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Author(s): Nicholas P. Schmidt, Matthew E. O'neal, Philip M. Dixon

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# Aphidophagous Predators in Iowa Soybean: A Community Comparison across Multiple Years and Sampling Methods

NICHOLAS P. SCHMIDT, MATTHEW E. O'NEAL,<sup>1</sup> AND PHILIP M. DIXON<sup>2</sup>

Department of Entomology, Iowa State University, Ames, IA 50011-3140

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**ABSTRACT** There is increasing evidence that *Aphis glycines* Matsumara (Hemiptera: Aphididae) populations are negatively impacted by endemic natural enemies within North America. In Iowa, surveys of natural enemies in soybean, *Glycine max* (L.) Merr., conducted before the arrival of *A. glycines* revealed a number of species that may contribute to their mortality. We used several sampling methods to determine the diversity of the natural enemy community in Iowa soybean since the arrival of *A. glycines*. Natural enemies were collected using field-counts (in situ sampling), destructive counts, sweep-net sampling, and yellow-sticky cards. When predaceous arthropods were combined across all sampling methods, six orders were identified, including nine families and 13 genera. In comparison with a similar study conducted 26 yr ago, we observed fewer native coccinellids with the most abundant being the exotics *Harmonia axyridis* (Pallas) and *Coccinella septempunctata* L. (Coleoptera: Coccinellidae). Combining all foliar-based sampling methods reveals a community of four aphidophagous taxa that account for >94% of the total captured: *Toxomerus* spp., *H. axyridis*, *Orius insidiosus* (Say), and *Chrysoperla* spp. In both years, destructive counts collected fewer species with more found using field-counts, sweep-net, and yellow-sticky cards. Sweep-net and yellow-sticky cards collected more agile life-stages and species as expected from sampling methods that rely on the insects' activity/density to be effective. Our data suggest absolute methods such as destructive and field-counts may underestimate the contribution of mobile predators on *A. glycines* mortality.

**KEY WORDS** soybean aphid, invasive species, predators

Suppression of *Aphis glycines* Matsumara (Hemiptera: Aphididae) by endemic natural enemies in North America provides evidence that biological control is a significant source of aphid mortality (Fox et al. 2004, Liu et al. 2004, Costamagna and Landis 2006, Schmidt et al. 2007). Soybean, *Glycine max* (L.) Merr., grown in North America contain an array of natural enemies, including *Orius insidiosus* (Say) and *Harmonia axyridis* (Pallas), which prey upon *A. glycines* (Rutledge et al. 2004, Fox et al. 2005). Unlike other aphid–natural enemy systems (Snyder and Ives 2003), currently there is little evidence that parasitoids play a role in regulating *A. glycines* populations (Landis et al. 2000; Fox et al. 2004, 2005). Rather, communities of predators often with broad host ranges have been found to limit *A. glycines* outbreaks. Twenty-two years before the arrival of *A. glycines*, Bechinski and Pedigo (1981a) found that Iowa soybean contained aphidophagous predators, which may now contribute to the mortality of *A. glycines*. These include *Nabis* spp., *O. insidiosus*, *Chrysopa* spp., and native coccinellids, all of which have been observed to feed on *A. glycines* (Rutledge

et al. 2004). Despite this preexisting community of natural enemies, by 2003 *A. glycines* had spread across every county in Iowa and outbreaks continue (O'Neal 2006).

In agricultural systems where natural enemies play a role in suppressing an insect pest, integrated pest management (IPM) programs should account for this preexisting control when management decisions are made. Such a program requires that growers factor the contribution of natural enemies to the biological control of a target pest into management decisions (Musser et al. 2004). Zhang and Swinton (2006) suggested an economic threshold for *A. glycines* that attempts to account for the impact of natural enemies. IPM programs for *A. glycines* that incorporate natural enemies will require improved understanding of their seasonal population dynamics and community structure and how these relate to *A. glycines* outbreaks. Describing the phenology of this community requires selecting the appropriate sampling method(s). Before the establishment of *A. glycines* in the United States, Bechinski and Pedigo (1982) compared sweep-net, plant shake, cut-and-bag, and vacuum net procedures, which were selected due to a lack of research in sampling precision and cost, and they described the predatory arthropod community in soybean. Their

<sup>1</sup> Corresponding author, e-mail: oneal@iastate.edu.

<sup>2</sup> Department of Statistics and Statistical Laboratory, Iowa State University, Ames, IA 50011-3140.

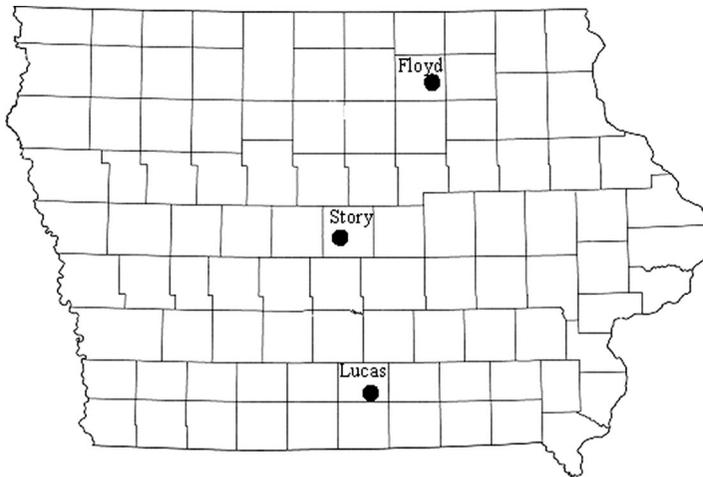


Fig. 1. Map of Iowa, indicating sampling sites in Floyd, Lucas, and Story counties.

objective was to identify the best method for sampling predatory arthropods in soybean.

