

Patterns of Spatial and Temporal Distribution of the Asparagus Miner (Diptera: Agromyzidae): Implications for Management

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ABSTRACT The asparagus miner is an obligatory feeder on asparagus and a putative vector for pathogenic fungi implicated in the early decline of asparagus fields. To date, the distribution of the asparagus miner over space and time is poorly understood. Our study evaluated the spatial and temporal pattern of adult asparagus miners in commercial asparagus fields in Michigan in 2011 and 2012. We sampled adults and damage weekly during the growing season using yellow sticky traps outside, at the edge, and inside commercial fields. Yellow sticky traps at each trapping location were placed at the canopy and ground level to determine vertical distribution of adults. During the first generation, adults were more evenly distributed throughout the field. In the second generation, adults were more commonly found on the edge of the field. Overall, there was a greater percent of mining damage near the edge of the field. Additionally, three times as many asparagus miners were found in the canopy compared with ground-level traps. There were 12 times as many asparagus miner adults on edges bordered by another asparagus field than on ones bordered by forest. Taken together, our results indicate that while asparagus miner management in the beginning of the growing season should focus on the entire field, in the latter half of the season, growers could save money and resources by targeting miner adults at the edges of fields. Finally, conserving the remaining naturally forested landscape and planting borders of trees may help ameliorate pest pressure in asparagus fields.

RESÚMEN *Ophiomyia simplex* se alimenta exclusivamente de espárrago y es un posible vector de hongos patógenos implicados en el deterioro temprano de campos de espárrago. A la fecha se tiene poco conocimiento sobre la distribución espacial y temporal de *O. simplex*. Nuestro estudio evaluó patrones espaciales y temporales de adultos del minador del espárrago en campos comerciales de espárrago en Michigan en el 2011 y 2012. Semanalmente se muestrearon adultos de *O. simplex* y su daño, durante la temporada de crecimiento del espárrago usando trampas adhesivas amarillas situadas en el exterior, borde e interior de cultivos comerciales. Para determinar la distribución vertical de adultos, las trampas fueron situadas tanto en el dosel como a nivel del suelo. Durante la primera generación los adultos se distribuyeron uniformemente a lo largo del cultivo. En la segunda generación los adultos se encontraron con mayor frecuencia en los bordes. En general, hubo un mayor porcentaje de daño por minado en los bordes del cultivo. Adicionalmente se encontró tres veces más adultos de *O. simplex* en el dosel del cultivo que en trampas ubicadas a nivel del suelo. Se encontró 12 veces más adultos en los bordes del cultivo rodeados de otros campos de espárrago, que en bordes rodeados por bosque. En conjunto nuestros resultados indican que mientras que al comienzo de la temporada del cultivo, el manejo del minador del espárrago se debe enfocar a todo el campo, en la segunda mitad de la temporada los agricultores podrían ahorrar dinero y recursos dirigiendo el control a los bordes del cultivo. Finalmente, la conservación del bosque natural y la siembra de árboles en los bordes del cultivo ayudará a disminuir la presión de las plagas en los campos de espárrago.

KEY WORDS integrated pest management (IPM), monitoring, trapping, vector, *Fusarium*

The asparagus miner (*Ophiomyia simplex* Loew; Diptera: Agromyzidae) is an obligatory asparagus (*Asparagus officinalis* L.) feeder and was likely introduced when asparagus was first brought to the United States from Europe (Barnes 1937). It is a cosmopolitan spe-

cies, commonly found in asparagus growing regions of the world (Giard 1904, Fink 1913, Dingler 1934, Barnes 1937). It overwinters as a pupa and adults appear in the field in Michigan during May (Lampert et al. 1984). During spring, asparagus spears are picked regularly, resulting in no canopy, but after harvest, asparagus plants branch out to form a canopy, often referred to

