverse effect on a nontarget species, a tool such as ecological risk assessment can be used. In this context, risk is defined as the joint probability of exposure and effect (NRC 1983). Exposure is the probability of temporal and spatial co-occurrence of the exotic predator and the nontarget prey. Effect is the probability of the predator feeding on the nontarget organism, if they co-occur. Here we present an overview of a risk assessment to evaluate the impact of *H. axyridis* on *D. plexippus*.

Case Study

Danaus plexippus is a summer resident of the upper Midwest. In this region, the primary host plant for larvae is common milkweed, *Asclepias syriaca* L. *A. syriaca* is a ubiquitous weed in many of the agricultural systems in which *H. axyridis* has become abundant, particularly in corn and soybean fields. This creates a situation where *D. plexippus* may be exposed to *H. axyridis*.

Exposure

To evaluate the exposure of *D. plexippus* to *H. axyridis*, we conducted season-long monitoring (2001–2003) of *A. syriaca* in a corn–soybean agroecosystem (RLK, unpublished data). On a whole-field scale, the phenology of *H. axyridis* overlapped that of second-generation *D. plexippus* eggs and larvae in all years. However, the degree of overlap was minimal in 2002, likely due to a relatively low abundance of *D. plexippus* after severe storms in the overwintering habitat. Based on our field data, we conducted an analysis to examine exposure on an individual-plant scale. Preliminary results indicated that the amount of time a single *D. plexippus* larva occurs on a plant with *H. axyridis* was relatively small compared with the amount of time each species is present in the field. However, the duration of co-occurrence was considerably greater in soybean fields heavily infested with the soybean aphid, *Aphis glycines* Matsumura. Although the phenologies of *D. plexippus* and *H. axyridis* overlap at the whole-field scale, the duration of exposure was generally low on an individual plant scale, but may be dependent upon the abundance of prey in the surrounding habitat. These results emphasize that the scale of exposure is important in any risk assessment.

An *H. axyridis* larva feeding on a *D. plexippus* larva (photo by R.L. Koch).

Effect

To evaluate the potential effects of *H. axyridis* on *D. plexippus*, we conducted laboratory and field predation studies. The first series of studies were done with *D. plexippus* eggs or neonates as the sole prey for *H. axyridis* (Koch et al. 2003). In laboratory functional response studies, third instar *H. axyridis* exhibited a Type II functional response, where the number of prey consumed plateaued at ~25 eggs or ~15 first instars per day. Predation by *H. axyridis* adults on *D. plexippus* eggs increased linearly with increasing prey density, with a maximum of ~30 eggs consumed per day. We attributed the linearity of the response to the initial prey densities being insufficient to satiate the predators. In a caged field predation study, survival of *D. plexippus* larvae decreased significantly with increasing predator density per cage, verifying that *H. axyridis* will feed on *D. plexippus* under more realistic field conditions.

Because *D. plexippus* is rarely the sole prey item on *A. syriaca* in the field, we conducted a second series of predation studies to examine the influence of alternative prey, *Aphis nerri* Boyer de Fonscolombe, on the predation of *D. plexippus* by *H. axyridis* (RLK, unpublished data). The laboratory and caged field predation studies showed that predation of *D. plexippus* larvae by *H. axyridis* decreased in the presence of aphids. As in Koch et al. (2003), the survival of *D. plexippus* in field cages decreased with increasing densities of *H. axyridis*. The results of the predation studies indicate that *H. axyridis* will indeed prey on *D. plexippus* eggs and larvae, but the presence of aphids may lessen the severity of predation.

Conclusions

An overall quantitative risk estimate could not be made at the time of the symposium because data were still being analyzed. However, a qualitative characterization of risk was made. Based on the analyses conducted to that time, it appears that the risk of exposure is low to moderate. From the predation studies, it appears that the risk of an effect occurring is moderate to high. Therefore, the overall risk of *H. axyridis* affecting *D. plexippus* can be qualitatively ranked as moderate, meaning that populations are likely to be reduced somewhat, but not driven to extinction.

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Response of the Multicolored Asian Lady Beetle (Coleoptera: Coccinellidae) to Low Temperatures: Implications for Winter Survival

M. A. Carrillo, R. L. Koch, R. C. Venette, C. A. Cannon, and W. D. Hutchison

The innate capacity to withstand exposure to low temperatures (i.e., cold hardiness) and the conditions experienced at an overwintering site determine whether an insect will survive the winter. In general, insects survive low temperatures through freeze tolerance or freeze avoidance (Lee 1991). Insects that cannot survive freezing use one or more mechanisms to avoid freezing (e.g., by moving to physically protected areas, or by supercooling). Supercooling is the depression of the freezing point of body fluids to levels where crystallization is avoided (Lee 1991). The temperature at which spontaneous freezing of the body fluids occurs has been called the supercooling point (SCP) and can be easily detected using simple surface contact thermometry (e.g., Carrillo et al. 2004).

By definition, freeze-intolerant insects do not survive when temperatures are at or below the SCP. The SCP, along with mortality at different low temperatures, has been widely used as an index of cold hardiness (e.g., Watanabe 2002, Koch et al. 2004). Information on insect cold hardiness may help researchers predict the possible geographic range and the probability of outbreaks for a particular species (Bale 2002).