Our long-term goal is to develop sampling plans for aphidophagous predators within soybean that could contribute to IPM for *A. glycines*. Herein, we report the diversity and abundance of the aphidophagous predators in Iowa soybean based on several sampling methods that could be easily adopted by growers and scouts. We selected methods that would allow for a comparison with a previous survey of the soybean natural enemy community. However, we consciously avoided using sampling methods that would have given us a complete measure of the insect community (e.g., D-vac, A-frame, and insecticide-fogging). Although these methods are used in ecological studies to determine community composition, they are not readily useful in IPM sampling programs. Therefore, our objectives were to determine 1) what aphidophagous predators are present in Iowa soybean and 2) how descriptions of this foliage-dwelling community vary by sampling method. We also 3) compared this community to the last extensive survey conducted in Iowa 26 yr ago. The communities were sampled during a 2-yr period (2004 and 2005), providing a comparison of the aphidophagous predator's numerical response when *A. glycines* abundance greatly varied.

### Materials and Methods

To accomplish the objectives, three locations were selected in Iowa that represented varying levels of risk to *A. glycines* outbreaks (Fig. 1). Since its arrival in 2000, aphid outbreaks have consistently occurred in the northern third of Iowa, with limited outbreaks occurring in the southern third of the state (O'Neal 2006). In 2004, four replicated plots 0.01 ha were located in Floyd and Story counties, IA. In Floyd County, soybean (NK S24-K4 RR) were planted on 6 May at a rate of 432,000 seeds  $\text{ha}^{-1}$  in 76 cm rows by using no-tillage production practices. In Story County, soybean (Prairie Brand 2494) were planted on 11 May

at a rate of 396,000 seeds  $\text{ha}^{-1}$  in 76 cm rows by using conventional tillage practices.

In 2005, four replicated plots 0.4 ha were located in Floyd, Lucas, and Story counties, IA. In all locations glyphosate-tolerant soybean varieties (Crows 2130 RR at Floyd County, Prairie Brand 2183 at Story County, and Stine 3532-4 RR at Lucas County) were planted at rates ranging from 408,000 to 432,000 seeds  $\text{ha}^{-1}$ . Both Floyd and Lucas counties used no-tillage production techniques, whereas Story County used conventional tillage.

Natural enemies were collected using four methods described below. A subset of these includes methods used to describe the natural enemy community in soybean before the arrival of *A. glycines* (Bechinski and Pedigo 1982). This included field-counts (in situ sampling), destructive counts (cut-and-bag), and sweep-net sampling. To focus our sampling effort on components of the community most likely to respond to *A. glycines*, we included yellow-sticky cards to collect more agile natural enemies such as adult coccinellids and syrphids.

**Sample Processing.** All *A. glycines* and natural enemy sampling was conducted once per week at each site, except in 2004 when yellow-sticky cards were used only once per month. Contents obtained from all sampling methods were bagged and stored at  $-20^{\circ}\text{C}$ . All natural enemies collected were sorted and identified to at least the family level except for *O. insidiosus*, *Podisus maculiventris* (Say), and Coccinellidae, which were identified to species. Both adult and immature stages of natural enemies were counted and voucher specimens were deposited in the Iowa State Insect Collection, at Iowa State University, Ames, IA.

**Field-Counts.** The sample unit consisted of 10 consecutive plants within the interior rows randomly selected using a random number table. Consecutive plants were examined to minimize the amount of time locating plants. All natural enemies were identified and counted on 10 plants from top to bottom. The counts from all 10 plants were pooled. Counts were

taken from 15 June to 13 September 2004 and from 2 June to 5 September 2005.

**Destructive Counts.** The sample unit (two in 2004 and five in 2005) consisted of randomly selected plants from the interior rows of a soybean plot. Plants were cut at soil surface, carefully removed from the row, and quickly placed in a plastic bag. Some actively flying or moving predators left the plant, and they were not counted; nonetheless, many remained attached to the plant or fell into the bag during sampling. The counts from plots were pooled. Destructive counts were taken from 7 July to 13 September 2004 and from 2 June to 5 September 2005.

**Sweep-Net.** The sample unit consisted of 20 continuous pendulum sweeps taken from a random location in the interior rows of a soybean plot. We selected an individual "sweeper" each week to limit variability in sweep-net samples across the multiple locations. In addition, the sweeper selected a row from which field or destructive counts were not taken. In this way, we avoided dislodging more agile predators from plants. Sweep-net samples were collected from 7 July to 13 September 2004 and from 27 June to 5 September 2005.

**Yellow-Sticky Cards.** The sample unit consisted of two unbaited yellow-sticky cards (Pherocon AM, Trécé, Inc., Adair, OK). Each yellow-sticky card was mounted on a wooden stake so the bottom of card was directly above soybean canopy, and each stake was placed one third of the total distance from the end of the plot. Yellow-sticky cards were deployed from 7 July to 30 August 2004 and from 2 June to 5 September 2005. In 2004, yellow-sticky cards were deployed for 7 d once per month from June to August. In 2005, yellow-sticky cards also were deployed for 7 d, but sampling was conducted four times per month from June to August.