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as fern. Throughout the growing season, eggs are deposited on the asparagus stems near the soil-air interface (Ferro and Gilbertson 1982). Once larvae hatch, they burrow into the stem underneath the epidermis to feed, and create tunnels. In asparagus, a portion of the photosynthesis occurs in the green stems (Downton and Törökfalvy 1975) and the mines destroy tissue that is essential for the development and survival of the plant. Mines and oviposition scars from the asparagus miner create infection sites for *Fusarium* spp., and stem rot from the fungus linearly increases with the number of mines (Damicone et al. 1987). Furthermore, *Fusarium* has been associated with all the life stages of the asparagus miner (Tuell and Hausbeck 2008), and has been linked to increasing inoculum and disease incidence in the field (Gilbertson et al. 1985). The disease has been implicated in the early decline of asparagus (Grogan and Kimble 1959) and in reducing asparagus yields over the past 30 yr (Elmer et al. 1996). Although there has been extensive research into controlling the fungus (e.g., Stephens et al. 1989; Pontaroli and Camadro 2001; Reid et al. 2001, 2002; Counts and Hausbeck 2008), research on the biology and management of the insect vector has been lacking (Morrison et al. 2011).

Distribution of asparagus miner adults and the patterns of larval damage in asparagus fields are poorly understood. Previous studies have demonstrated that adult asparagus miners are more abundant in the canopy than near the ground, and prefer recently planted fields to older ones (Tuell 2003). Early in the season, most miner pupae occur ≈ 3 cm below the soil surface, but as the miners prepare to overwinter, most pupae can be found between 5–7 cm belowground in the stem (Lampert et al. 1984). However, knowledge of asparagus miner distribution at the field and between-field scale is lacking, which our study aimed to address.

Spatial dynamics have implications for effective pest management in the field. For example, if pests primarily occur in a particular area of the field, management methods such as insecticides can be targeted to that location to reduce pesticide use and harmful environmental effects (Ferguson et al. 2003). Some pest flies, such as the papaya fruit fly, have a greater abundance near the edge of orchards than further into the field (Aluja et al. 1997). However, the distribution of other insects, such as the apple maggot fly, changes over the course of the season, ranging from being aggregated, to randomly and finally to evenly distributed in hawthorn trees (Averill and Prokopy 1989). The asparagus miner is a strong flier (Ferro and Gilbertson 1982), which may allow for directed dispersal, aggregated distribution in the field and active host-finding, which is dissimilar from weakly flying insects that are often wind-dispersed such as aphids (Pasek 1988). Information on the spatial distribution of the asparagus miner in the field, both horizontally and vertically, may provide pest managers much needed precision for their management actions, reducing the overall usage of potentially harmful chemicals.

Currently, asparagus growers do not have a targeted management plan for the asparagus miner (Morrison

Table 1. Summary information of asparagus field sites located in Oceana Co., MI

ID	Area (ha)	Year planted	Variety	Sampled	Edge habitat
Field 1	6.06	2009	Millennium	2011, 2012	As, As, Ag, Ag ^a
Field 2	3.77	2009	Millennium	2011, 2012	Ag, As, F, F
Field 3	3.54	2009	Millennium	2011, 2012	F, F, F, G
Field 4	1.82	2008	Millennium	2011	F, F, G, G
Field 5	3.66	2010	Millennium	2011	Ag, Ag, Ag, Ag

^a F, forest; G, grassland; Ag, agricultural; As, interspaced between asparagus fields.

et al. 2011). The organophosphate, diazinon, has been shown to reduce the abundance of asparagus miner adults in the field, as well as stem rot from *Fusarium* (Damicone et al. 1987). However, the Environmental Protection Agency (EPA) is reevaluating and phasing out many organophosphates (USEPA 2012). The asparagus insect control program for growers consists of multiple broad-spectrum insecticides applied at various times in the season. In total, there were 24.9 metric tons of broad-spectrum insecticides used on asparagus in the United States in 2010 (USDA–NASS 2011), and their use has been associated with harmful effects on beneficial insects in other perennial systems (Epstein et al. 2000). Therefore, there is a need to develop a sustainable asparagus miner management strategy that decreases the reliance on broad-spectrum insecticides and increases the use of appropriately timed, environmentally sound, economically feasible, and socially acceptable management alternatives. Because the immature life stages of the asparagus miner remain protected within the stem of asparagus and are impervious to registered pesticides, we focused our study on asparagus miner adults because this life stage is susceptible to currently available insecticides. Reducing adults will ultimately decrease immature abundance in the field and the damage associated with that life stage. The aim of our study was to evaluate the field-level spatial and temporal distribution of adult asparagus miner as well as its damage in commercial fields.