The multicolored Asian lady beetle, *Harmonia axyridis* (Pallas), is currently present in much of the United States and southern Canada (Koch 2003). The potential geographic range of this exotic coccinellid may depend on its overwintering behavior and cold hardiness. Adult *H. axyridis* have been reported to overwinter close to prominent objects on the horizon (e.g., buildings or mountains) (Koch 2003), which may confer a degree of protection from low temperatures. In addition, Watanabe (2002) and Koch et al. (2004) have shown that *H. axyridis* acquires cold hardiness by cold acclimation and protects itself against low temperatures by supercooling. Furthermore, Watanabe (2002) observed a degree of chill tolerance for this species, with adult *H. axyridis* of a Japanese strain surviving up to 200 d at –5°C.

Recently, we evaluated several aspects of the cold hardiness of *H. axyridis* in North America (Koch et al. 2004). The SCP and mortality at low temperatures of field-collected and insectary-reared *H. axyridis* were measured as indices of cold hardiness. Sex and color morph (i.e., red: f. *succinea* versus black: f. *spectabilis*) had no effect on the SCP of adult *H. axyridis* (Koch et al. 2004). However, the mean SCP of adult *H. axyridis* changed significantly with season. Adults from Minnesota froze at significantly lower temperatures during winter (≈ –23°C) versus summer (≈ –8°C) months. The mean SCP of adults from Georgia had a similar seasonal trend, but with less change between seasons. This observed seasonal trend corroborated reports from Japan about this species (Watanabe 2002).

We also found that the mean SCPs for eggs and pupae occurred at lower temperatures than for larvae and adults (Koch et al. 2004). These results suggest that food in the digestive tract may induce ice nucleation and increase the SCP. Therefore, by clearing their guts (Iperti and Bértrand 2001), adult *H. axyridis* may reduce their SCP in preparation for overwintering. In addition, Watanabe (2002) found a negative correlation between the SCP and the concentration of a cryoprotectant, *myo*-inositol, and he speculated that this compound may also contribute to the increased cold hardiness of *H. axyridis* during winter.

Although the SCP has been used frequently as an index of cold hardiness because it is relatively easy to measure, its ecological significance may be unclear. The analysis of mortality at low temperatures appears to be a more robust index of cold hardiness.

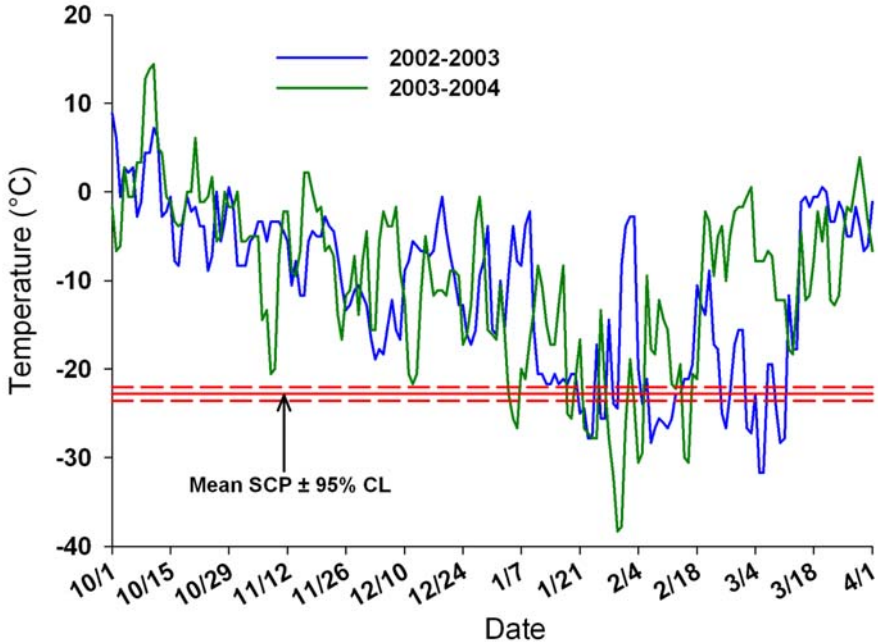

Fig. 1. The lowest mean supercooling point (SCP) observed for adult *Harmonia axyridis* (Koch et al. 2004) plotted with daily minimum temperatures recorded from Brainerd, MN.

Mortality of adult *H. axyridis* increased significantly after exposure to temperatures below the mean SCP of the population (Koch et al. 2004). However, mortality of adult *H. axyridis* did not occur immediately at the SCP but increased with time after the SCP was reached. Similar results have been observed for other chill-tolerant/freeze-intolerant insects in which mortality was proportional to the amount of ice formed inside the body (e.g., Salt 1953). Although the SCP appeared to be a good indicator of adult mortality at minimum exposure (i.e., 1 min), Watanabe (2002) found that some pre-freeze mortality occurred when adult *H. axyridis* where exposed to subzero temperatures for a longer period of time (i.e., 24 h).

Within the current North American range of *H. axyridis*, minimum air temperatures can exceed the minimum mean SCP of adult *H. axyridis* (i.e., ≈ –23°C) (Fig. 1), and should be lethal for this coccinellid. Thus, local air temperature alone appears to be a poor predictor of the distribution of this species. Consequently, adult *H. axyridis* most likely survive extreme winter conditions by finding microclimates that provide protection from lethal temperatures. Therefore, the capacity of *H. axyridis* to survive winter conditions in northern locations may be more related to the availability of quality overwintering sites than to its capacity to increase cold hardiness.