**A. glycines.** In 2004, *A. glycines* populations were estimated by counting all aphids on 10 consecutive plants during field-counts of natural enemies. However, in 2005, to reduce the amount of time spent on an individual plant and ultimately minimize the number of natural enemies emigrating off a plant, *A. glycines* populations were obtained by counting all aphids from the five plants selected for destructive counts.

**Descriptive Statistics.** To determine whether the total number of natural enemies differed between years, sites, and methods, sampling data were transformed using a natural log ( $x + 0.2$ ) to meet the assumptions of analysis of variance (ANOVA) (Sokal and Rohlf 1995). For this comparison, the Lucas County site, which was added in 2005, was not included in the analysis. Furthermore, five destructive subsamples were taken in 2005 instead of the two in 2004; therefore, 2005 destructive data were standardized by randomly selecting two of the five samples to make an appropriate comparison between both years. In addition, yellow-sticky cards were only sampled at three dates in 2004 (6 July and 3 and 28 August), so only comparable dates were used from 2005 data. To test the impact of years, a split-plot ANOVA was used with year as the whole plot factor, and the date and

location factorial as the split factor (PROC GLM, SAS Institute 2002).

To determine whether there was an effect among sites in sampling methods, the total number of natural enemies from 2004 and 2005 were transformed using a natural log ( $x + 0.2$ ) to meet the assumptions of ANOVA. Both 2004 and 2005 data were analyzed independently of each other with ANOVA. To test for a difference among sites, the model used was a randomized complete block design with site and method as fixed factors (PROC GLM, SAS Institute 2002). Finally, least squares means were estimated with the 2005 data to compare the natural enemy abundance across the three sites.

**Comparison of Natural Enemy Community Description across Sampling Methods.** An ordination analysis, nonmetric multidimensional scaling (NMDS) was used to compare the natural enemy community collected across the four sampling methods. NMDS summarizes relationships between all pairs of species data and represents it in multiple dimensions as distances, so the closer two points are, the more similar they are (e.g., same species composition; Kenkel and Orlóci 1986). The four sampling methods greatly varied in sampling effort; therefore, the Horn-Morisita distance measure was used, which is independent of the size of the sampling unit (Anderson et al. 2005). Natural enemy totals for all sampling methods were analyzed with NMDS (metaMDS from the vegan package) for each month and year by using the statistical software R (R Development Core Team 2005). Differences in species composition were visualized by drawing convex hulls for each group.

To estimate the level of precision inherent in each sampling method, the relative variation (RV = standard error/mean) was calculated from all samples within an individual method (Pedigo and Buntin 1994). Larger RV values indicate a lower level of precision; thus, large RV values indicate the difficulty of accurately estimating low densities of natural enemies with a limited number of samples.

## Results and Discussion

**Survey of Natural Enemy Community.** We observed a community made up of six orders, nine families, and 13 genera when all predaceous arthropods captured in every sample from all four sampling methods were combined (Table 1). This includes two non-insect arthropod orders: Araneae and Opiliones. From these foliage-dwelling natural enemies, we only identified known aphidophagous taxa to species. Although *Chrysoperla* spp. are aphidophagous, their contribution to suppressing aphid populations is considered limited (Rosenheim et al. 1993). Therefore, we did not identify *Chrysoperla* beyond genus.

There were some similarities and discrepancies between Bechinski and Pedigo (1981a) in the species collected from 2004 and 2005. We did not collect the following coccinellids: *Coccinella transversoguttata* Brown, *Hyperaspis undulata* (Say), and *Scymnus* spp., whereas Bechinski and Pedigo (1981a) did not collect

**Table 1.** Natural enemies<sup>a</sup> collected from Iowa soybean fields in 2004 and 2005

Classification	
Hemiptera	
Anthocoridae	
<i>Orius insidiosus</i>	
Nabidae	
<i>Nabis</i> spp.	
Pentatomidae	
<i>Podisus maculiventris</i>	
Coleoptera	
Carabidae	
Cicindelinae	
Coccinellidae	
<i>Anatis quindecimpunctata</i>	
<i>Brachyacantha ursina</i> F.	
<i>Coccinella septempunctata</i>	
<i>Coleomegilla maculata</i>	
<i>Cycloneda munda</i>	
<i>Harmonia axyridis</i>	
<i>Hippodamia convergens</i>	
<i>Hippodamia parenthesis</i> Say	
<i>Hippodamia tredecimpunctata</i> L.	
Neuroptera	
Chrysopidae	
<i>Chrysoperla</i> spp.	
Hemerobiidae	
No further identification	
Hymenoptera	
Diptera	
Dolichopodidae	
<i>Condylostylus siphon</i> (Say)	
Syrphidae	
<i>Toxomerus</i> spp.	
Araneae	

<sup>a</sup> Natural enemies collected from destructive, field-counts, sweep-net, and yellow-sticky cards.

syrphids (*Toxomerus* spp.) and the following coccinellids: *Anatis quindecimpunctata* (Olivier) and the two exotic species *H. axyridis* and *C. septempunctata*.

