Evaluation of Strawberry Sap Beetle (Coleoptera: Nitidulidae) Use of Habitats Surrounding Strawberry Plantings as Food Resources and Overwintering Sites

REBECCA L. LOUGHNER,[1,2] GREGORY M. LOEB,[1] KATHLEEN DEMCHAK,[3] AND SONIA SCHLOEMANN[4]

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ABSTRACT The matrix of strawberry and alternate host crops, wooded areas, and uncultivated sections that comprises a farm landscape provides not only food resources but also habitat in both a spatial and temporal context. Reports of the strawberry sap beetle as a pest in strawberry in the northeastern United States have increased along with a trend to produce a wider diversity of fruit crops on individual farms. The three objectives of this study focused on determining which, if any, habitats outside strawberry plantings are important to consider when developing control strategies for strawberry sap beetles. First, sampling of wooded areas and multiple crops showed that strawberry sap beetles overwinter not only in wooded areas but also in blueberry and raspberry. No overwintering beetles were found in strawberry. Second, up to a 70-fold increase in mean number of strawberry sap beetles in a no-choice food source experiment indicated that considerable reproduction can occur on blueberry, cherry, raspberry, and strawberry. Third, sampling summer-bearing raspberry, peach, blueberry, and cherry in 2004 and 2005 confirmed that beetles were present, often in high densities (0.1–108.5 strawberry sap beetles/m^2), in commercial fields with fruit or vegetable material on the ground. In summary, the beetles are able to feed, complete development, and overwinter in habitats other than strawberry. An effective integrated pest management program to control strawberry sap beetles will need to consider the type of habitat surrounding strawberry fields.

KEY WORDS *Stelidota geminata*, integrated pest management, crop diversity

The strawberry sap beetle is a pest of increasing concern for strawberry growers in the northeastern United States. The adults feed on ripe and overripe berries creating holes, but more significantly, larvae contaminate harvestable fruit, leading to consumer complaints and the need to prematurely end the picking season. During the same time period that strawberry sap beetles have been increasing as a pest, small fruit farms in the Northeast have been diversifying the number of crops grown in response to a trend to market locally grown produce through roadside farm stands, pick your own sales, and farmer's markets. As evidence of this trend, revenue from direct marketing of fruit in New York has almost tripled in recent years, growing from $12.8 million in 1987 to $36.7 million in 2000 (New York State Agricultural Statistics Service 2002). Although a pest primarily on strawberry, strawberry sap beetles have been reported on a number of crops (Blackmer and Phelan 1992). It is not atypical to find strawberries, raspberries, cherries, apples, melons, and sweet corn, all potential food sources for strawberry sap beetles, growing on the same farm. The expanding availability of these alternate food sources both spatially across a farm and temporally throughout the growing season may contribute to larger overwintering populations of strawberry sap beetles that can damage strawberry fruit the following spring.

The matrix of strawberry and alternate host crops, wooded areas, and uncultivated sections that comprises a farm landscape provides not only food resources but also habitat in both a spatial and temporal context. Root (1973) developed the idea that a mixture of plant species compared with a monoculture of the same area could reduce the chance of a specialist arthropod detecting a particular plant species or increase the chance of leaving the area and thus reduce damage to the host plant (the resource concentration hypothesis). It is unclear to what extent similar conclusions can be applied to a matrix of habitats at a landscape scale with generalist herbivores. A review of the literature on the effect of diet breadth on herbivore arthropod abundance in response to polyculture found that polyphagous species were more likely to have a higher density in a polyculture than were monophagous species (Andow 1991).

[1] Department of Entomology, Cornell University, New York State Agricultural Experiment Station, 630 W. North St., Geneva, NY 14456.
[2] Corresponding author, e-mail: RLL26@cornell.edu.
[3] Department of Horticulture, The Pennsylvania State University, 107A Tyson Building, University Park, PA 16802.
[4] Department of Plant and Soil Sciences, University of Massachusetts, Amherst, MA 01003.