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Impact of Multicolored Asian Lady Beetles as a Pest of Fruit and People

Joseph Kovach

In 2000, extension agents in Ohio began reporting that adults of the multicolored Asian lady beetle (MALB), *Harmonia axyridis* Pallas, were feeding on several ripening fruit crops, including peaches, apples, raspberries, and grapes (Fig. 1). Also at this time, judges at state wine competitions noticed that a small percentage of the wines, ~5%, had a defect that was described as a rancid peanut or cooked spinach odor and masked the variety characteristics of the wine. Some judges said that it smelled like the ladybugs that were found in their houses.

The MALB has been in Ohio since the mid-1990s, and many homeowners have complained to extension personnel that this beetle is biting them. After examining 34 state extension fact sheets, I realized that not all extension entomology specialists agree that these beetles bite people. Thirty-two percent of the fact sheets did not mention biting; 26% stated that MALB do not bite humans; and 23% declared that they do bite people (Table 1).

Therefore, I have tried to address these issues and answer several questions about MALB behavior:

How big a problem is the MALB on fruit grown in Ohio?
Is this feeding injury primary or secondary?
How many beetles does it take to ruin wine?
Do these beetles bite people?

Fruit Studies

In 2002, a grower survey was conducted at the Ohio Fruit and Vegetable Congress in Toledo (22 primarily tree fruit growers) and at the Ohio State University Grape Short Course in Delaware, Ohio (36 primarily grape growers). When asked if they experienced problems with the MALB on fruit crops in 2001, 71% of the growers answered in the affirmative (81% at the tree fruit meeting and 55% at the grape meeting). At the grape meeting, when asked if problems had occurred with the MALB in past years, 20% of the growers reported

Fig. 1. Multicolored Asian lady beetles feeding on grapes. (Photo: J. Kovach)

Table 1. The percentage of extension fact sheets on MALB that discuss or mention adult MALB biting of humans (34 states).

Category	Percent
Not mentioned	32
Don't bite	26
Do bite	23
Pinch	11
Harmless	10

Table 2. The mean number of adult MALB feeding on injured vs noninjured apples, peaches and grapes*.

Crop (n = 50 beetles)	Injured	Non-injured
Apple	10a	0.6b
Peach	8a	0.0b
Grape	22a	3.0b

*means followed by the same letter within a row are not significantly different (LSD, $P > 0.05$)

that they encountered problems in 2000 and 55% had problems in 2001. Pooled data from both meetings showed that 50% of the growers reported the MALB feeding on grapes, 29% reported feeding on apples, 28% on peaches, 7% on plums, 5% on pears, and 5% on raspberries. Growers also were asked if they thought that the MALB feeding was the primary cause of the damage or if it was secondary and only occurred on previously injured fruit; 27% of the growers thought that the damage was primary, 12% thought it was secondary, 37% thought that it was a combination, and 15% did not know.

To determine whether MALB feeding was primary or secondary, a small study was conducted in August 2002. Two replicates of 10 fruits each of 'Gala' apples, 'Redhaven' peaches, and 'Red Flame' seedless grapes were used. Each fruit was placed in a single screen-covered container. Five fruits of each type were wounded to simulate bird damage; five fruits were uninjured and served as a control. Two wounds were created on the apples and peaches using a 2-mm diam probe that was inserted about 2.5 cm deep into the flesh (Fig. 2). The same probe was used to injure the single grapes, but the probe was only inserted deep enough to break the skin, about 2mm. Five field collected MALB adults, starved for 2 days, were placed in each container.

The fruits were evaluated 24 h to determine the number of beetles feeding on the fruit. As shown in Table 2, significantly more beetles were observed feeding on the injured sites of the fruit than on the noninjured fruit. About twice as many adult MALB were observed feeding on the grapes as were observed on the wounded apples or peaches. These results are consistent with the growers' observations.

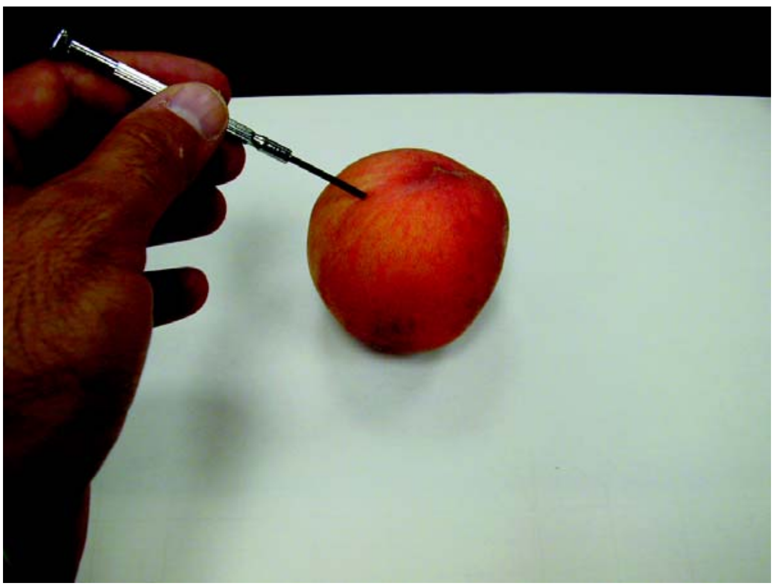

Fig. 2. Probe used to injure fruit to simulate bird damage (2 mm diam). (Photo: J. Kovach)

Fig. 3. One hundred MALB crushed in 100 mL of wine. After centrifuging and filtering, this mixture was used to "spike" the test wines for sensory detection limits with consumer panels. (Photo: J. Kovach)

Wine Tasting

When adult MALB are handled or threatened they release a foul-smelling fluid from their leg joints in a reaction called reflex bleeding. This defensive secretion contains compounds that may contaminate wine, if the beetles are present during the grape crush. A preliminary study was conducted to determine the sensory detection limit of a consumer panel and to determine the number of beetles required to reach this limit.