In 2004 and 2005 when all foliar-based sampling methods are combined (Table 2), the natural enemy community included five dominant aphidophagous taxa—Coccinellidae, Syrphidae, Anthocoridae, Nabidae, and Chrysopidae—accounting for 96.4% of the total captured in 2004 and 94.4% in 2005 (Table 2). Of all the coccinellids collected, only *C. septempunctata*, *Coleomegilla maculata* (DeGeer), *H. axyridis*, and *Hippodamia convergens* Guerin-Meneville are reported to feed on *A. glycines* (Rutledge et al. 2004). In contrast, Bechinski and Pedigo (1981a) observed a natural enemy community made up of four of the five same taxa we observed (excluding Syrphidae) that accounted for 98.4 and 95.7% of the predators collected in 1977 and 1978, respectively.

**A. glycines Abundance.** In 2004 and 2005, *A. glycines* arrived during the first week of July in all sites but Floyd County in 2004, where *A. glycines* did not arrive until the first week of August. When *A. glycines* were averaged over all sites the abundance of *A. glycines* varied between the 2 yr. Populations in 2005 were above the economic threshold of 250 aphids per plant (Ragsdale et al. 2007), in contrast, 2004 populations peaked at 36 aphids per plant (Fig. 2). In 2004, aphids peaked at  $64 \pm 13$  and  $7 \pm 1$  aphids per plant at Story and Floyd counties (Table 3). In contrast, *A. glycines* populations were consistently higher across all of the 2005 study sites, ranging from  $336 \pm 138$ ,  $741 \pm 316$ , and  $71 \pm 25$  aphids per plant at Story, Floyd, and Lucas counties, respectively (Table 3). Significant differences were observed among sites in both years, and LSMeans values are reported for 2004 and 2005 study sites (Table 3).

**Natural Enemy Abundance.** To account for the variability among sites, 2004 and 2005 data were analyzed by sampling method. In 2004, there was a significant difference between the two sites for all sampling

**Table 2.** Comparison of the predominant foliage-dwelling natural enemies collected in Iowa soybean before and after the arrival of *A. glycines*

Natural enemies (order/family) <sup>a</sup>	Species	% total natural enemies			
		1977 <sup>b</sup>	1978 <sup>b</sup>	2004	2005
Coleoptera					
Coccinellidae	<i>Harmonia axyridis</i> <sup>c</sup>			27.4	18.2
	<i>Coccinella septempunctata</i> <sup>c</sup>	3.0	0.8	2.5	7.6
	Total native <sup>d</sup>			1.6	2.3
Diptera					
Syrphidae	<i>Toxomerus</i> spp.			27.0	34.2
	<i>Toxomerus</i> spp. immatures			1.0	2.1
Hemiptera					
Anthocoridae	<i>Orius insidiosus</i>	58.8	25.0	21.5	12.4
	<i>Nabis</i> spp.	22.9	38.9	0.7	2.5
Neuroptera					
Chrysopidae	<i>Chrysoperla</i> spp.	1.8	1.2	2.6	10.9
	<i>Chrysoperla</i> spp. immatures			1.0	0.3
Araneae					
Total		98.4	95.7	96.4	94.4

<sup>a</sup> Natural enemies collected by destructive, field-counts, sweep-net, and yellow sticky cards.

<sup>b</sup> Data collected by Bechinski and Pedigo (1981a).

<sup>c</sup> Coccinellids not native to the United States.

<sup>d</sup> Coccinellid species native to Iowa: *Anatis quindecimpunctata*, *Brachyacantha ursina*, *Coleomegilla maculata*, *Cycloneda munda*, *Hippodamia convergens*, *Hippodamia parenthesis*, and *Hippodamia tredecimpunctata*.

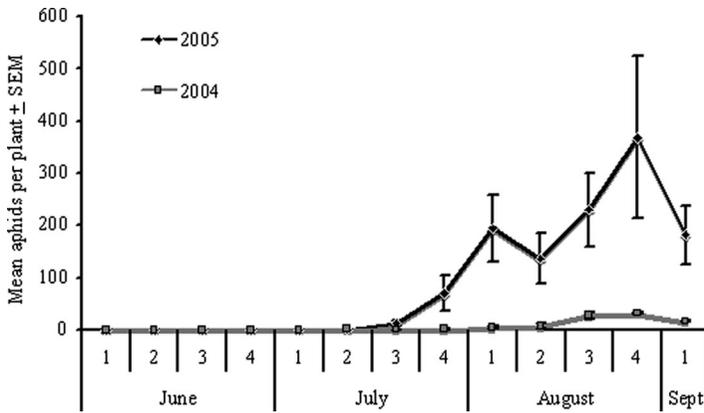


Fig. 2. Mean ( $\pm$  SEM) *A. glycines* for all locations in Iowa by year.

methods (destructive,  $F = 5.6$ ;  $df = 1, 35$ ;  $P < 0.0236$ ; field-counts,  $F = 13.42$ ;  $df = 1, 41$ ;  $P < 0.0007$ ; sweep-net,  $F = 8.92$ ,  $df = 1, 30$ ;  $P < 0.0056$ ; and yellow-sticky cards,  $F = 25.98$ ,  $df = 1, 9$ ;  $P < 0.0006$ ). In 2005, significant differences were only found in destructive and yellow-sticky cards among the three sites in 2005; LSMeans values are reported for three locations (Table 3).

