

## Predator-Prey Relationships on Apiaceae at an Organic Farm

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**ABSTRACT** *Orius insidiosus* (Say) and *O. pumilio* (Champion) were confirmed to be sympatric in north central Florida as the major predators of the Florida flower thrips, *Frankliniella bispinosa* (Morgan), on flowers of Queen Anne's lace, *Daucus carota* L. and false Queen Anne's lace, *Ammi majus* L. *F. bispinosa* was the predominant thrips observed on both flowers but colonized *D. carota* to a greater extent and earlier in the season than *A. majus*. Despite differences in the abundance of *F. bispinosa* on the two plants, neither *Orius* species showed host plant affinities. Population profiles for the thrips and *Orius* spp. followed a density dependent response of prey to predator with a large initial prey population followed by a rapid decline as the predator populations increased. The temporal increases in *Orius* spp. populations during the flowering season suggest that they were based on reproductive activity. As observed in a previous study, *O. insidiosus* had a larger population than *O. pumilio* and also had a predominantly male population on the flowers. By examining carcasses of the prey, there appeared to be no sexual preference of the thrips as prey by the *Orius* spp. as the prey pattern followed the demographics of the thrips sex ratio. Few immatures of either thrips or *Orius* spp. were observed on *D. carota* or *A. majus*, which suggests that oviposition and nymphal development occurred elsewhere. Based on these findings, *D. carota* and *A. majus* could serve as a banker plant system for *Orius* spp.

**KEY WORDS** banker plants, *Orius*, minute pirate bugs, *Frankliniella*, thrips

Biological control of pest insects can be highly effective through augmentative inoculation, inundative release, or conservation of natural predators or parasitoids (Elzen and King 1999, Hajek 2004). A low cost option to the release of beneficial insects is to aid in the establishment and conservation of natural or augmented populations by using banker plants that provide alternative food, habitat, or reproductive sites (Huang et al. 2011). The identification of plant species that are attractive refuges for beneficial insects and that can be conveniently integrated into the cropping

regimen is central to the development of a banker plant system (Huang et al. 2011).

In Florida, the flower thrips, *Frankliniella* spp. (Thysanoptera: Thripidae), represent a major polyphagous pest group infesting fruiting vegetable crops (Funderburk 2009). An increasing proportion of these vegetables are grown on organic farms (Nguyen et al. 2008). The number of certified organic farms has nearly doubled in Florida from 63 operations in 2006 to 113 in 2008, whereas acreage has increased from 6,541 to 11,493 during the same period (Green and Parker 2011). This growth in organic farming poses considerable difficulties in providing effective control of thrips with methods that are compatible with the National Organic Standards (NOS). Although not used extensively, the implementation of alternative methods such as push-pull strategies, in which pest insects are repelled from the crop and attracted to peripheral sites where control can be applied (Cook et al. 2007), or banker plants, which attract predators or parasitoids (Pickett et al. 2004, Bailey et al. 2009, Huang et al. 2011) to provide efficient biocontrol as components of integrated pest management are used to assure the success of this emerging industry. Fundamental to these management programs is developing a description of seasonal population dynamics for insect pests as well as for the predators or parasitoids that feed on them.

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The minute pirate bugs, *Orius* spp. (Hemiptera: Anthocoridae) are naturally occurring predators that provide significant control of thrips on peppers and other vegetable crops (Funderburk et al. 2000, Ramachandran et al. 2001, Reitz et al. 2003). The high reproductive rate of these bugs, their effective predatory behaviors, and an apparent ability to respond to various environments allow *Orius* spp. to rapidly respond numerically to increases in thrips populations (Coll and Ridgway 1995, Baez et al. 2004, Reitz et al. 2006). Two species of *Orius* are commonly found on the Florida peninsula: *O. insidiosus* (Say) and *O. pumilio* (Champion). Although *O. insidiosus* is found throughout North and South America (Herring 1966), *O. pumilio* has been reported in Florida, Mexico, and the West Indies (Herring 1966), but no farther north than Alachua County, FL (Shapiro et al. 2009). A third species from the western United States, *O. tristicolor* (White), also has been established in Florida through inadvertent introduction (Halbert 2009).

As a means of increasing the populations of *Orius* spp. and thereby offering a low cost method of improving biocontrol on organic farms, vegetation management through the planting of noncrop plants that attract or harbor these predators could be implemented (Huang et al. 2011). Previously, a stand of false Queen Anne's lace (large bullwort), *Ammi majus* L. (Apiales: Apiaceae), growing on an organic farm in north central Florida during the spring of 2008 was examined for the presence of *Orius* spp. (Shapiro et al. 2009). Both *O. insidiosus* and *O. pumilio* were found feeding on a large infestation of the Florida flower thrips *F. bispinosa* (Morgan) present on the false Queen Anne's lace. The large floral heads (inflorescence) of the false Queen Anne's lace evidently provided an environmental oasis where both species of *Orius* found plentiful food and an increased opportunity for mating facilitating the sympatric coexistence of these two species in this region. Although both species were present, there was a larger population of *O. insidiosus* than of *O. pumilio*. However, the larger *O. insidiosus* population showed a skewed sex ratio with three times as many males as females, suggesting a difference in the population dynamics between the two species. The male-predominant sex ratio of *O. insidiosus* was limited to the observed field collections and was not evident in the laboratory progeny of field collected adults (Shapiro et al. 2009).