One hundred adult MALB were crushed in 100 mL of white wine (Fig. 3). This beetle/wine mixture was then centrifuged, filtered, and used to "spike" bottles of white wine to create different concentrations of MALB-contaminated wine. Using a duo–trio test (2 coded samples with a reference), 35 consumer judges representing 315 observations evaluated the contaminated wine. Analysis indi-

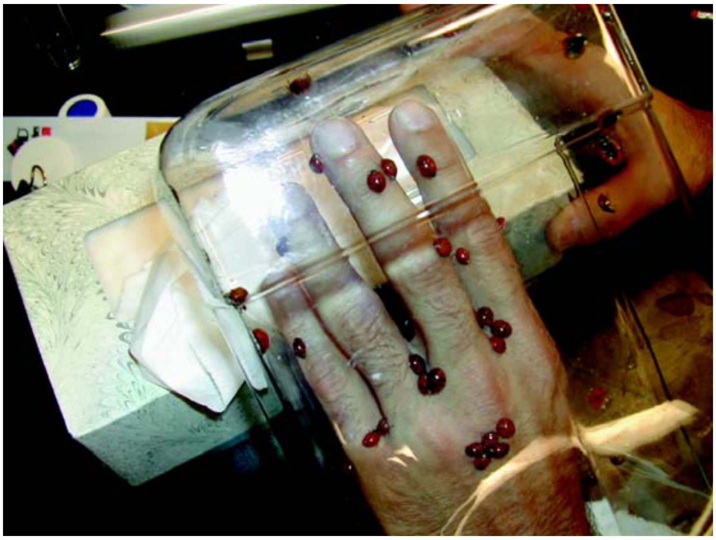

Fig. 4. A close-up of the MALB biting the author's hand. Note the group of beetles on top of the hand. (Photo: S. Wright)

cated a detection aroma threshold of ~1.25 beetles per liter (about one beetle per bottle), but there was a wide variation among individuals. In the field, this concentration corresponds to ~12 beetles, or one contaminated grape cluster per lug of grapes(14 kg).

There are several possible remedies for removing or masking the lady beetle defect in wine. One method would be to use fining agents to strip the wine of this defect: however, this may also strip the wine of its unique character. Another method could be to blend the wine with a fruity aromatic wine to mask the defect, also not an ideal solution. The best solution may be to find methods to exclude or collect the lady beetles in the field or at the winery before the grapes are processed.

Fig. 5. Wounds to hand caused by MALB biting and feeding. (Photo: S. Wright)

Biting Study

To determine whether adult MALB bite humans and whether one sex is more likely to bite than the other, a study was conducted in the fall of 2002. MALB were collected from multiple locations near Wooster, Ohio, watered, sexed, and placed in 11 plastic containers (4-L). The number of beetles in each container varied (21–185) depending on collection site. Before I inserted my hands into the beetle-filled containers, I washed, surface sterilized with 95% ethanol, and air-dried them. I then placed my hands into each container for about 30 min. I removed any beetles biting my hands, counted, and sexed them (Fig. 4). After I removed my hands from a container, I again washed, surface sterilized, and air-dried them, before inserting them into another container. I continued this process until beetles in all containers had been exposed to the hands.

About 26% of the 641 evaluated beetles did bite my hands. Beetles began walking over the entire hand and wrist area, but preferred to feed in areas with minimal hair, such as between the fingers, knuckles, and on the inside of the wrist (Fig. 5). Once the skin was broken, additional beetles would feed at the same site. This behavior was similar to the injured fruit study. When left undisturbed, some beetles fed for as long as 30 min. Both sexes did bite, with females being slightly more likely to bite than males (27.6% vs 24.2%).

Conclusions

MALB can injure fruit. In Ohio, grapes were the most affected crop, but apples and peaches were also impacted. Consumer sensory panels were able to detect MALB contaminated wine at sensory limits of about 1 beetle per bottle or about 12 beetles per grape lug. Adult MALB seem to prefer wounded areas for feeding, but they can break the skin of whole fruit and humans. About 25% of the MALB tested in Ohio did bite; and if left undisturbed, they would cause minor bleeding.

Acknowledgments

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Behavior and Treatment of the Multicolored Asian Lady Beetle (*Harmonia axyridis*) in the Urban Environment

Margaret Huelsman and Joe Kovach

The first established populations of the multicolored Asian Lady beetle, *Harmonia axyridis* Pallas, were reported in Louisiana in 1988; and since that time, it has become well established in many parts of the United States, including Ohio. While much heralded for their activity as a biocontrol agent during the growing season, *H. axyridis* becomes a serious nuisance pest to homeowners during the fall, winter, and early spring.