Correlated with the year-to-year variation in *A. glycines* abundance was nearly a two-fold increase in natural enemy abundance from 2004 (1,099) to 2005 (1,919 adjusted from 4,194 to account for increased sampling effort (Table 4; Fig. 3). A significant difference in natural enemy abundance was observed ( $F = 7.68$ ;  $df = 1, 179$ ;  $P < 0.0062$ ) among sample dates (6 July and 3 and 28 August) for all sampling methods between years. Although a significant increase was observed in natural enemy abundance from 2004 to 2005 for destructive counts ( $F = 17.07$ ;  $df = 1, 33$ ;  $P < 0.0002$ ) and marginally significant for field-counts ( $F = 3.94$ ;  $df = 1, 31$ ;  $P < 0.0560$ ), there was no difference observed for sweep-net ( $F = 3.22$ ;  $df = 1, 31$ ;  $P < 0.0823$ ) and yellow-sticky cards ( $F = 0.11$ ;  $df = 1, 30$ ;  $P < 0.747$ ).

**Comparison of Sampling Methods.** In general, we observed significant differences in the natural enemy

community across the four foliar-based sampling methods used in this study. In 2004 and 2005, destructive counts collected the same six taxa (Table 4), whereas consistently more species were found in field-counts, sweep-net, and yellow-sticky cards. In both years, sweep-net and yellow-sticky cards collected more taxa, these included more agile species [i.e., *Cycloneda munda* (Say), *C. maculata*, and *H. paraenthesis*) and life stages of species (adult *Chrysoperla*) as expected from sampling methods that rely on the activity of insects to be effective.

We used NMDS to visually compare how the sampling methods described the natural enemy community. Overall, we observed no difference in the NMDS representation of the 2004 and 2005 communities; therefore, the combined data are reported (Fig. 4A-D). The arrangement of hulls, which represent sampling methods, seem to be consistent for June, July, and August, regardless of differences in *A. glycines* populations that occurred among these times. The arrangement of hulls does vary between months due to a difference in species composition at varying times of the year. The overlapping hulls indicate that the natural enemy community observed in the destructive and field-counts were very similar. In contrast, hulls representing yellow-sticky cards and destructive

Table 3. Peak abundance of *A. glycines* and natural enemies collected from all locations in 2004 and 2005

County	<i>A. glycines</i> <sup>a,b</sup>	Destructive <sup>c,d</sup>	Field-counts <sup>c,e</sup>	Sweep-net <sup>c,f</sup>	Yellow-sticky <sup>c,g</sup>
2004					
Floyd	7 $\pm$ 0.7A	1.3 $\pm$ 1.1B	1.1 $\pm$ 0.8B	1.2 $\pm$ 1.1B	25.8 $\pm$ 8.5A
Story	64 $\pm$ 13B	6.2 $\pm$ 7.1A	4.0 $\pm$ 2.2A	4.0 $\pm$ 3.6A	14.8 $\pm$ 5.8B
2005					
Floyd	741 $\pm$ 316A	8.0 $\pm$ 5.8A	6.2 $\pm$ 6.6A	7.3 $\pm$ 4.8A	20.1 $\pm$ 7.1A
Story	336 $\pm$ 138B	6.2 $\pm$ 3.7A	3.9 $\pm$ 2.9A	4.3 $\pm$ 2.1A	17.7 $\pm$ 4.9A
Lucas	71 $\pm$ 11C	2.5 $\pm$ 3.1B	5.2 $\pm$ 3.8A	2.8 $\pm$ 1.4A	12.2 $\pm$ 5.4B

<sup>a</sup> Peak mean  $\pm$  SEM *A. glycines* per location. In 2004, aphid counts were collected from 10 field-counts and in 2005 from five destructive counts.

<sup>b</sup> Uppercase letters indicate LSMeans between sites in a year (2004:  $df = 1, 14$ ;  $P = 0.0001$  and 2005:  $df = 2, 15$ ;  $P = 0.0001$ ).

<sup>c</sup> Capital letters indicate LSMeans between sites in a year (2004:  $df = 1, 58$ ;  $P = 0.05$  and 2005:  $df = 2, 82$ ;  $P = 0.05$ ).

<sup>d</sup> In 2004, the sample unit was two plants per plot and in 2005 five plants per plot.

<sup>e</sup> In 2004 and 2005, the sample unit was 10 plants per plot.

<sup>f</sup> In 2004 and 2005, the sample unit was 20 pendulum sweeps per plot.

<sup>g</sup> In 2004 and 2005 the sample unit was two yellow-sticky cards per plot.

Table 4. Total natural enemies collected by destructive, field-counts, sweep-net, and yellow sticky card sampling methods in Iowa soybean from 2004 and 2005