The species identity of each of the *Orius* populations was confirmed based on detailed comparisons of male and female genital morphology, on DNA sequence divergence of 18s rDNA ITS-1, on the lack of significant egg production after interspecific mating, and on the failure of interspecific mating to effect a change in female reproductive physiology (egg maturation) (Shapiro et al. 2010).

To more clearly understand the population dynamics for the insects species present on both false Queen Anne's lace, *A. majus*, and Queen Anne's lace, *Daucus carota* (Apiales: Apiaceae) growing separately on an organic farm, the fluctuations in the insect populations were observed and correlated to establish a baseline

for utilization of these two flowers as banker plants for *Orius* spp.

## Materials and Methods

**Insect Collection.** The 2009 test plots for insect collection were on a certified organic farm of 4 ha located near Gainesville, FL (<http://www.plowsharescsa.org>) that included a 20 m by 5 m patch of volunteer *A. majus* grown from seeds planted in 2007 and a 65-m-long newly planted row of *D. carota*. The two plantings of flowers were separated from one another by  $\approx 60$  m where various vegetable crops were planted. Each collection station for *A. majus* included eight inflorescences within a 1 m by 1 m area, whereas for *D. carota* each station included eight inflorescences within a 3 m section of the planted row. Depending on the stage of inflorescence, collections from up to six stations per plant species were made on each of the sampling dates.

Collection of insects from the flowers of *A. majus* and *D. carota* began on 3 April and sampling was conducted once a week for 8 wk through 8 June 2009. The start of sampling coincided with the opening of the buds on the most mature inflorescences and ended when the last inflorescences had completed flowering and had begun to set seeds. The only interruption to the periodic sampling occurred on week 8 because of weather. Rainfall reported in Bronson, FL, which is located west of the organic farm, was 0.33 cm on 21 May 2009, 0.07 cm on 22 May 2009, and 0.63 cm on 23 May 2009. This amount of consistent rainfall during this week precluded collection of samples.

The insects on the floral heads were collected by inserting the flowers into a 31 cm-diameter funnel (Bel-Art Products, Pequannock, NJ) attached to a DC515 cordless wet/dry vacuum (DeWALT Industrial Tool Co., Baltimore MD). After the 10 flowers were vacuumed of insects, the insects were sealed in the vacuum bag, transported to the CMAVE laboratory, and frozen at  $-85^{\circ}\text{C}$ . Subsequently, the insects were transferred from the vacuum bag into 95% ethanol for identification, counting, and preservation.

**Taxonomic Identification.** Taxonomic identifications of *Orius* spp. were based on the morphological characters described in Herring (1966) and Salas (1995). Thrips were identified using the taxonomic keys of Mound and Marullo (1996) and Moritz et al. (2004). Predation on thrips by *Orius* spp. was evidenced by characteristic puncture wounds to the thrips bodies.

**Statistical Analysis.** Because of the variable numbers of samples collected on each date and patterns of variation over time, data were analyzed separately for each date. Numbers of *F. bispinosa* were compared between plant species by a one-way analysis of variance (ANOVA), using a lognormal distribution with the identity link function (SAS Institute 2006). Sex ratio and predation data for thrips were analyzed by one-way ANOVA, using a binomial distribution with a logit link function. Comparisons of the abundance of each *Orius* species across host plants were made by

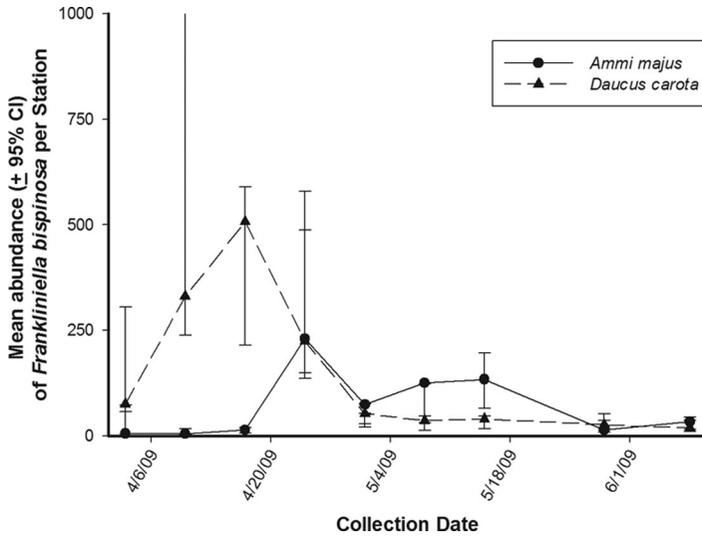


Fig. 1. Mean abundance (± 95% Confidence Interval) of *F. bispinosa* adults collected from *A. majus* and *D. carota* on each sampling date during a flowering season (3 April–8 June 2009). Data are based on back-transformed values of logarithmically transformed data.

two-way ANOVA, using a negative binomial distribution with the log link function. Comparisons of the sex ratios (proportion female) between *Orius* species across host plants were made by two-way ANOVA, using a binomial distribution with a logit link function.