Problems begin during the fall when the beetles aggregate in large numbers in search of overwintering sites. In Asia, *H. axyridis* normally overwinter in cracks and crevices of cliff sides and rock outcroppings. Where such structures are uncommon, the preferred overwintering site has become individual homes. This aggregation usually begins in early October in Ohio with large swarms moving across the landscape and settling on or around individual homes. Over the years, the nuisance problem has grown tremendously, and now many homes throughout Ohio are being invaded each year (Fig. 1).

In May 2001, a statewide survey of Ohio homeowners experiencing a *H. axyridis* nuisance problem was conducted. A toll-free number was set up and advertised by county extension agents so that individuals who had experienced a problem could call and request that a survey be sent to them. The survey was designed to gain an understanding of the kinds of houses that are infested by *H. axyridis* and the specific nature of the infestation. Using standard statistical procedures, data were collected, analyzed, and summarized. In some cases, to further refine the results, the data were grouped into three categories, according to whether the respondents reported low (hundreds or less), medium (thousands), or high (millions or too many to count) beetle densities in their homes.

Survey Results

Nearly 1150 surveys were returned. When asked in what year problems were first experienced with *H. axyridis*, the respondents in the Appalachian foothills of southeastern Ohio reported 1993 as the beginning of their beetle problems. By 2001 all counties in Ohio had experienced some *H. axyridis* problems.

The survey respondents were then asked to describe their home. More than half (57%) of the respondents had two-story homes, and 31% had a single story. On the exterior of the home, 54% had wood, 43% had vinyl, and 23% had brick. Survey results did not indicate that house siding material, color, or roof color were determinants for an infestation problem. Even when the data were broken down into the low-, medium-, and high-population categories, the beetles equally invaded houses of light, medium, or dark color. The average house age of the survey respondents was 53 years, and although house age was not a de-

Fig. 1. The windowsill of a girl's bedroom in southern Ohio after one day filled with *Harmonia axyridis.*

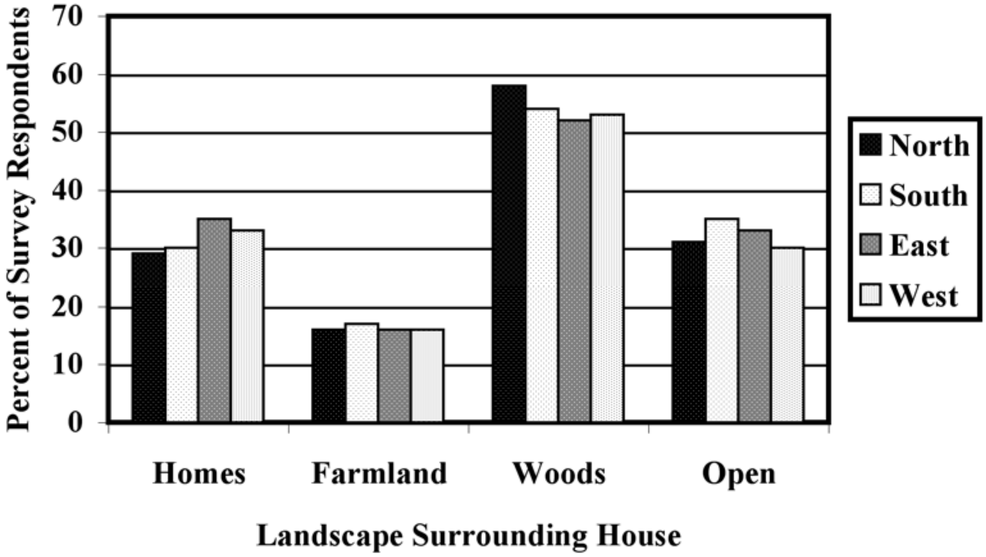

Fig. 2. Landscape surrounding the survey respondents' houses in the four cardinal directions.

terminant of an infestation problem, older houses (>75years) were slightly more likely to experience high populations of lady beetles, primarily because of the difficultly in sealing cracks and crevices.

The survey respondents were also asked to describe the landscape immediately surrounding their home in each of the four directions (north, south, east, and west). As shown in Fig. 2, having trees or a forest to any of the four cardinal directions, particularly the north, was a good indicator of an *H. axyridis* infestation problem, probably because the trees contrasted with the house and gave the house a more clifflike appearance.

Questions were also designed to gain an understanding of the nature of the infestation problem. The respondents were asked in what room and on what surface the beetles most frequently appeared. Most of the respondents experienced problems in their living rooms (58%), bedrooms (53%), and kitchens (46%), with the beetles appearing most frequently on the windows (86%) and ceilings (64%).

When asked about the problems associated with a *H. axyridis* infestation, the respondents most frequently mentioned that the beetles produced a foul odor (77%) and stained various surfaces (71%) throughout the house. A notable number also indicated that they were bitten by the beetles (42%) or that the beetles ended up falling into their food and drinks (41%).

The respondents were also asked if they experienced an allergic reaction to the beetles. Overall, 13% of the respondents reported having allergic reactions, and 6% actually had that reaction confirmed by a doctor. Furthermore, the data does suggest a dose response. More people had allergic reactions in highly beetle-infested houses (26%) than in medium- (15%) and low-population houses (7%).

Finally, the respondents were asked what action they took against the lady beetles. Most of the respondents relied heavily on vacuuming (90%), usually numerous times a day, as their primary method of managing their infestation problem. Some people even indicated that they purchased a vacuum or shop vac just for this purpose. Although this method did not eliminate *H. axyridis* from the home, it did provide some help. It should be noted that all beetles vacuumed were disposed of, not released outside.