The potential impact of these spatially available resources at the landscape scale has been studied most extensively for natural enemies, with diversification often contributing to enhanced natural enemy populations (Landis et al. 2000); however, much less attention has been directed to effects of spatial and temporal diversification on herbivore populations. Other fruit crops grown near strawberry potentially provide strawberry sap beetles with additional food resources, both spatially across the farm and temporally throughout the summer. Strawberry is among the first fruit crops to ripen in the spring, followed by raspberry, blueberry, and tree fruit. Assuming that these crops are suitable hosts for strawberry sap beetles and that the adults are mobile enough to take advantage of ephemeral food resources within the local area, multiple generations of the beetles in a year are possible. Weber and Connell (1975) reported adults living an average of 58.4 d in the laboratory, suggesting that some of the first generation of beetles that emerge from late June to mid-July could survive until beetles stop looking for food around mid-September in New York, although multiple generations would probably be necessary for larger strawberry sap beetle populations to build up in a particular location. Strawberry sap beetles overwinter as adults (Gertz 1968; Weber and Connell 1975) and have been reported to overwinter in wooded areas (Blackmer and Phelan 1995; Miller and Williams 1982; Gertz 1968) and possibly in other crops such as raspberry and corn (Miller and Williams 1982).

The overwintered adults appear in strawberry fields as fruit ripens in the spring (Williams et al. 1996). Females oviposit in the soil, and the first generation of strawberry sap beetles emerges ~3 wk later (Weber and Connell 1975; unpublished data). Adult beetles cause feeding damage to ripening fruit and larvae contaminate marketable berries. The field effectiveness of insecticide applications in controlling strawberry sap beetles is highly variable (Rhainds and English-Loeb 2002), because the beetles tend to feed on the undersides of fruit touching the ground, making beetles more difficult to contact with insecticide.

The focus of this work was to assess the importance of habitat outside strawberry in development of an integrated pest management (IPM) strategy for strawberry sap beetles. If late-season use of other crops is connected to increased strawberry sap beetle damage in strawberry the following year, it may be appropriate to manage strawberry sap beetles in crops where the beetle is not currently regarded as an economically significant pest. Indications that the strawberry sap beetle population in strawberry is using other crops as late-season food resources and overwintering sites would include presence of overwintering beetles outside but not within strawberry plantings, ability of strawberry sap beetles to complete development on other crops, and presence of beetles on other crops in the field. The specific objectives of this study were to (1) identify habitats in which strawberry sap beetles successfully overwinter, (2) determine which crops provide suitable food sources for strawberry sap beetle larvae to develop into adults, and (3) quantify the density of strawberry sap beetles in various crops.

Materials and Methods

Overwintering and Growing Season Habitat Use. Samples were collected in April 2004 and April to early June 2005 to assess overwintering in different habitat types in New York, Pennsylvania, and Massachusetts. In 2004, 12.7-cm-diameter by 11-cm-deep cores of leaf litter and soil were collected from strawberry, blueberry, raspberry, apple, peach, cherry, edges of wooded areas, and interiors of wooded areas. Samples in each of the crops were collected in a 3 by 4 grid pattern, at locations at least 2 m apart. In wooded areas, 10 samples were collected from the edge and 10 samples from 10 m into a wooded area near a sampled strawberry field. Strawberry sap beetle adults were extracted from the samples with Berlese-Tullgren funnels (Southwood 1978). The sampling was modified in 2005 by taking only a 2- to 3-cm depth of soil and any leaf litter from a 26 by 26-cm area. Sampling was limited to wooded areas, strawberry, blueberry, and summer and fall-bearing raspberry at one farm in each of the three states to permit processing of larger volumes of soil per field relative to 2004. Thirty samples were collected in each wooded area or field from a location where ripe fruit would be present later in the season. A second set of samples was collected from each crop in a similar manner after the fruit ripened. The mean and range of the total number of strawberry sap beetles collected were calculated for each crop before and after fruit was present.

Population Growth in No-Choice Assay. Strawberry sap beetle adults were collected in traps baited with whole wheat bread dough (Williams et al. 1994) along wooded edges at the perimeter of a strawberry field in western New York from 3 to 8 June 2004. On 9 June, 10 male and 10 female strawberry sap beetle adults were placed into cages with one of six food sources: strawberry, raspberry, sweet corn, blueberry, cherry, or apple. The experiment was begun in mid-June such that the locally produced strawberries would be available at the same time as early ripening varieties of raspberry and cherry, with the remaining foods being purchased from a grocery store when locally produced varieties were unavailable. A mixture of sweet and sour cherries was used over the course of the experiment depending on availability. Eight replicate cages for each food source (total of 48 cages) were arranged in a completely randomized design in a screened outdoor rearing facility at the New York State Agricultural Experiment Station in Geneva, NY. Rearing cages for the experiment were 23 by 23 by 9-cm plastic storage containers ventilated with nylon knit fusible interfacing (HTC-Handler Textile, Secaucus, NJ) over a 19.5 by 19.5-cm opening in the lid. Cages were lined with ≈2 cm of moistened sand for pupation and oviposition, because strawberry sap