Species by year	Sampling method				
	Destructive	Field-count	Sweep-net	Yellow-sticky	Total
2004					
<i>Harmonia axyridis</i> <sup>a</sup>	157	25	51	181	414
<i>Toxomerus</i> spp. <sup>b</sup>	13	12	8	220	253
<i>Orius insidiosus</i> <sup>c</sup>	70	60	56	0	186
<i>Chrysoperla</i> spp. <sup>b</sup>	24	54	10	20	108
Araneae <sup>d</sup>	10	21	24	4	59
Parasitic wasp <sup>d</sup>	0	1	8	33	42
<i>Coccinella septempunctata</i> <sup>d</sup>	0	0	1	13	14
<i>Podisus maculiventris</i> <sup>e</sup>	2	1	3	0	6
<i>Nabis</i> spp. <sup>c</sup>	0	0	6	0	6
<i>Cycloneda munda</i> <sup>d</sup>	0	0	0	3	3
Hemeroptera <sup>d</sup>	0	3	0	0	3
<i>Hippodamia parenthesis</i> <sup>d</sup>	0	0	0	2	2
<i>Coccinella maculata</i> <sup>d</sup>	0	0	0	1	1
<i>Hippodamia convergens</i> <sup>d</sup>	0	0	0	1	1
<i>Brachyacantha ursina</i> <sup>d</sup>	0	0	0	1	1
2004 totals	276	177	167	479	1,099
2005					
<i>Toxomerus</i> spp. <sup>b</sup>	36	78	26	1,153	1,293
<i>Harmonia axyridis</i> <sup>a</sup>	169	136	186	454	945
<i>Chrysoperla</i> spp. <sup>b</sup>	112	71	52	350	585
<i>Orius insidiosus</i> <sup>c</sup>	276	230	57	2	565
<i>Hippodamia convergens</i> <sup>d</sup>	0	0	0	172	172
<i>Podisus maculiventris</i> <sup>e</sup>	37	77	40	0	154
Parasitic wasp <sup>d</sup>	0	0	5	124	129
<i>Nabis</i> spp. <sup>c</sup>	0	4	85	0	89
<i>Coccinella septempunctata</i> <sup>d</sup>	0	2	2	78	82
Araneae <sup>d</sup>	7	6	28	17	58
<i>Cycloneda munda</i> <sup>d</sup>	0	1	3	37	41
<i>Coccinella maculata</i> <sup>d</sup>	0	0	5	33	38
<i>Hippodamia parenthesis</i> <sup>d</sup>	0	0	0	15	15
Hemeroptera <sup>d</sup>	0	1	0	12	13
Opiliones <sup>d</sup>	0	3	2	0	5
<i>Anatis quindecimpunctata</i> <sup>d</sup>	0	0	0	5	5
<i>Brachyacantha ursina</i> <sup>d</sup>	0	0	0	4	4
<i>Hippodamia tredecimpunctata</i> <sup>d</sup>	0	0	0	1	1
2005 totals	637	609	491	2,457	4,194

<sup>a</sup> The species total includes eggs, larvae, pupae, and adults.

<sup>b</sup> The species total includes eggs, larvae, and adults.

<sup>c</sup> The species total includes nymphs and adults.

<sup>d</sup> The species total only includes adults.

<sup>e</sup> The species total includes eggs, nymphs, and adults.

counts did not overlap, indicating they collect very different natural enemy communities. Overall, hulls representing field-counts and destructive counts overlapped, as did yellow-sticky cards and sweep-net, indicating that these pairs of sampling methods collected similar insect communities.

**Conclusions.** In general, we observed a positive response by a community of generalist predators in Iowa soybean fields to the availability of an invasive herbivore. Evidence for this conclusion is found in a comparison with a previous survey by Bechinski and Pedigo (1981a) in which syrphids were not observed. In both 2004 and 2005 syrphids were the second most common aphid predator found (Table 4). Further evidence of the predator communities' response to *A. glycines* is the increased abundance of all predators between 2004 and 2005 when aphid populations increased by a factor of 10. Interestingly, this difference in predator abundance between 2004 and 2005 was only significant when measured with destructive counts and field counts. When a comparison of pred-

ator abundance on yellow sticky traps was corrected for differences in sampling effort between the 2 yr, no difference was observed. Why yellow-sticky traps did not reveal a difference in predator abundance and what its value is as a tool for measuring natural enemy abundance is discussed below.

The sampling methods used here varied in the effectiveness to collect individual members of the aphidophagous community in soybean. Field and destructive counts were most effective at collecting eggs, pupae, larvae, and nymphs of natural enemies and adult *O. insidiosus*; however, it was less effective at observing adults of the more active crawling and flying natural enemies such as adult coccinellids and syrphids. Sweep-nets collected more active natural enemies than field and destructive methods, such as adult coccinellids, syrphids, parasitic wasps, and Araneae. However, sweep-nets were less effective at collecting *O. insidiosus* (both adult and nymphs). Yellow-sticky cards collected the most natural enemies, but it is known that escape from yellow-sticky cards can be

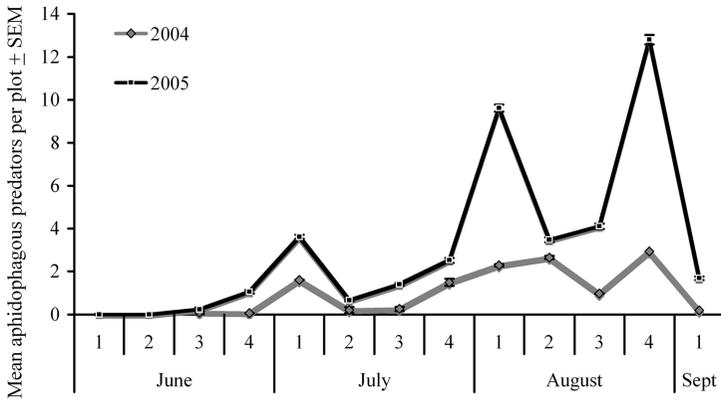


Fig. 3. Mean ( $\pm$  SEM) aphidophagous predators from all sampling methods in all locations in Iowa by year. Predators included in this mean are listed in Table 1.

high for some coccinellid species, specifically *H. axyridis* (Stephens and Losey 2004). Despite these losses, Stephens and Losey (2004) found yellow-sticky cards collected significantly more coccinellids than sweep-nets and field-counts. In corn, *Zea mays* L., Musser et al. (2004) suggested that yellow-sticky cards were unreliable for predicting *C. maculata* activity or density. They suggest that field-counts were the most precise sampling method for monitoring the three major predators in New York (*O. insidiosus*, *C. maculata*, and *H. axyridis*).