Other methods included applying pesticides (44%), sealing and caulking (34%), and trapping (7%). Those that reported caulking around windows and doors in addition to filling in any other visible cracks thought that this method alone was not successful in keeping the beetles out of the home. However, when used in conjunction with other methods, especially exterior pesticide sprays, they indicated a significant reduction in the number of beetles entering the home.

The most popular and effective method reported for reducing *H. axyridis* in the home was to apply a pesticide to the exterior of the house. The products used by homeowners most frequently contained the pesticides cyfluthrin, permethrin, and tralomethrin. Cyfluthrin also topped the list of chemicals applied by a pest control company, followed by lambda-cyhalothrin and the combination of deltamethrin plus cypermethrin.

Precise timing of the application of the chemicals did not appear to affect its efficacy, although pesticides applied a week before or after the lady beetles arrived received the highest ratings for efficacy.

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Orientation of Multicolored Asian Lady Beetles to Buildings

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The multicolored Asian lady beetle, *Harmonia axyridis* (Pallas), is often a pest during the autumn, when large numbers alight on the outside of structures, then move into interior spaces seeking winter shelter. In building interiors, the beetles encroach on eating, sleeping, and recreational activities. Their defensive secretions stain carpets, curtains, and furniture; they are malodorous, known to bite, and can trigger allergic reactions (Yarbrough et al. 1999, Heulsman et al. 2002). The beetles are also hazards in institutions that have a zero-tolerance policy for biocontaminants, such as hospital operating rooms and drug-testing facilities (M. Waldvogel, North Carolina State University personal communication).

H. axyridis is one of many coccinellid species that assemble in large numbers prior to dormancy, but the factors mediating this behavior are poorly known. In general, the aggregation process in lady beetles can be characterized by a series of stepwise, distinct behaviors.

1. After departing from feeding and breeding locations, beetles first orient to macrosites, here defined as large-scale visual landmarks such as buildings or mountaintops, detected at a distance by flying individuals.
2. The beetles alight on the surface of the macrosite.
3. They determine whether it is made of an appropriate substrate.
4. The insects begin a walking local search for cracks, crevices, recesses, or other acceptable microhabitats.
5. Finally, they assemble and settle within these. Beetles may take flight and reinitiate the process if appropriate winter shelter is not detected during local evaluation and search.

The beetles respond to a series of sensory cues during this stepwise behavioral sequence. There is evidence that initial orientation to macrosites (Step 1) is guided by hypsotaxis: while in flight, the beetles are visually attracted to conspicuous, isolated features that form a contrasting silhouette on the horizon (Obata et al. 1986, Hodek et al. 1993). Here we tested whether visual cues also influence where beetles terminate their migratory flight (Step 2). In natural habitats, adult *H. axyridis* typically winter in the cracks and crevices of granite outcroppings, large rocks, and bald rocky hills, and in the spaces beneath small stones on slopes (Voronin 1969, Hodek 1973, Obata et al. 1986). We reasoned that buildings are full of contrasting linear elements that mimic the dark-on-light linear contrast of rock fissures on a sun-exposed cliff side. We also noticed that beetles frequently land on the contrasting linear elements of buildings: gutters, drainpipes, siding, doorframes, window sashes and muntins, railings, patterns of brick and mortar, and the exposed frame elements of porches (Fig. 1).

Open field experiments were conducted during the annual flight of *H. axyridis* to determine whether linear contrast visually attracts the beetles to overwintering sites. White targets printed with 61×15 cm stripes that varied in orientation (horizontal vs. vertical) and degree of contrast (0, 25, 50, 75, and 100% black), were covered in insect adhesive and attached to a white background panel. We then erected panels at two North Carolina macrosites known to be attractive to flying beetles.

The beetles significantly chose targets with high contrast, 100% black stripes; the number of beetles landing on all other contrast levels did not differ significantly from controls. Vertically positioned stripes attracted more beetles than horizontal ones, but not significantly. Attraction to high contrast was absolute rather than relative, as the number of beetles landing on targets with 50% contrast stripes did not increase when these were the highest contrast targets available.

The results indicate that as beetles arrive in the vicinity of a macrosite, black-on-white linear contrast attracts the beetles and acts as a stimulus for terminating migratory flight. The first two stages of aggregation behavior in *H. axyridis* are thus strongly visual, with similar mechanisms accounting for not only long-range orientation, but also short-range approach and landing behavior.

The results of this study suggest that it may be possible to reduce the number of beetles approaching and alighting on a building by decreasing its number of contrasting elements, e.g., dark trim on a light house or vice versa. Unfortunately, in strong, directional afternoon sunlight, the only conditions in which these beetles fly, dark, linear shadows cast by gutters, drainpipes, windows, doorframes, over-

Reported at the 2003 ESA meeting by Kathleen A. Kidd.

Fig. 1. *Harmonia axyridis* alighting in the vicinity of a crevice on Pilot Mountain, a quartzite monadnock in the piedmont of North Carolina (left), and on a drainpipe of a home near Asheville, NC (right).

hangs, and other architectural features are also attractive to *H. axyridis*. It would be difficult to suppress shadow contrasts in a building of any color short of removing the offending elements. It is unlikely that traps that relied on visual attraction, no matter how well designed, would be able to compete successfully with contrasting elements already on a building. Contrasting linear features of a building may, however, be useful as guidelines in the precise placement of insecticides or beetle repellents currently in development (e.g., Riddick et al. 2000).