Table 1. Mean density ± SEM and range for fruit and adult strawberry sap beetles in crops sampled during the 2004 growing season

Crop	n	Mean total area/field (m^2)	Number of fruit/m^2		Fruit weight (g/m^2)		SSB adults/m^2	
			Mean[a]	Range	Mean[a]	Range	Mean[a]	Range
Apple	1	87.1	3.7		355.0		0.7	
Blueberry	6	50.8 (18.9)	44.2 (10.7)	2.2–80.2	33.5 (9.3)	1.4–68.2	29.1 (25.3)	0.1–155.1
Cherry	1	8.7	151.0		532.4		108.5	
Sweet corn	2	61.4	2.1	0.6–3.6	394.0	79.6–708.3	2.7	2.0–3.4
Melon	1	170.7	0.3		387.8		0.3	
Peach	3	264.5 (114.8)	3.0 (2.6)	0.3–8.1	220.5 (190.1)	21.8–600.5	19.5 (12.4)	6.7–44.3
Raspberry (summer)	6	21.2 (2.7)	28.6 (5.8)	9.2–49.5	71.6 (15.1)	18.9–132.0	44.6 (17.2)	12.9–128.5
Raspberry (fall)	1	15.0	91.6		159.3		0.1	
Strawberry	17	20.9 (1.2)	58.1 (7.1)	14.0–120.3	353.3 (64.8)	49.0–1056.8	1.5 (0.4)	0–7.3

[a] SEM, in parentheses, shown only for crops with more than two fields sampled.

beetles generally oviposit in the soil (Weber and Connell 1975).

All foods except sweet corn were washed in soapy water because preliminary work indicated this prevented any pesticide residue that may have been present on fruit from affecting strawberry sap beetle feeding. Foods were rinsed several times and allowed to dry before being added to cages. A slit was cut into apples and two to three cherries per date to mimic the damaged nature of fruit typically found on the ground in orchards. An excess of all foods was provided, with fresh food added to cages as older fruits began to desiccate or to develop fungal infections. Sand was kept moist throughout the experiment. Excess moisture from decomposing fruit was an issue in some of the strawberry cages, potentially affecting the survival of the larvae.

Fruit was removed from cages on 16 July, ~5 wk after the experiment was initiated, and placed in Berlese funnels to extract adults and larvae. Sand from the cages was placed in Berlese funnels overnight and run through a series of sieves (four and eight holes per centimeter) to remove any remaining strawberry sap beetles, including pupae. Both the number of adults and the total number of strawberry sap beetles (adults, larvae, and pupae combined) recovered from each cage were log-transformed and analyzed with analysis of variance (ANOVA) using SAS version 9.1 (SAS Institute 2006) with the Tukey option specified for the mean separation procedure.

Density in Commercial Fields. Crops sampled included strawberry, summer and fall-bearing raspberry, blueberry, apple, cherry, peach, sweet corn, and melon. Sampling was conducted in 2004 as growers were either ready to harvest the crop (sweet corn and melons) or as overripe and damaged fruit accumulated on the ground. Up to two fields for each sampled crop were selected at each of 10 farms with known strawberry sap beetle populations in New York, Massachusetts, and Pennsylvania. In some cases, only one field of a particular crop was available across all of the farms. The mean total area sampled per field varied by crop (Table 1). Typically, alternating rows of crop were sampled, with a minimum of 1 m of space between sampling points within each row. Sampled areas were either a length of row or a section underneath a tree, such that calculating a mean density of strawberry sap beetles across an entire field (rows and space between rows) was possible. Fruit and/or fruit residue on the ground was collected and inspected for strawberry sap beetle adults. A small amount of soil was collected along with the fruit on the ground, except in strawberry, and Berlese funnels were used to extract adult strawberry sap beetles. In raspberry, fruit was sampled on the canes and the ground after strawberry sap beetles were seen in the canes during sampling. Number and wet weight of fruit, along with the number of beetles in fruit, were recorded for all samples. Means per square meter of field were calculated for number of fruit, fruit weight, and number of strawberry sap beetle adults. Pearson correlation coefficients for strawberry sap beetle density with number of fruit and fruit weight per square meter were calculated using SAS version 9.1 (SAS Institute 2006).