Results

**Frankliniella Populations.** The only abundant thrips species observed on either *D. carota* or *A. majus* throughout the sampling period was *F. bispinosa*, which comprised >99.9% of the sampled thrips. The abundance of *F. bispinosa* varied considerably over the course of the season with the greatest number of adults on both flower species occurring in April (Fig. 1). Comparison of the total number of *F. bispinosa* occurring on the two host plants during the flowering season showed that there were more thrips on *D. carota* ( $x = 93.1$  [95% CI: 63.3–136.8] per sample) than on *A. majus* ( $x = 46.2$  [95% CI: 28.4–75.2] per sample) where the means per sample date ranged from <20 to >530 for *D. carota*, and <8 to >240 for *A. majus*.

A counting of the live *F. bispinosa* showed overall greater numbers of adults on both flower species during the first half of the growing season than during the latter half (Fig. 1). During the first three sample dates, significantly more *F. bispinosa* were collected from *D. carota* than from *A. majus* (Table 1). The female thrips population increased rapidly on *D. carota* to a maximum on 10 April (week 2) and sustained that level for two additional weeks (Table 1). The number of male thrips also increased rapidly on *D. carota* but continued the rapid increase to a maximum on 17 April (week 3) which was nearly double the number of females present. By 1 May (week 5) the population on *D. carota* had decreased precipitously to numbers below that observed in week 1 and remained low until the end of the season.

In contrast to the profile from *D. carota*, the combined total of female and male *F. bispinosa* on *A. majus* remained below 17 per station through 17 April (week 3) and then increased to a maximum of 244.5 (SEM ± 30.4) on 24 April (week 4), which was only ≈40% of the maximum abundance found on *D. carota*. By 1 May (week 5), the numbers of both sexes decreased and were below the population at the beginning of the flowering period (Fig. 1).

During weeks 4 and 5 (24 April to 1 May), there were no significant differences in abundance of *F. bispinosa* between the two host plants. On the two subsequent sampling dates (8 May and 15), the pattern of abundance differed between host plants, with significantly more *F. bispinosa* found on *A. majus* than on *D. carota* (Table 1; Fig. 1). On these sampling dates (weeks 6 and 7), there were ≈3 times more *F. bispinosa* present on *A. majus* than on *D. carota*. However, during the last two sampling dates at the end of the flowering period (29 May and 8 June), *F. bispinosa* populations were very low and there was no signifi-

Table 1. ANOVA results for the effect of host plant on the abundance and sex ratio of live *Frankliniella bispinosa* collected on each sample date

Date	Sample week	df	<i>F. bispinosa</i> abundance		<i>F. bispinosa</i> sex ratio	
			F	P	F	P
4/3/2009	1	1.2	14.16	0.064	2.07	0.287
4/10/2009	2	1.6	31.19	0.001	0.95	0.367
4/17/2009	3	1.7	102.50	<0.0001	0.19	0.678
4/24/2009	4	1.7	0.00	0.967	48.75	0.0002
5/1/2009	5	1.6	1.46	0.272	3.92	0.095
5/8/2009	6	1.7	21.40	0.002	0.67	0.441
5/15/2009	7	1.8	9.98	0.013	32.88	0.0004
5/29/2009	8	1.8	0.97	0.354	3.59	0.095
6/8/2009	9	1.4	2.44	0.193	0.00	0.980

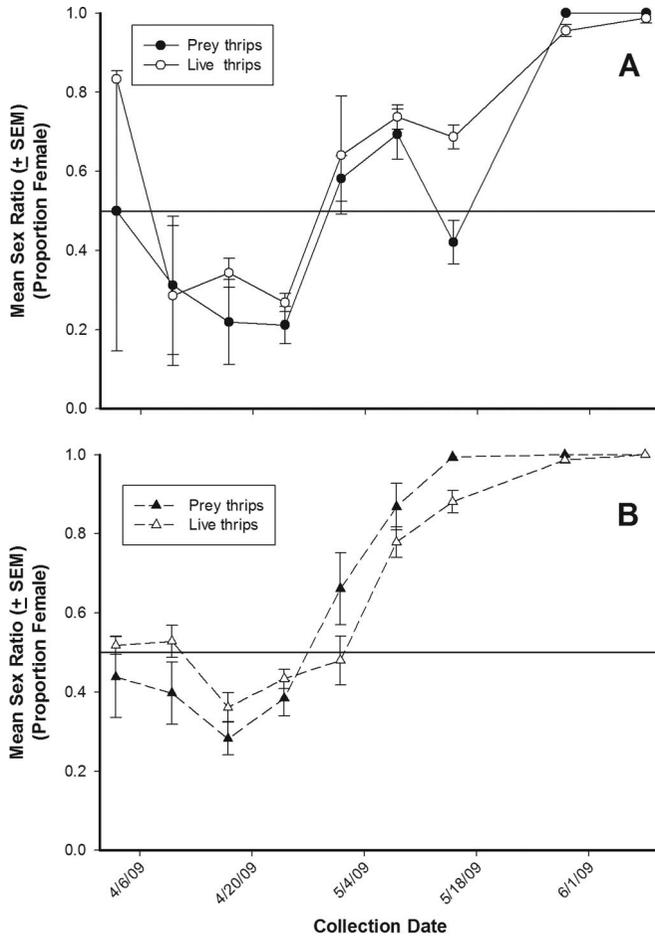


Fig. 2. Mean sex ratio ( $\pm$  SEM) of live and predated *F. bispinosa* collected from the flowers of *A. majus* (A) and *D. carota* (B) on each sampling date during a flowering season (3 April–8 June 2009). Sex ratios are expressed as the proportion of females in each sample. Reference lines represent an equally distributed sex ratio (0.5 females).

cant difference in abundance between *A. majus* and *D. carota* (Table 1).