Materials and Methods

Study Site. The five commercial asparagus fields used in this study in 2011 and three fields in 2012 were located 1.21–16.14 km apart in Oceana County, MI (Table 1). The asparagus fields were bordered with some combination of the following types of habitats: mixed coniferous-deciduous forest patches, grassland, other asparagus fields, or some type of anthropogenic modification, such as a road or building. This fragmented habitat is typical of this part of Michigan, and is representative of the asparagus-producing region of the state.

Adult Asparagus Miner Sampling. Asparagus miner adult abundance was measured with yellow sticky traps (7.5 by 12.3 cm, Great Lakes IPM, Vestaburg, MI). Thirty-two sticky traps were set up per field ($N = 160$ for all fields combined), and these were checked and changed every 6–10 d. Asparagus miners were

counted on traps and their numbers recorded. Sampling occurred from the beginning of asparagus emergence on 11 May to end of adult flight on 3 October 2011 and 22 March to 7 October 2012. The traps were arranged in transects, with sampling points at 0, 10, 20, and 30 meters into the asparagus field from the field edge. Three sets of transects were placed 10 meters apart in each field. Additionally, there were two traps placed 10 meters from the field edge outside the field in border habitats. At each sampling point, there was a canopy trap, placed on a 1 meters long steel conduit, paired with a ground-level trap (10 cm above ground), except during asparagus harvest when only ground traps were used for practical reasons. This experimental design was intended to assess vertical and the horizontal distribution of the asparagus miner.

In addition, to approximate how neighboring habitat affects asparagus miner abundance, the type of habitat on each border of the field was assigned to one of four types, including: forest, grass, agricultural land (agricultural), or interspace between asparagus fields (asparagus). Forest included either deciduous forest or coniferous forest, while agricultural land consisted of other crop types (rye or cherry orchard) or landscapes that have been modified by humans (e.g., barns, buildings, roads, etc.). These categories were noted for each yellow sticky trap on the field edge and were later used in the analysis of asparagus miner distribution as described in the statistical analysis section.

In 2012, sampling for adults was performed in a cherry orchard located next to an asparagus field to evaluate abundance of the asparagus miner in areas where they may be using alternative resources. Ground-level yellow sticky traps were placed in three transects spaced 16 meters apart, with traps located in the cherry orchard at 9.3, 21.8, and 34.3 meters away from the adjacent asparagus field. Similarly to above, traps were changed weekly from 26 April to 7 October 2012 and the abundance of asparagus miner adults were recorded.

Damage Data Collection. In 2012, two measures were taken to quantify the damage in asparagus fields. The percent damage (intensity of damage) within 5 cm of the base of an asparagus stem was recorded for 10 stems at 0, 10, 20, and 30 meter points into the field, offset from the sticky traps by 5 meters to avoid confounding effects near the traps. Percent damage was estimated visually by the area of the epidermis that exhibited mining damage around the circumference of asparagus stem. This was done for the three transects set up for sampling the abundance, each separated by 10 meters. The first measurement for damage was taken 2 wk after the asparagus harvest ended in a field and the plants went to fern (range: 159–172 Julian days). Thereafter, sampling for damage happened every 2–3 wk in the growing season at three time points. Secondly, the proportion of stems damaged (out of the 10 sampled at each point above) was noted to quantify the extent of damage in the field.

Statistical Analysis. A repeated measures analysis of variance (ANOVA) with first order autoregressive correlation among the time points was used to eval-

uate the fit of the abundance of adult asparagus miners' horizontal and vertical distribution within and outside the asparagus field. This was done with the Julian date as the time parameter and sticky trap at a specific height in a given field and at a certain distance into the field as the repeated subject. Asparagus miner adult abundance was used as the dependent variable and trap height, distance of trap into field, and year of data collection were used as independent variables in the linear mixed model with a generalized least squares function (R Development Core Team 2012). The field was used as a random variable. Two additional random variables were the error terms, which was an interaction between field, distance, and transect, and an interaction between field, distance, transect number, height of trap, and year. The autoregressive model was the best fit to the data when comparing AIC and BIC criteria among similar models with different correlation structures. A Kenward–Rogers correction was used to calculate the degrees of freedom to avoid its artificial inflation because of the repeated measures. The residuals were analyzed to evaluate assumptions of normality and the data were log-transformed to meet assumptions of homogeneity of variances and normal distribution. Results were considered to be significant at $\alpha = 0.05$ for this analysis and all subsequent ones.