Results

Overwintering and Growing Season Habitat Use. A total of five adult strawberry sap beetles was found in the 220 soil cores collected from wooded areas in early spring 2004, whereas no strawberry sap beetles were present in the 480 samples taken from other crops at this same time during the season (data not presented). All overwintering beetles were found in samples from two farms known to have high densities of strawberry sap beetles in strawberry. More beetles were found in 2005 (Table 2) after increasing the area sampled per field for overwintering strawberry sap beetles from 0.16 (wooded area) or 0.26 m^2 (crops) in 2004 to 2.03 m^2 in 2005. Adults were found in both of the two wooded areas sampled, below blueberry bushes, and below raspberry canes for samples collected early in the spring and after fruit residue was present in 2005. No strawberry sap beetles were found in any of the three strawberry fields for the overwintering samples collected in early spring. However, adults were found in samples collected from all crops during the growing season when fruit was present in the fields (see below). Other species of Nitidulids found in samples from wooded areas included *Epuraea rufa* (Say) and *Stelidota octomaculata* (Say).

Table 2. Mean ± SEM and range for adult strawberry sap beetles collected over the total area (2.8 m²) sampled in each crop or wooded habitat site for overwintering beetles and strawberry sap beetles using crops as a food source in 2005

Crop/habitat	n	Before fruiting (overwintering)		Fruit present (use of food source)	
		Mean total strawberry sap beetles[a]	Range of strawberry sap beetles	Mean total strawberry sap beetles[a]	Range of strawberry sap beetles
Blueberry	3	3.0 (1.5)	0–5	223.0 (52.3)	131–312
Raspberry (summer)	2	0.5	0–1	908.5	566–1251
Raspberry (fall)	1	1.0		194.0	
Strawberry	3	0.0 (0.0)		177.7 (148.7)	25–475
Wooded area	2	22.5	5–40	NA[b]	NA[b]

[a] SEM, in parentheses, shown only for crops with more than two fields sampled.
[b] Late season samples were collected only from crops and not wooded areas.

Population Growth in No-Choice Assay. Larvae and pupae were present in all cages of apple, blueberry, sweet corn, cherry, raspberry, and strawberry after 5 wk. The mean total number of beetles per cage increased substantially from the original 20 adults to between ≈200 and 1,400 adults, larvae, and pupae depending on the food source (Fig. 1A). The mean total number of beetles was significantly lower in apple and corn than in blueberry, cherry, raspberry, or strawberry ($F = 18.40$; df = 5, 42; $P < 0.0001$). The number of adults also differed significantly with food source ($F = 195.94$; df = 5, 42; $P < 0.0001$). Development was delayed in both sweet corn and apple as seen in the low mean number of adults relative to the mean total number of beetles in the same food sources (Fig. 1B). The mean number of adults for apple was no greater than the initial 20 adults used to inoculate the cages.

Density in Commercial Fields. Strawberry sap beetle adults and larvae were present in all crops sampled in 2004, although for some crops, only one site was available. The mean adult strawberry sap beetle density varied from 0.1 to 108.5 adults/m², with the highest densities found in blueberry, cherry, peach, and summer-bearing raspberry (Table 1). The mean density of strawberry sap beetles in strawberry, 1.5 ± 0.4 adults/m², was low compared with most other fruit crops. Sampled fruit was generally in contact with the ground, especially in strawberry. Few strawberry sap beetles were seen during casual observation of peaches, cherries, and blueberries on plants, except in damaged fruit, such as cherries that were split or damaged by birds. Beetles were noted in fruit on raspberry bushes and in fruit on the ground under the bushes. The mean number of strawberry sap beetles found on the raspberry bushes (10.5 ± 2.9 adults/m²) represented about one fourth of the total strawberry sap beetles in the plots (44.6 ± 17.2 adults/m²).

Strawberry sap beetle adult density was not correlated with weight of fruit (Pearson correlation coefficient = 0.22; $P = 0.5673$); however, beetle density was positively correlated with the number of fruit (Pearson correlation coefficient = 0.70; $P = 0.0353$). Crops with a greater number of fruit tended to be those like blueberry, raspberry, and strawberry, all of which are softer fruit than apples or melons, for example. Although not explicitly noted during sampling, factors including ripeness of the residue and farm seemed to influence strawberry sap beetle density. Residue that was soft and overripe tended to have more beetles. A farm that had a substantial population of strawberry sap beetles in one crop generally had a high density of strawberry sap beetles in other crops present at that farm. In the 2005 sampling of blueberry, summer and fall-bearing raspberry, and strawberry at some of these higher strawberry sap beetle density farms, the mean total strawberry sap beetle density ranged from 177.7 to 908.5 adults in a 2.8-m² area (Table 2).