The sex ratios of adult *F. bispinosa* changed over the course of the flowering season. Early in the season, sex ratios were even or male biased, but became progressively female biased later in the season (Fig. 2). From week 5 and onward, the proportion of females increased until the populations were almost exclusively female at the end of the flowering season. Although the overall sex ratio of *F. bispinosa* changed dramatically over the course of the flowering season, there was little evidence of a host plant effect on the distribution of the sexes. On most sample dates, there were no significant differences in the sex ratios between those found on inflorescences of *D. carota* or *A. majus* (Table 1; Fig. 2). There were two exceptions to this pattern. On 24 April (week 4), the sex ratios on both *A. majus* and *D. carota* were male biased. However, the male bias on *D. carota* was significantly less ( $40 \pm 1\%$  female) than the male bias on *A. majus* ( $26 \pm 1\%$ ) (Table 1). Subsequently, on 15 May (week 7) sex ratios on *A. majus* and *D. carota* were female biased.

Similarly, there was a significantly greater proportion of females found on *D. carota* ( $88 \pm 2\%$ ) than on *A. majus* ( $70 \pm 2\%$ ), even though there was a greater overall abundance of *F. bispinosa* on *A. majus*.

**Orius Populations.** Populations of both *O. insidiosus* and *O. pumilio* reached maxima on week 5 (1 May), which coincided with the rapid population decline of *F. bispinosa* (Figs. 1 and 3). Despite differences in the abundance of thrips on the two host plants, no apparent host plant preference was exhibited by either *Orius* species, as there were no significant population differences between *D. carota* and *A. majus* (Table 2). There was one exception to this pattern, when on 17 April (week 3) there was a greater abundance of *Orius* spp. on *D. carota*. However, overall *Orius* populations were still relatively small at this time. Unlike the thrips, *Orius* populations were less abundant on both plants, but generally, significantly more *O. insidiosus* were present throughout the season than *O. pumilio* (Table 2; Fig. 3).

Both females and males of *O. pumilio* were present on *D. carota* at low numbers ( $<3$  females or males per

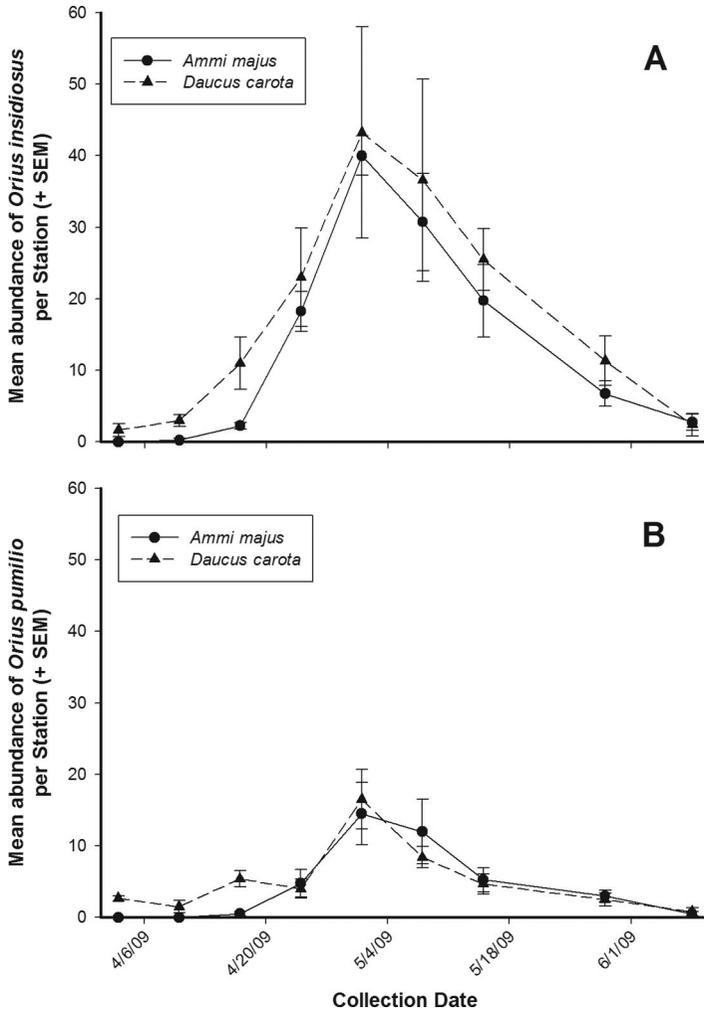


Fig. 3. Mean abundance ( $\pm$  SEM) of *O. insidiosus* (A) and *O. pumilio* (B) adults collected from the flowers of *D. carota* and *A. majus* on each sampling date during a flowering season (3 April–8 June 2009).

station) in initial collections but began an increase after week 3 (Fig. 3B). However, *O. pumilio* was not observed on *A. majus* until week 3 when the population increased to numbers similar to those observed

*D. carota*. The female populations of *O. pumilio* reached a maximum on both species of host plant by 1 May (week 5) and then declined to low numbers by week 7. The males followed a similar profile and abundance reaching maximal numbers on *A. majus* on week 5 and then declining to low numbers for the remainder of the flowering season.