Despite the results of our experiments, it is still not easy to determine why beetles target a particular building on the basis of its color, trim, and architecture. The visual background of a structure and the presence of trees that obscure beetle line-of-sight are influential. Nonvisual, location-specific features may also dilute or enhance the number of *H. axyridis* attracted to a given building. Structures near late-season aphid infestations consistently attract large numbers of beetles, and the interaction of air currents and topography also have a significant effect (Balduf 1935, Hodek et al. 1993), particularly in high-elevation complex terrain.

Superimposed on this variation in visual and environmental stimuli is the behavior of the insect itself. Alighting during migratory flight often seems haphazard, as beetles land on people, laundry, fences, and other sites inappropriate for overwintering. It may be that migrating *H. axyridis* explore any contrasting linear profile, and the sequence of take-off, flight, and alighting continues until appropriate winter shelter is found. Reduced light, increased wind speed, and flight exhaustion may alter behavioral thresholds for flight termination.

Lastly, *H. axyridis* appears quite versatile in the final choice of winter shelter. Although the species is thought to be classically hypsotactic, orienting to mountains in natural locations because ventilated rock crevices reduce the danger of mycosis (Hagen 1962, Hodek 1973), they also have been found in surprisingly damp places. These include backyard woodpiles, leaf litter in wooded and urban areas, and under the loose bark of standing and recumbent dead trees (R. L. Koch, University of Minnesota personal communication; R. M. Lippard and C.A.N, unpublished observations).

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Search for Repellents, Attractants, and Pheromones of the Multicolored Asian Lady Beetle

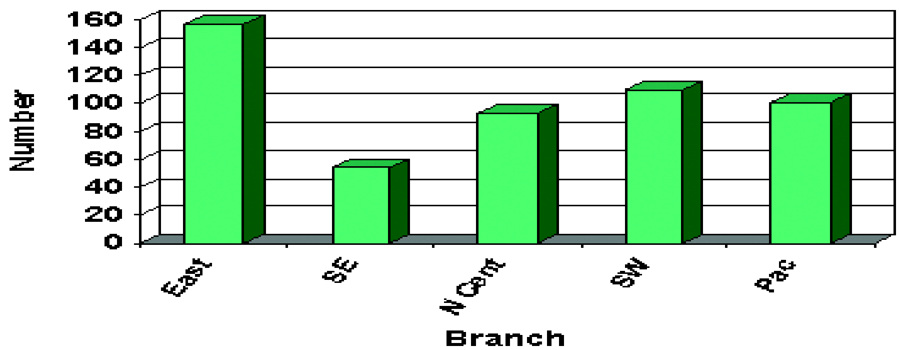
E. W. Riddick and J. R. Aldrich

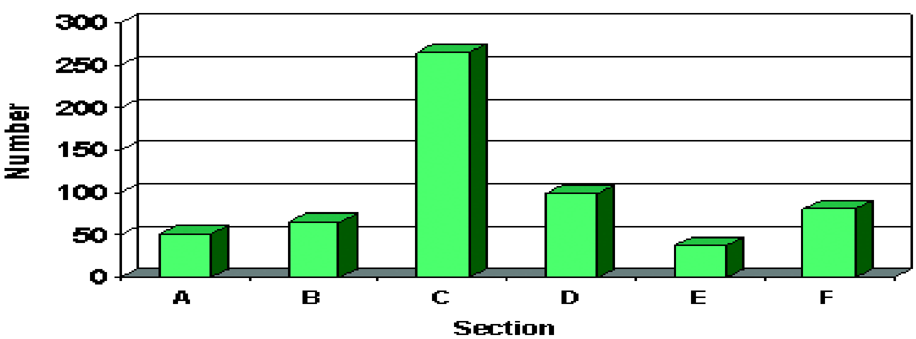
In this article, we present research on the potential of using least-toxic chemicals to manage populations of the multicolored Asian lady beetle, *Harmonia axyridis* (Pallas), in the fall season. The objectives of the study were to describe the behavior of *H. axyridis* adults in urban areas, to introduce a "push-pull-store" strategy for managing populations, and to present preliminary evidence of chemical repellents, attractants, and/or pheromones of *H. axyridis*.