An additional repeated measures ANOVA with the same structure as above was used to assess how the abundance of asparagus miners was affected by habitat type on the edges of the fields. Abundance of asparagus miner adults was the dependent variable, while height of trap, habitat type, and year were independent variables. A separate ANOVA was required because of different sampling points not included in the above analysis outside of the field and unequal replication between treatments. The two error terms for this model (both random variables) were an interaction between direction (of field edge), field and habitat, and an interaction between height (of traps), direction, field, habitat, and year. Post hoc Tukey's honestly significant difference (HSD) test was used to assess pairwise comparisons between asparagus miner abundance at different distances into the field, pairwise differences between habitat types on the field edge in adult abundance, and was also used to evaluate pairwise comparisons between different distances into the cherry orchard for asparagus miner abundance.

A final repeated measures ANOVA was performed to assess overall differences in percent mining damage (intensity of mining per stem) at different distances into the field, because this was a separate dataset from the abundance data and did not contain the same sampling points. The percent mining damage was used as a dependent variable and the distance into the field as the independent variable, with a first-order autoregressive correlation structure. There were two random variables: field and an interaction between field, distance, and transect number (error term). Residuals were inspected for normality assumptions, which

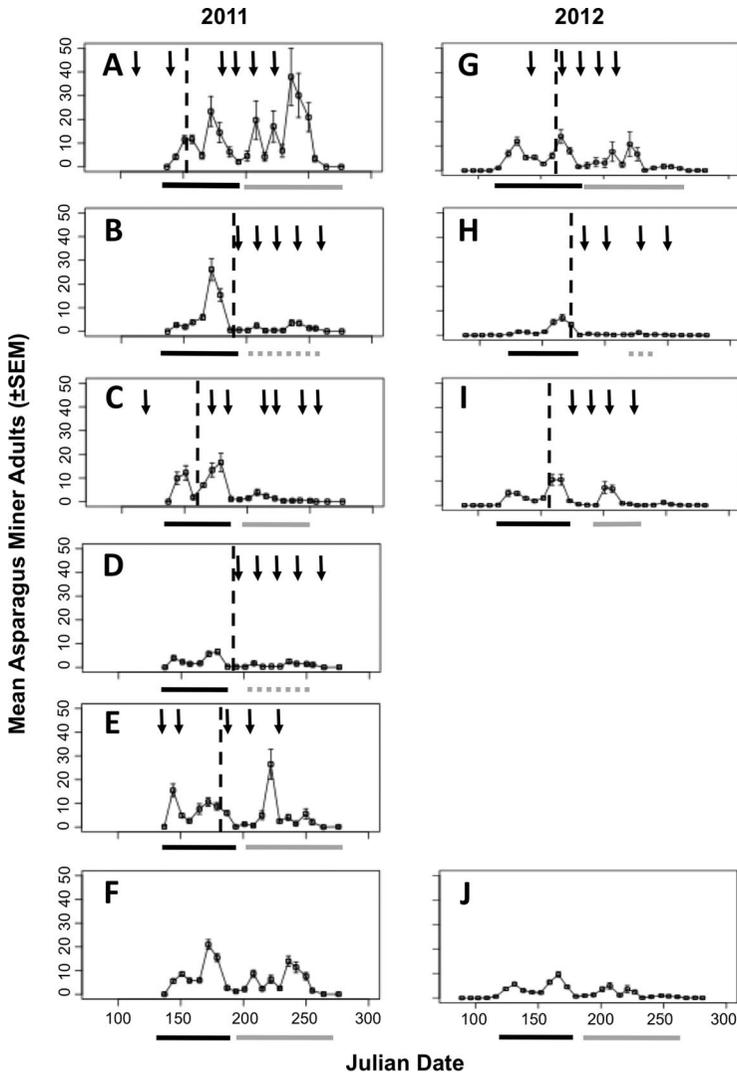


Fig. 1. Variation in mean (\pm SEM) asparagus miner adult abundance by field per yellow sticky trap for 2011 (A–F) and 2012 (G–J) for field 1 (A, G), field 2 (B, H), field 3 (C, I), field 4 (D), field 5 (E), and overall (F, J). Dashed lines indicate the date at which asparagus harvesting stopped, and arrows indicate insecticide applications. Some graphs are not present because certain fields were only sampled in 2011. The overall graph shows average abundance combined over the fields for a year. The horizontal bars underneath each graph show the first generation (black solid line) and whether the second generation was full (solid gray line) or reduced (dotted gray line) compared with the first generation.