Table 2. ANOVA results for the abundance of *Orius* in relation to host plant and *Orius* species. No two-way interactions between *Orius* species and host plant were significant ( $P > 0.15$ ), and thus are not included in these results

Date	Host plant				<i>Orius</i> species		
	Sample week	df	F	P	df	F	P
4/3/2009	1	-	-	-	-	-	-
4/10/2009	2	1.3	1.99	0.253	1.4	2.04	0.226
4/17/2009	3	1.7	14.12	0.008	1.8	12.45	0.001
4/24/2009	4	1.7	0.03	0.867	1.8	79.91	<0.0001
5/1/2009	5	1.6	0.00	0.972	1.7	41.71	0.0003
5/8/2009	6	1.7	0.05	0.835	1.8	32.82	0.0004
5/15/2009	7	1.8	0.21	0.656	1.9	38.54	0.0002
5/29/2009	8	1.8	0.15	0.700	1.9	28.82	0.0005
6/8/2009	9	1.7	0.33	0.586	1.8	6.74	0.032

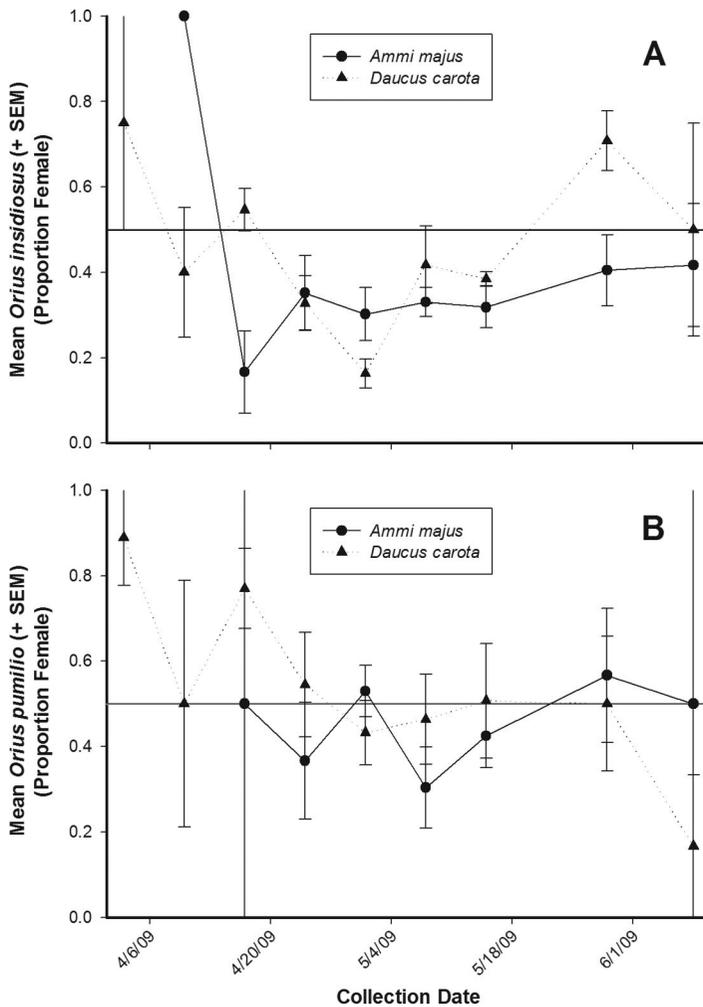
*O. insidiosus* did not appear frequently on *D. carota* or *A. majus* until 17 April (week 3) (Fig. 3A). The numbers of *O. insidiosus* females increased slowly on *D. carota* and *A. majus* to a maximum of similar magnitude on 1 May (week 5). This was followed by a slow decline of the female *O. insidiosus* over the remaining weeks of observation. *O. insidiosus* males appeared on both plants on 17 April (week 3) and then rapidly increased to a maximum on 1 May (week 5) that was >3 times the number of females on *D. carota* and 2.6 times the number of females on *A. majus* (Fig. 3). The males then slowly declined to low numbers over the remainder of the flowering season.

**Table 3.** ANOVA results for relationship of *Orius* species and host plant on the sex ratio of *Orius*. No two-way interactions between *Orius* species and host plant were significant ( $P > 0.30$ ), and thus are not included in these results

Date	Sample week	Host plant			<i>Orius</i> species		
		df	F	P	df	F	P
4/3/2009	1	-	-	-	-	-	-
4/10/2009	2	-	-	-	-	-	-
4/17/2009	3	1.7	2.96	0.129	1.6	2.70	0.154
4/24/2009	4	1.7	0.03	0.874	1.8	2.97	0.123
5/1/2009	5	1.6	4.43	0.080	1.7	24.77	0.002
5/8/2009	6	1.7	0.38	0.560	1.8	4.67	0.063
5/15/2009	7	1.8	0.30	0.597	1.9	1.74	0.220
5/29/2009	8	1.8	4.93	0.057	1.8	0.02	0.880
6/8/2009	9	1.4	0.30	0.613	1.3	0.45	0.550

There was no evidence for a host plant effect on the sex ratios of either *Orius* species as the sex ratios were similar between *D. carota* and *A. majus* (Table 3; Fig.