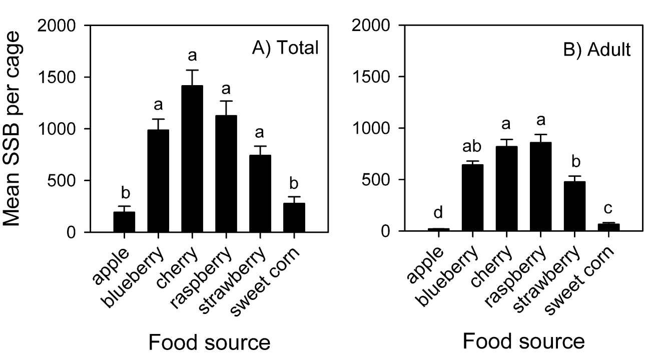

Fig. 1. Mean ± SEM for strawberry sap beetles (SSB) in no-choice feeding assay for (A) the total number of strawberry sap beetles (larvae, pupae, and adults combined) and (B) the number of adults only. Bars with the same letter are not significantly different at $P < 0.05$ based on a Tukey mean separation.

Discussion

It has been unclear whether the strawberry sap beetles in strawberry are from the same population as the strawberry sap beetles reported on other later-ripening crops and in wooded areas near strawberry fields. Data from this study suggested that a number of fruit crops that ripened after strawberry were suitable hosts for strawberry sap beetles. A wide diet breadth coupled with the mobility of the beetles (Loughner 2007) allowed strawberry sap beetles to take advantage of overwintering sites and food resources across a farm.

Two findings were significant from the overwintering habitat sampling: (1) strawberry sap beetles do not use strawberry as an overwintering site and (2) overwintering was not limited to wooded areas. The absence of overwintering adults from strawberry fields in early spring means the beetles must be either choosing to leave the field in search of other habitats after the fruit is gone or conditions do not allow beetles to survive the winter in the field. In either case, overwintered adults were moving into strawberry from habitats outside the field in the spring. Sampling indicated that most of these overwintered adults came from the leaf litter of wooded areas, although some overwintered in blueberry and raspberry plantings (Table 2).

The absence of strawberry sap beetles overwintering in strawberry makes it seem reasonable to expect the next generation of beetles to leave strawberry in search of other habitats after the fruit is gone. For the strawberry sap beetle population to increase in size later in the season, the beetles must be able to complete development on these crops. The no-choice food assay showed that considerable population growth can occur on crops such as blueberry, cherry, and raspberry after strawberry harvest is completed. Even if a large number of immature beetles do not survive to adult stage, the 70-fold increase in total number of beetles seen in cherry over the 5-wk time period would result in many more beetles in the field. The lower than expected mean total strawberry sap beetles in strawberry relative to other foods likely reflected loss of some larvae caused by saturation of the sand with moisture in some cages as fruit became overripe. Although strawberry sap beetles have been reported on apple and corn (Blackmer and Phelan 1992), development of beetles was delayed in the no-choice cages of both foods. Peng and Williams (1991) similarly found a significantly longer preoviposition period for another Nitidulid, *Glischrochilus quadrisignatus* (Say), when fed apple compared with tomato or prepared diet. If apple and corn are lower-quality food sources, lower densities of strawberry sap beetles are expected in the field for apple and corn than for other fruit crops.

Sampling of commercial fields in 2004 and 2005 confirmed that (1) strawberry sap beetles were found in a variety of crops when fruit or vegetable residue was present and (2) densities of strawberry sap beetles were relatively low in corn and apple compared with other sampled crops, as expected from the no-choice food assay (Tables 1 and 2). The density of adult beetles found in summer-bearing raspberry, peach, blueberry, and cherry clearly indicated the beetles used these crops as a food resource after strawberry fruit was no longer available (Tables 1 and 2). Presence of larvae in all crops showed the beetles were capable of reproducing while using these fruits as food sources. Although the correlation between mean strawberry sap beetle density and mean number of fruit was statistically significant, the number of fruit alone seemed unsatisfactory for predicting presence of strawberry sap beetles because of the wide range of data used to calculate the means for both variables.