were not fulfilled. The data were inverse transformed to meet normality assumptions, and pairwise comparisons between mining damage at different distances into the field assessed with Tukey’s HSD. A different measure of damage, the proportion of stems damaged (extent of mining damage) out of 30 stems sampled per point at the different distances into the field was analyzed using a Pearson’s χ^2 test and Monte Carlo simulations with 10,000 simulations to obtain a *P* value. The data were pooled between the three fields for overall frequencies of damage and comparisons were made to the null hypothesis that damage was equally distributed at the edge, 10, 20, and 30 meters into the field.

Results

Temporal and Spatial Within-field Distribution of Adults. Adult miner abundance was significantly different in the two sampling years (repeated measures ANOVA, year: $F = 38.96$; $df = 1, 152$; $P < 0.01$). Specifically, there was an almost three-fold greater abundance of adult asparagus miners caught in 2011 compared with 2012. As a result, all further analyses were done separately for 2011 and 2012 for the adults.

Overall, there were two generations in a year for adults in 2011 and 2012 (Fig. 1F and J). Despite increased broad-spectrum insecticide sprays in certain fields (Fig. 1A, C, E, G, and I), there was a greater

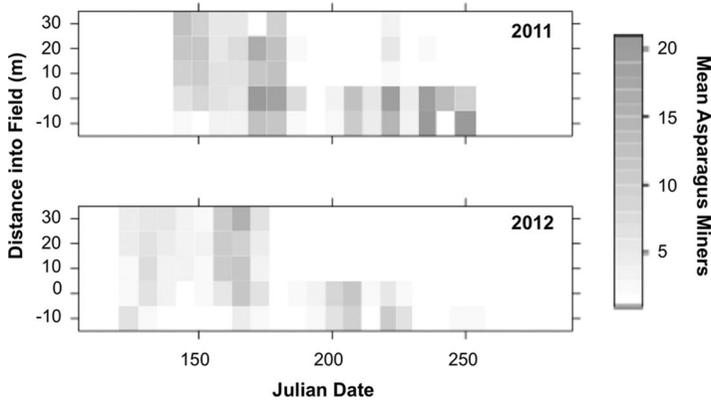


Fig. 2. Mean distribution of adult asparagus miners over all sampled fields by Julian date at different distances into the field in commercial asparagus fields in Oceana Co., MI, for (A) 2011 and (B) 2012. Darker shades indicate a greater abundance of asparagus miners.

abundance of asparagus miner adults in these fields compared with ones that received fewer sprays (Fig. 1B, D, and H). Regardless of whether asparagus harvesting stopped during (Fig. 1A, C, G, and I) or after the first adult generation's peak (Fig. 1B, D, E, and H), this did not seem to influence the overall abundance of adults.