4). In general, there were no significant differences between the sex ratios of *O. insidiosus* and *O. pumilio* (Table 3). One exception occurred on 1 May (week 5) when the number of male *O. insidiosus* reached a maximum that resulted in a highly male biased sex ratio which produced a significant difference between the *Orius* species (Table 3). The population profiles of *O. insidiosus* showed that during the middle part of the season (24 April–15 May), there was a disproportionate frequency of males observed on the inflorescences of both host plants (Fig. 4). Assessment of the sex ratio for the *O. insidiosus* populations during the flowering season showed there was a predominance of males present on both *D. carota* and *A. majus* during the midflowering period from weeks 4–8 (Fig. 4A). Males comprised as much as three fourths of the *O. insidiosus* population during this period. However, sex ratios were more variable when small populations were present at the beginning and end of the flowering season.



**Fig. 4.** Mean sex ratio ( $\pm$  SEM) of *O. insidiosus* (A) and *O. pumilio* (B) adults collected from the flowers of *D. carota* and *A. majus* on each sampling date during a flowering season (3 April–8 June 2009). Sex ratios are expressed as the proportion of females in each sample. Reference lines represent an equally distributed sex ratio (0.5 females).

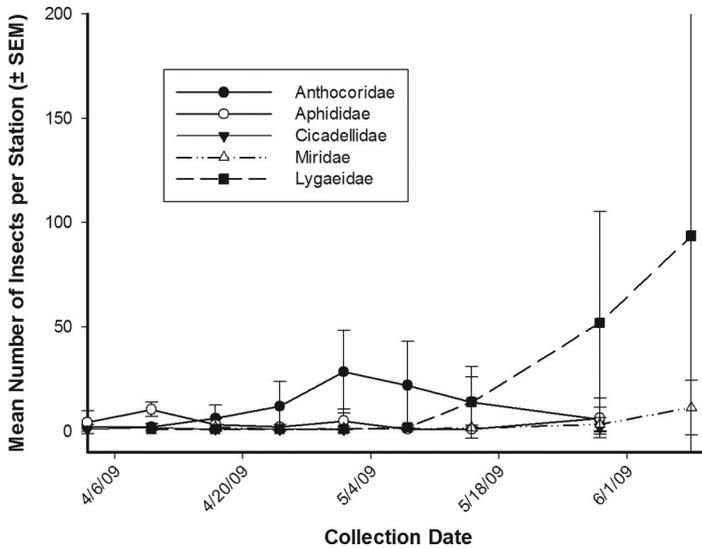


Fig. 5. Mean abundance for the Hemiptera families collected from the flowers of *D. carota* and *A. majus* on each sampling date during a flowering season (3 April–8 June 2009).

This was not the case for *O. pumilio*, which tended to have balanced sex ratios throughout the mid-flowering period (Fig. 4B). As with *O. insidiosus*, the ratios were more variable when small populations were present at the beginning and end of the flowering season.

**Other Hemiptera.** The other major groups of insects observed in the collections were from the families Aphididae (Homoptera), Cicadellidae (Hemiptera), Lygaeidae (Hemiptera) and Miridae (Hemiptera). All of these families were present in low numbers except for the Lygaeidae, which achieved large populations on both host plants during the last 2 wk of the flowering season (Fig. 5).

**Patterns of Predation on *F. bispinosa*.** The collection method resulted in the inclusion of the carcasses of thrips that had been preyed on by *Orius* spp. This permitted an assessment of the numbers and sex preference of the thrips as prey by *Orius* spp. Predation was observed on both host plants from the onset of flowering, but patterns of predation changed over the course of the season. Early in the season the predator to prey ratio was low (Fig. 6A) and consequently the predation rates (ratio of predated thrips to total thrips) were low (Fig. 6B). During this 4-wk period, the predation rates tended to be significantly higher on *A. majus* than on *D. carota* (Table 4; Fig. 6B). However, this pattern reversed at midseason, with significantly higher predation rates occurring on *D. carota* after 1 May (week 5) than on *A. majus*. Predation rates on both host plants then declined toward the end of the season as populations of both thrips and *Orius* spp. declined. The major collapse in thrips abundance occurred around 1 May and coincided with the rapid increase in the abundance of *Orius* spp. There was a consequent rise in the ratio of *Orius* to thrips abundance, and these predator to prey ratios remained relatively high through the remainder of the flowering season (Fig. 6A).

The sex ratios of predated *F. bispinosa* correlated with the overall sex ratios found on the two host plants (*A. majus*:  $r = 0.663$ ,  $P = 0.0002$ ; *D. carota*:  $r = 0.725$ ,  $P < 0.0001$ ), indicating that there was no differential predation for either sex (Table 4). The predominant sex of the *F. bispinosa* carcasses from week 3–4 was male on both host plants, which correlated with the male-biased population of *F. bispinosa* on the inflorescences during this period. During the second half of the season, the predominant sex of the carcasses was female, which again correlated with the female-biased population of *F. bispinosa* during that period of the flowering season. The only exception to this trend was observed on 15 May (week 7) on *A. majus* when there were more male carcasses observed than female.