An empirical study such as this study describes a community, and it cannot address whether the more agile natural enemies, such as the adult coccinellids, chrysopids, and nabids, make a significant contribution to *A. glycines* predation. However, it is interesting to note that *C. septumpunctata* was not observed in any destructive counts, and in 2005 only two were observed in field-counts, yet 78 were observed on yellow-sticky cards. Similarly, *H. convergens* was only found on yellow-sticky cards (Table 4). *C. septumpunctata* is attracted to methyl salicylate, a volatile produced by soybean from *A. glycines* herbivory (Zhu and Park 2005). It is not clear whether these coccinellids are responding to low, highly dispersed populations of *A. glycines*, possibly feeding on patches of aphids but not laying eggs. Data presented here suggest that absolute methods such as destructive counts and field-counts would underestimate the contributions of these mobile predators. Yellow-sticky traps, either by being deployed over a longer period or having an innate attractiveness for insects were able to detect these predators as they moved through a soybean field. To what extent these predators are grazing on *A. glycines* as they disperse through these fields is not clear. Estimating their impact may be important to reveal how predator diversity may contribute to the suppression of this economic pest. Sampling methods such as destructive or field-counts which measured the lowest species richness of the sampling methods used herein would fail to reveal the impact of predators such as *C. septumpunctata* and *H. convergens*.

There have been several studies demonstrating that the existing predator community, specifically *H. axyridis* and *O. insidiosus*, suppress *A. glycines* populations in soybean (Fox et al. 2004, Rutledge et al. 2004, Mignault et al. 2006, Schmidt et al. 2007). *O. insidiosus* has been found to suppress *A. glycines* populations for up to 12 d (Rutledge and O’Neil 2005). Using solely a “cut-and-bag” method similar to the destructive sampling method, it was found that *O. insidiosus* made up 85–90% of predators collected in Tippecanoe County, IN, resulting in a significant negative relationship between aphid growth and *O. insidiosus* abundance (Desneux et al. 2006). Using only sweep-nets, *Propylea quatuordecimpunctata* (L.) was the most abundantly collected coccinellid followed by *H. axyridis* within soybean in Canada; however, *H. axyridis* was most adept at using *A. glycines* as a host compared with other coccinellids (Mignault et al. 2006). Estimating the contribution that any one member of this community plays in suppressing *A. glycines* will require sampling methods that account for all members. Our data suggest that these initial estimates may not include all members because they may over- or underestimate the predator community depending on what sampling method was used.

Further study of *A. glycines* population dynamics will likely include estimating the contribution that *O. insidiosus* and *H. axyridis* play in suppressing outbreaks. Based on relative variation the most precise sampling method for estimating adult *O. insidiosus* was field-counts (RV = 1.2 in 2004 and 0.9 in 2005); in contrast, the most precise method for nymph *O. insidiosus* was destructive counts (RV = 1.2 in 2004 and 1.0 in 2005; Table 5). It should be noted that Bechinski and Pedigo (1981b) found the most precise sampling method for adult and nymph *O. insidiosus* to be plant-shake samples. We did not conduct plant-shake samples, so it is difficult to compare these results to ours. More importantly, it seems that *O. insidiosus* is best collected using an absolute method that covers the entire plant. The most precise method for sampling *H. axyridis* adults was yellow-sticky cards (RV = 0.7 in 2004 and 0.9 in