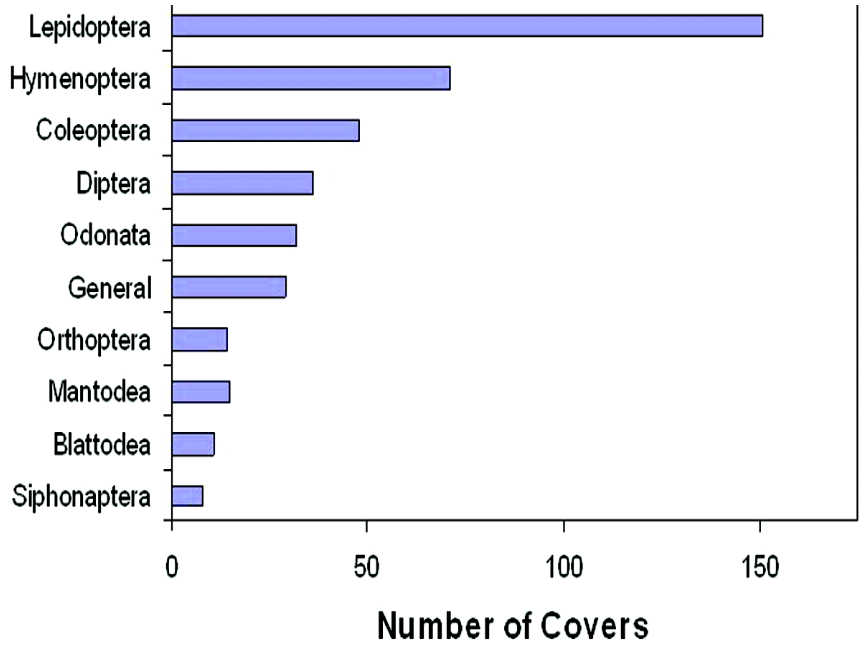
Beginning in the fall of 1993, *H. axyridis* adults were found creating a nuisance in homes in Georgia, Oregon, and Washington. Since then, adults have expanded their range and have been found in homes in much of the eastern United States, several midwestern states, and southern Canada. In the fall, aggregating *H. axyridis* adults first orient visually to prominent objects (e. g., buildings) in the landscape. Once at a preferred overwintering habitat, adults may depend upon chemical cues to guide them to the precise site (crevice) leading into the actual overwintering cavity behind the outer wall or within the structure itself (Fig. 1). The propensity of adults to enter houses in the fall season has become a concern to homeowners. Beetles that successfully enter houses can aggregate by the thousands in secluded dark places (e.g., attics).

On warm spells during the winter, beetles often become active and become a nuisance in interior living spaces—by their mere presence or by reflex bleeding when crushed or handled roughly. Reflexed blood has an unpleasant odor and can stain walls, furniture, and draperies. There is a need to discover effective least-toxic methods to prevent adults from entering buildings.

Perhaps a "push-pull-store" strategy (Fig. 2.) can be used to manage the multicolored Asian lady beetle: chemical repellents could push beetles away







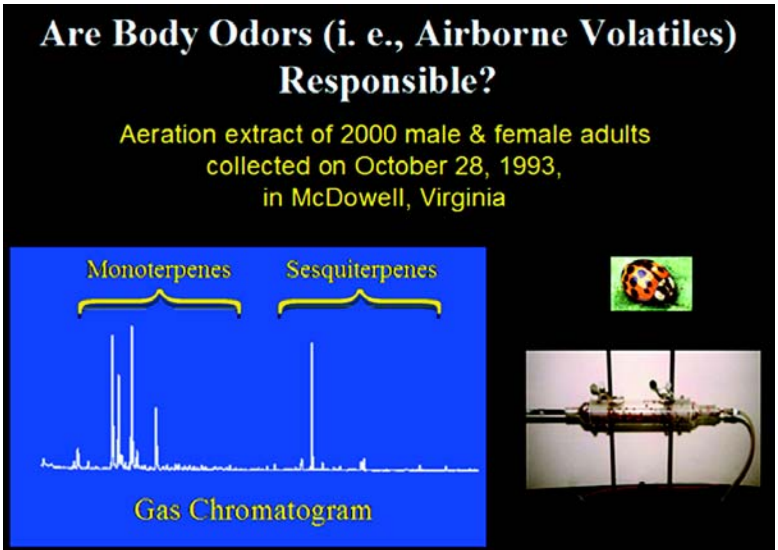


Fig. 3.

from house exteriors, and chemical attractants or pheromones could pull beetles into collecting vessels or traps. Collected beetles could then be cold-stored in depositories and released in the spring to function as predators of aphids and other small, soft-bodied insects.

We initiated our research to assess the potential of plant-derived natural products to repel *H. axyridis* adults. Laboratory bioassays showed that several monoterpenes had repellent activity. Most notably, in laboratory bioassays using treated filter paper within glass Petri dishes or olfactometers, camphor repelled adults. Under field conditions, however, the repellent activity of camphor was short lived; beetles were no longer repelled from treated surfaces 48 h after application (Riddick et al. 2000. Ann. Entomol. Soc. Am. 93: 1314–1321). Additional laboratory experiments considered the potential of DEET to repel *H. axyridis* adults.

Research indicated that DEET successfully repelled beetles from treated filter paper in glass Petri dishes and olfactometers. DEET also had some residual activity; filter paper strips treated with a 1% or 10% formulation of DEET and paraffin repulsed beetles in Petri dish arenas for as much as 23 d after application (Riddick et al. 2004. J. Entomol. Sci. 39: 373–385). However, DEET needs to be field tested on urban structures.

The establishment of overwintering aggregations of *H. axyridis* adults in buildings could be precipitated by the odor of feces and/or dead beetles that expired at the site in the previous season, body odor of live beetles arriving at the preferred site, or a persistent pheromone deposited at the entrance of the preferred site. We have conducted bioassays that trapped airborne odors (i.e., headspace volatiles) emitted from male and female beetles that had been removed from overwintering aggregations. GC-MS analysis of trapped volatiles has provided tentative evidence that several compounds, including methoxypyrazines, monoterpenes, and sesquiterpenes (Fig. 3), might be responsible for the establishment of *H. axyridis* aggregations in structures (JRA, unpublished data).

Our search for effective repellents, attractants, and pheromones of *H. axyridis* is ongoing. Once effective behavior-modifying chemicals have been identified and an effective outdoor trap has been designed, all components of a "push-pull-store" strategy can be tested. Depositories for cold storage of captured beetles could then be established.

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