Asparagus miners were more evenly distributed in fields in the beginning of the season (Fig. 2). However, in the latter half of the season, adults were found primarily on the edges and outside the field. This pattern was true in 2011 for the first generation where there were no significant differences across different distances (repeated measures ANOVA; distance into field: $F = 0.22$, $df = 4$, 16.4 , $P = 0.65$) and the second generation, which showed a greater abundance near the edge of the field ($F = 5.73$; $df = 4$, 16.4 ; $P < 0.01$). The case was also similar in 2012 for both generations (repeated measures ANOVA; first generation, distance into field: $F = 3.73$, $df = 4$, 9.95 , $P = 0.05$; second generation: $F = 5.83$, $df = 4$, 19.8 , $P < 0.01$). Overall for both years, adult asparagus miners occurred in greater frequency on the edges and outside the field rather than within the asparagus fields (distances in 2011: $F = 2.69$, $df = 4$, 36 , $P < 0.05$; 2012: $F = 3.41$, $df = 1$, 20.5 , $P < 0.03$; Fig. 3). On average, there were 8.1 ± 0.67 flies per yellow sticky trap at the edge or outside the field in 2011 compared with 3.2 ± 0.23 flies inside the field. In 2012, on average there was an almost two-fold greater number of adults on the edges (2.70 ± 0.28 flies per yellow sticky trap) compared with adults within the field (1.45 ± 0.10). In addition, two-fold greater abundance of asparagus miners were caught in canopy compared with ground-level traps in both years (2011: $F = 9.73$, $df = 1$, 36.6 , $P < 0.01$; 2012: $F = 45.9$, $df = 1$, 22.3 , $P < 0.01$; Fig. 3).

Asparagus Miner Damage. Asparagus miner damage was greater near the edge than further inside the field in 2012 (Fig. 3). Distance into the field significantly affected the percent mining damage found on stems ($F = 19.63$; $df = 3$, 6 ; $P < 0.01$), as well as the proportion of stems damaged (χ^2 test: $df = 3$; $\chi^2 = 59.82$;

$P = 0.02$); $\approx 40\%$ of the total damaged stems were found along the edge of the field, compared with $\approx 16\%$ at locations 30 meters into the field. Around 15% of the total damage occurred during the first generation of adults, while 85% occurred during the second generation.

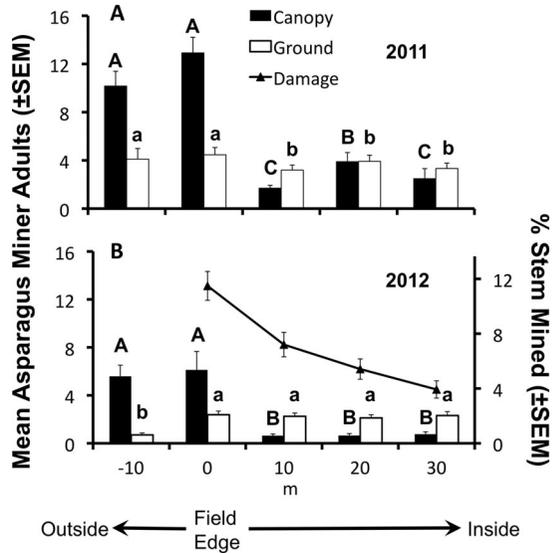


Fig. 3. Mean (\pm SEM) abundance of asparagus miner adults at different distances (m) into the field in commercial asparagus fields in Oceana Co., MI, for (A) 2011 and (B) 2012, with damage data (average % stem mined) at different distances into the field for 2012. Black bars are canopy-level yellow sticky traps while white bars are ground-level traps. Upper case letters are for pairwise comparison (Tukey's HSD) within canopy-level traps, while lower case letters are for comparisons within ground-level traps for a specific year; shared letters indicate no significant differences. All damage measurements are significantly different at the various distances into the field (Tukey's HSD). Damage was not evaluated in 2011.

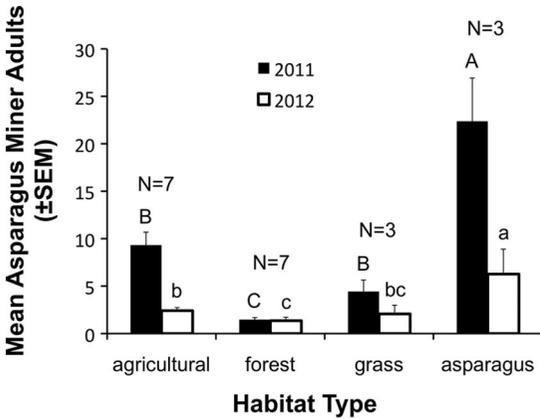


Fig. 4. Mean (+SEM) adult asparagus miner abundance in different edge habitats. Uppercase letters are for pairwise comparisons within habitat type for 2011, while lowercase letters are for 2012. Shared letters above bars indicate values that are not significantly different from one another (Tukey's HSD; $\alpha = 0.05$). The N above each group of bars represents the number of independent field edges classified as a given type of habitat for the analysis.