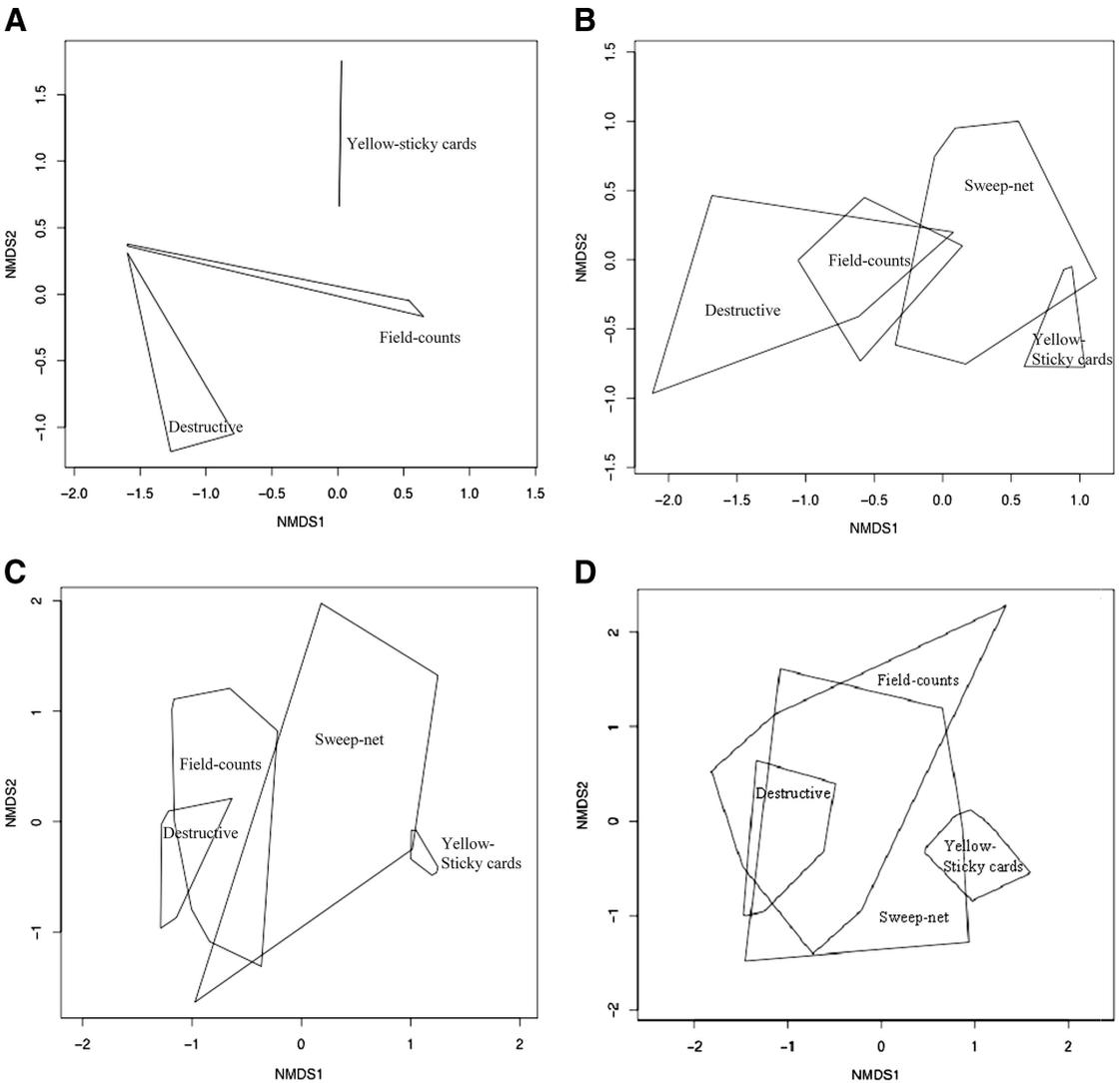


Fig. 4. Representation of the natural enemy community by NMDS across four separate sampling methods from combined years (2004 and 2005). Data for June (A), July (B), August (C), and seasonal total (D) (June–August). Nonoverlapping hulls indicate different species composition.

2005), followed by sweep-net samples ( $RV = 1.4$  in 2004 and 1.2 in 2005; Table 5). In addition, all other coccinellids were most precisely estimated with yellow-sticky cards ( $RV = 0.7$  in 2004 and 0.9 in 2005; Table 5), if they were found at all (e.g., *C. septumpunctata* and *H. convergens*). Future efforts to incorporate the abundance of these natural enemies for management of *A. glycines* should consider the inherent variability across the sampling methods studied here.

To what extent these generalist predators interact will make it difficult to determine whether a key species is responsible for *A. glycines* suppression. It has been observed in other aphid predator systems (Losey and Denno 1998, Cardinale et al. 2003) that additive or even synergistic relationships may exist among aphid predators. We did not observe a significant linear

relationship between *A. glycines* abundance and either *O. insidiosus* or *H. axyridis* alone or in combination (data not shown). To what degree these predators interact in a negative manner (e.g., intraguild predation) is not clear. Furthermore, it is not known the extent that the other predators that coexist with these two species can assist in the suppression of *A. glycines* abundance and population growth. Therefore, we suggest future development of *A. glycines* IPM should focus on answering the following questions: 1) which natural enemies are most important for *A. glycines* suppression, 2) does the incorporation of the diversity and abundance of these mostly generalist predators improve upon predicting the need for a foliar insecticide application (Ragsdale et al. 2007), and 3) can we accurately measure the natural enemy community to make such a prediction?

**Table 5.** Mean seasonal density (RV) for samples of natural enemies in Iowa soybean from 2004 and 2005

Method	<i>O. insidiosus</i>		<i>H. axyridis</i>	Native coccinellids <sup>a</sup>	
	Nymph	Adult	Adult	Larvae	Adult
2004					
Field	0.28 (1.5)	0.28 (1.2)	0.10 (2.5)	0.08 (2.8)	
Destructive	0.61 (1.2)	0.14 (1.4)	0.01 (4.8)	0.27 (3.3)	
Sweep	0.13 (2.9)	0.50 (1.3)	0.49 (1.4)	0.08 (2.4)	0.01 (4.7)
Yellow-sticky			7.54 (0.7)		0.88 (0.7)
2005					
Field	0.92 (1.0)	0.48 (0.9)	0.10 (2.6)	0.41 (5.7)	0.02 (3.7)
Destructive	1.31 (1.0)	0.36 (1.1)	0.07 (1.9)	0.29 (3.2)	
Sweep	0.04 (4.7)	0.45 (1.8)	1.59 (1.2)	0.01 (10.8)	0.07 (2.1)
Yellow-sticky		0.01 (6.4)	2.73 (0.9)	0.04 (7.3)	2.10 (0.9)

<sup>a</sup> All native coccinellids collected, excluding *H. axyridis* and *C. septempunctata*.

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