Strawberry sap beetles have been reported as an occasional pest in summer-bearing raspberry, and sampling showed a large portion of the adult beetle population was in marketable raspberries on the canes. The presence of strawberry sap beetle adults in the raspberry canes offered evidence that strawberry sap beetles could feed on strawberry fruit that was not in contact with the ground. The density of adult strawberry sap beetles in strawberry was lower than expected (Table 1). Strawberry fields were sampled in the mid- to late part of the harvest, and many of the first-generation emerging adults may have already left the fields. The low density of strawberry sap beetles found in two of the later-ripening crops, apple and corn, was consistent with the low population growth observed on these foods in the no-choice cage assay. While the late ripening time in the field may prevent strawberry sap beetles from extensively feeding on apple, it seems that low quality of apple and corn for strawberry sap beetles was the best explanation for the low densities in the field and the poor performance in the no-choice assay.

The work presented here showed that (1) strawberry sap beetles successfully overwintered in wooded habitats and blueberry and raspberry but not in strawberry, (2) crops including raspberry, blueberry, and cherry were suitable food sources for strawberry sap beetle larvae to develop into adults, and (3) strawberry sap beetles were found in the field on summer-bearing raspberry, peach, blueberry, and cherry in substantial densities. The food and overwintering resources provided by other crops and wooded habitat adjacent to strawberry fields is likely to influence the population dynamics and overall abundance of strawberry sap beetles throughout the growing season and potentially into the following season. Although we have not directly tested the assumption that population density during the current year is positively correlated with density in the following spring, the consistency of farms to have either high or low populations of strawberry sap beetles across years indicates this assumption is valid. Casual observation suggested that factors influencing strawberry sap beetle densities were more connected with individual farms than geographic location.

The hypothesis underlying this research was that diversifying the mixture of crops in a landscape could reduce pest abundance, and consequently, reduce pesticide use. This study focused on a generalist pest, strawberry sap beetle, as a model system to ask whether the specific predictions from the resource concentration hypothesis could be applied to generalist pests on a landscape scale. The data from this study documented that strawberry sap beetles fed and reproduced on multiple fruit crops in the landscape and overwintered in multiple habitats. These results strongly suggest that diversifying the crops on a farm will not likely reduce the abundance of strawberry sap beetles and instead contribute to a larger strawberry sap beetle population late in the season that can overwinter and damage strawberry the following spring. The importance of habitat surrounding a crop may extend to other pests characterized by generalist feeding habits, multiple generations, and at least moderate dispersal capability.

The accessibility of a particular crop within a mixture of habitats could be reduced by changing the specific mixture of crops grown, altering the spatial arrangement of crops such that alternate hosts are located further away from the crop being damaged, or manipulating the temporal availability of alternate hosts to minimize the contribution of later-ripening food sources to insect population growth. In the case of strawberry sap beetles, farms growing strawberry also tend to grow vegetables and other fruit crops to supply roadside farm stands with produce throughout the growing season. A combination of the perennial nature of fruit crops and the relatively small size of most strawberry farms in the Northeast limits the potential to successfully protect the strawberry crop from strawberry sap beetles by modifying either the spatial arrangement or ripening times of crops within a farm. The absence of strawberry sap beetle overwintering in strawberry presents an opportunity to reduce the number of overwintering adults that enter strawberry fields in the spring from wooded areas and other crops, such as blueberry and raspberry.

One promising control option involves taking advantage of the beetles' communication system to develop a mass-trapping method. Traps containing a synthetic strawberry sap beetle male-produced aggregation pheromone, a food odor, and an insecticide could be deployed early in the spring in strawberry sap beetle overwintering habitat, thus reducing the size of the strawberry sap beetle population before fruit ripens. Traps baited with a pheromone and a co-attractant odor have successfully minimized fruit damage from related sap beetles (*Carpophilus* spp.) when traps were placed around the perimeter of small blocks of stone fruit plantings (James et al. 2001, Hossain et al. 2006).

Developing such alternative management strategies that are cost effective depends on applying a broad understanding of the effects of crop diversity to individual pest species, with the goal of identifying which crop resources are important hosts at specific times during the season for each insect. Control strategies can then be implemented in habitats, even if outside of the crop to be protected, that will lead to the greatest reduction in pest abundance and pesticide use.

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