Asparagus Miner Adults in Field-Border Habitats.

There was a significant effect of habitat type on asparagus miner abundance for 2011 (repeated measures ANOVA; habitat type: $F = 50.58$, $df = 3, 30.3$, $P < 0.01$) and for 2012 (habitat type: $F = 5.56$, $df = 3, 12.6$, $P < 0.01$; Fig. 4). In each year, the traps located between two asparagus fields had the greatest abundance of asparagus miner adults, followed by agricultural areas. Traps in forests around asparagus fields had the fewest asparagus miners both years, with ≈ 15 times and five times fewer adults than the traps in between two asparagus fields in 2011 and 2012, respectively.

Asparagus miners were significantly more abundant on traps located near the edge of the cherry orchard closest to the asparagus field compared with traps further away from the asparagus field (Tukey's HSD; Fig. 5). On

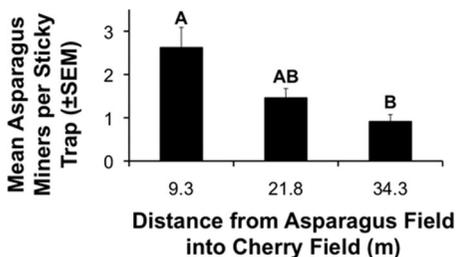


Fig. 5. Mean (+SEM) overall abundance of adult asparagus miners in a cherry orchard adjacent to an asparagus field in Oceana Co., MI, at different distances into the orchard in 2012. Traps were placed at the edge of the orchard (9.5 meters away from the asparagus field), and at 21.8 meters and 34.3 meters from the edge, in three transects with ground-level yellow sticky traps. Traps were changed weekly. Different letters above bars represent statistically significant differences (Tukey's test; $\alpha = 0.05$).

average, there were ≈ 3 times as many asparagus miners on traps located 9.3 meters as 34.3 meters away from the asparagus field. The total number of asparagus miners over the season in the cherry orchard was 338 adults, 61 of which were found 35 meters away from the asparagus field. Overall, adult miners averaged 0.91 ± 0.16 flies per sticky trap (Fig. 5).

Discussion

This study investigated the horizontal and vertical distribution of asparagus miner adults in commercial asparagus fields. In addition, we have examined the spatial variation of asparagus miner damage. Asparagus miner adults are evenly distributed in the field during the first generation, and located primarily on the edges or outside the field during the second generation. There are several possible explanations for this pattern. During asparagus harvest, plants are broken off at the soil surface, and the stubs of picked stalks have phloem fluid at the top, which adults frequently feed from (W. R. Morrison, unpublished data). These small point sources of valuable resource are evenly distributed throughout the field, and miner adults may easily access them. As a result, there is a more even distribution of adults in the beginning of the season. In contrast, the second generation might emigrate from the field in search of mates or new oviposition sites, especially as population density increases in the first generation postharvest and fewer optimal oviposition sites remain. According to our findings, it may be beneficial for growers to concentrate their asparagus miner management programs during the latter half of the season to the edges of fields and along the field margins. This would result in lower amounts of pesticide loading in agricultural landscapes, ameliorating the deleterious effects of synthetic insecticides on nontarget organisms (Epstein et al. 2000). In addition, treating only the field edges would give the natural enemies of the asparagus miner a refuge, while still eliminating most of the miner adults in the area. Refuges for natural enemies have been shown to be important in agricultural systems for increasing biological control (Schellhorn et al. 2008); thus, such an edge-based tactic would have the added benefit of increasing the suppression of the remaining asparagus miners by its natural enemies. Reducing the area treated for asparagus miners can have significant economic benefits, because in 2011 there were 28 broad-spectrum insecticide applications in five fields and in 2012 there were 13 in three fields. In other insect species, certain generations have corresponded to the dispersing stage, for example in *Anticarsia gemmatilis* Hübner (Lepidoptera: Noctuidae), the second generation disperses when population densities exceed a certain threshold (Fescemyer and Hammond 1988). Another explanation of the differential distribution between first and second generation adults is that this could be because of a sampling artifact created by an interaction between the asparagus fern and the visually attractive traps used for sampling. Asparagus plants during the first adult miner generation are short

stalks; thus, traps are clearly visible during this time, but asparagus miner adults might not see the traps as readily in the second generation as a result of occlusion by the fern when asparagus plants can reach up to 2 meters. However this explanation is not likely, given our findings with the damage in the field, which was greater near the edge of the field.