## Discussion

The flowers of the introduced Queen Anne's lace, *D. carota*, were infested exclusively with the Florida flower thrips, *F. bispinosa*, 3 wk before the flowers of the false Queen Anne's lace, *A. majus*. In addition, during the growing season the *F. bispinosa* achieved a population on *D. carota* that was nearly three times that observed on the *A. majus*. However, the lack of larvae in the collections from either plant suggests that both plants were only a food source for the thrips and not a reproductive host like field peppers (Funderburk et al. 2000, Ramachandran et al. 2001) where larvae comprise a significant component of the observed population. This suggests that infestations on *D. carota* were primarily the result of colonization and not because of reproduction on the host plant. It is clear that the *F. bispinosa* preferred the *D. carota* as a food source but the nature of the increased attraction was not apparent in this study.

The major predators of *F. bispinosa* were the two *Orius* species present. None of the other insects ob-

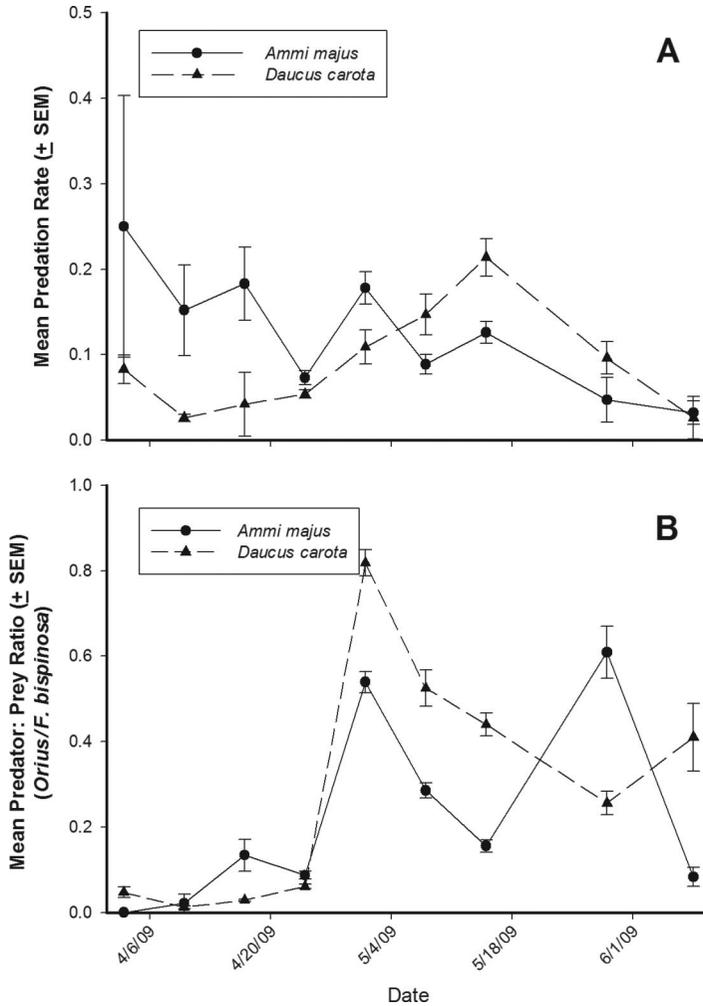


Fig. 6. Predation by *Orius* spp. on *F. bispinosa* on the flowers of *D. carota* and *A. majus* on each sampling date during a flowering season (3 April–8 June 2009). The mean predator to prey ratio (A) is the ratio of *Orius* spp. to total *F. bispinosa* observed in each sample. The mean predation rate (B) is the proportion of predated *F. bispinosa* observed in each sample.

served in the samples collected were obvious predators of thrips or present in sufficient quantities to impact the thrips population. Neither species of *Orius* showed any preference to a host plant. Both *O. insi-*

*diosus* and *O. pumilio* were found in small numbers along with *F. bispinosa* on *D. carota* from the beginning of the collections (Fig. 3) but were not observed on *A. majus* until week 3 when *F. bispinosa* were also found. Although the *F. bispinosa* population on *D. carota* increased rapidly during the first three weeks, neither *Orius* species showed any significant increase in population until week 3. The time of development from egg to adult in the laboratory for both species of *Orius* is  $\approx 16$  d at 25°C, 75–80% RH (Shapiro et al. 2009) which would suggest that the population increase for both species is the result of reproductive activity from the beginning of the initial colonization by *F. bispinosa*. These findings are in agreement with those reported previously that *O. insidiosus* and *O. pumilio* are sympatric in north central Florida (Shapiro et al. 2009). Where the eggs of *O. insidiosus* and *O. pumilio* were oviposited and where the developing nymphs of *O. insidiosus* and *O. pumilio* were residing and feeding

Table 4. ANOVA results for the effect of host plant on predation rates *Frankliniella bispinosa* collected on each sample date