We found that the date at which asparagus harvest stopped had no relationship with the severity of the first or second generation of asparagus miners in the field. This may indicate that most asparagus miners can deposit eggs far enough down on the asparagus stalk that they are not disturbed when harvesters pick spears. Indeed, previous studies have found pupae up to 3–7.6 cm below the soil surface (Lampert et al. 1984), which would be enough refuge from pickers. In addition, picking asparagus spears also did not affect emergence of adults, indicating that asparagus miner adults remain protected within the base of the plant as pupae. However, it is notable that intensive use of broad-spectrum insecticides resulted in reducing the abundance of the second generation's adults in two of our fields in 2011 and one in 2012. Nonetheless, we suggest that it is more economical, less time-intensive, and ecologically safer to have fewer well-timed applications during the growing season.

Similarly to Tuell (2003), adults were more abundant in the canopy than near the ground. The fact that adults were more abundant in canopy-level traps, despite the fern, suggests that the observed preference of asparagus miners for the edge and outside the field might not be a sampling artifact. Adult miners have been previously observed mating on asparagus fern (Ferro and Suchak 1980), and the adult flies feed on sugar, nectar, and plant sap, which are resources found in the asparagus canopy (Ferro and Gilbertson 1982). When sampling for asparagus miners, it may be useful to use both canopy- and ground-level traps, because ground-level traps capture abundance early in the season, during asparagus harvest when the canopy is absent. Ground-level traps likely are not needed after the asparagus has grown fern, because only low numbers of adults are found in these traps later in the season.

Ours is the first study to characterize how landscape features affect asparagus miner distribution, and we found that asparagus miner adults cross the field margins and move into habitats near commercial asparagus fields. Here we show that asparagus miner adults can be found up to 34 meters away from an asparagus field. Because adult asparagus miners feed on sugar and nectar, it is thus plausible that these adults move away from asparagus fields to find flowers as alternative food sources, especially when asparagus plants drop their flowers during the latter half of the season.

Forested borders in our study had fewer asparagus miner adults than agricultural, grassy, and asparagus borders. This indicates that there is value in conserving the remaining forested segments of the landscape, which are characteristic of the Michigan asparagus-growing region. Creating borders around asparagus fields that are less suitable for the asparagus miners may lead to a reduction in their abundance inside the

field. The impact of the type of habitat near the field border on the abundance of a pest has been documented with other insect species. For example, the grape berry moth was less abundant where grasses bordered vineyards compared with coniferous woods (Botero-Garcés and Isaacs 2004). In this case, the presence of an alternative host plant in the woods was causing increased moth pressure at the field borders. We did not observe volunteer asparagus plants in forests (Z. Szendrei, unpublished data), but in grassy areas sometimes these plants can be present, which can explain the slight increase in miner abundance in these border areas relative to the forest borders. Another potential benefit to conserving forest habitat around asparagus fields is that these may have food and refuges for natural enemies that increase their abundance and efficacy as biocontrol agents (Tscharntke et al. 2007) of the asparagus miner. Because the asparagus miner is a specialist on asparagus, we expected it to be more abundant in between two asparagus fields and it is likely that these insects are moving between asparagus fields. Thus, it is likely common for an asparagus miner to leave the field in which it developed and seek out resources in the nearby habitat. Future studies with asparagus miners will address potential dispersal capacity and resource use in the landscape.

Overall, our results suggest that growers may be able to spare economic and ecological costs by targeting asparagus miner management along field edges in the latter part of the season. In addition, conserving existing forested borders around fields may help with decreasing asparagus miner movement and abundance. These strategies can be used as part of an IPM program for controlling the asparagus miner and mitigating against infection by *Fusarium* spp.

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