Date	Sample week	df	Predation rate		Predator prey ratio	
			F	P	F	P
4/3/2009	1	1.2	2.36	0.264	0.00	0.980
4/10/2009	2	1.6	18.55	0.005	0.31	0.599
4/17/2009	3	1.7	29.31	0.001	23.48	0.002
4/24/2009	4	1.7	4.43	0.073	7.55	0.029
5/1/2009	5	1.6	5.54	0.056	33.76	0.002
5/8/2009	6	1.7	5.73	0.048	27.73	0.003
5/15/2009	7	1.8	13.21	0.007	88.11	<0.0001
5/29/2009	8	1.8	1.51	0.253	26.13	0.001
6/8/2009	9	1.4	0.04	0.846	21.81	0.009

during this time were not determined in this study. However, it was clear that neither *D. carota* nor *A. majus* was a preferred ovipositional host because negligible numbers of nymphs of either *Orius* species were observed in the collections from these plants.

The precipitous decline in the size of the thrips populations on *D. carota* and *A. majus* after 24 April (week 4) could be attributed to the increasing number of *Orius* present. Previously, the threshold for control and near extinction of thrips by *O. insidiosus* on field peppers was achieved when the predator to prey ratio surpassed 1:40 (Funderburk et al. 2000). In this field study, the *O. insidiosus* on *D. carota* reached a ratio of 1:50 by 17 April (week 3) but when the additional population of *O. pumilio* was considered, the ratio was 1:32 surpassing the numbers required to bring about the observed decline of the *F. bispinosa* population as predicted by the criteria of Funderburk et al. (2000). A similar precipitous decline in *F. bispinosa* population was observed on 1 May (week 5) on *A. majus* where again the combined populations of *O. insidiosus* and *O. pumilio* surpassed the threshold for control; *O. insidiosus* was present at 1:12 on 24 April (week 4), *O. pumilio* was at 1:47, while the combined *Orius* populations was 1:10 and sufficient to exceed the numbers of predators to cause a decline in the thrips population. On week 5 (1 May), the overall predator to prey ratio was <1:2.

The *Orius* appeared to feed on the thrips that were present. Early in the flowering season, the sex ratio for the *F. bispinosa* population showed there to be more males than females and the incidence of male carcasses correlated with this ratio. Subsequently, during the latter half of the flowering season, the ratio shifted to a female biased ratio and consequently more female carcasses were observed in the collections. This suggests that the two *Orius* species showed no preference according to the sex of the *F. bispinosa* and preyed in a frequency dependent manner.

When comparing the two host plants, even though there was a larger population of *F. bispinosa* on *D. carota* than on *A. majus*, there was no discernable difference in the size of *O. insidiosus* populations found on either *D. carota* or *A. majus*. Similarly, the size of the *O. pumilio* populations found on *D. carota* and *A. majus* were the same. However, *O. insidiosus* populations were three times greater than those of *O. pumilio* on both host plants. This observation was similar to the previous report of larger *O. insidiosus* populations than *O. pumilio* on *A. majus* on this organic farm (Shapiro et al. 2009). The large male component in the *O. insidiosus* population accounted for the differences in the size of the two *Orius* populations. In the current study, as much as three-fourths of the *O. insidiosus* on *D. carota* and two thirds on *A. majus* were males similar to the male predominant population previously observed (Shapiro et al. 2009). What accounts for these periods of male predominant populations has not been determined. When mated in the laboratory, the field collected *O. insidiosus* produced a 1:1 sex ratio that demonstrated that there was no genetic component causing the skew (Shapiro et al.

2009). Because *D. carota* and *A. majus* are apparently not ovipositional substrates, it is likely that the skewed sex ratios result from a behavioral pattern which results in *O. insidiosus* females spending a disproportionate amount of time off the host plants searching for ovipositional sites, thus effectively producing a male bias in the sex ratio.

The inflorescences of *D. carota* and *A. majus* attract dense populations of the Florida flower thrips, which in turn attracts large populations of *O. insidiosus* and *O. pumilio*. This scenario fulfills the majority of the five criteria for developing a banker plant system contributing to the biological control of thrips in vegetable crops (Huang et al. 2011): 1) Infestations of thrips are a persistent problem in vegetable crops such as field peppers in Florida (Funderburk 2009); 2) *Orius* spp. are effective natural predators of the thrips (Funderburk et al. 2000, Ramachandran et al. 2001, Hansen et al. 2003, Reitz et al. 2003, Baez et al. 2004, Reitz et al. 2006, Northfield et al. 2008, Funderburk 2009); 3) *D. carota* and *A. majus* are planted easily as a row crop along with the vegetable crops; 4) infestations of thrips are effectively suppressed by natural populations of *Orius* spp.; and 5) for small organic farms growing vegetable crops, augmentative mass releases of *Orius* would add to the cost of production, although management and attraction of naturally occurring populations of *Orius* spp. would provide a low cost alternative. Alternatively, *D. carota* and *A. majus* could also be considered as part of a push-pull system where the inflorescences provide the "pull" by attracting the *F. bispinosa* to a site away from the crop where the *Orius* exert the control through predation. Regardless of perspective, planting of the Queen Anne's lace *D. carota*, which is the more attractive of the two Apiaceae examined in this study, has the potential of functioning as an effective banker plant system for the control of thrips by *Orius* when the flowers are planted in close proximity to field peppers or other flowering vegetable crops.

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