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RESEARCH

Population Dynamics of *Empoasca fabae* (Hemiptera: Cicadellidae) in Central Iowa Alfalfa Fields

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ABSTRACT. Adults and nymphs of *Empoasca fabae* Harris (Hemiptera: Cicadellidae) and adults of predatory species in the families Coccinellidae, Anthocoridae, Nabidae, Chrysopidae, and Hemerobiidae were sampled in Iowa alfalfa fields from June to September in 1999 and 2000. The relationship between each predatory taxa and *E. fabae* was examined using regression analysis. In 2000, all predators were found to be positively correlated with the presence of *E. fabae* during all periods sampled and most likely contributed to mortality. *Orius insidiosus* (Say) (Hemiptera: Anthoridae) was the most numerous insect predatory species; population numbers ranged from 0 to 1 and 0.1 to 3.7 adults per 0.25 m² in 1999 and 2000, respectively. Partial life tables were constructed for *E. fabae* nymphs for two alfalfa-growing periods. Nymphs were grouped into three age intervals: first and second, third and fourth, and fifth instars. For the first alfalfa growing period examined, *E. fabae* nymphal mortality was 70% in 1999 and 49% in 2000. During the last growing period of each season (August–September), total nymphal mortality was relatively low (<25%). Adult *E. fabae* density ranged from 5.4 to 25.6 and 1.4–9.2 per 0.25 m² in 1999 and 2000, respectively. *E. fabae* population peaks were similar for each age interval in all growing periods. This study provides further information on the population dynamics of *E. fabae* and its relationship with select predatory species in Iowa alfalfa fields.

Key Words: potato leafhopper, *Medicago sativa*, predator, population dynamics

The potato leafhopper, *Empoasca fabae* (Harris) (Hemiptera: Cicadellidae) is a key pest of alfalfa (*Medicago sativa* L.) in the midwestern United States (Giles et al. 1999, Chasen et al. 2014). *E. fabae* overwinters in states along the Gulf of Mexico on evergreens (Pinaceae) and herbaceous vegetation (mostly Fabaceae) and then migrates north in spring (Medler 1957, Taylor et al. 1993, Taylor and Shields 1995, Sidumo et al. 2005). The first appearance of *E. fabae* in the midwestern United States occurs in late-April to mid-May (Medler 1957, Maredia et al. 1998). Arrival of *E. fabae* in these areas coincides with low-pressure weather systems, suggesting transport is passive on warm low-level jet streams (Carlson et al. 1992). While *E. fabae* are found in alfalfa at this time, populations do not reach damaging levels in Iowa alfalfa fields until after the first cutting (mid-May to early June) (Steffey and Armbrust 1991, DeGooyer et al. 1998a, Giles et al. 1999).

Most alfalfa is typically harvested approximately every 45 d, which results in three harvests a season. However, for high-performance livestock, alfalfa may be harvested every 35 d resulting in four harvests a season (Barnhart 2010). Feeding on alfalfa by *E. fabae* reduces quality and yield by reducing the amount of photosynthate produced in the plant (Medler 1941). Eggs are laid singly in stems or petioles of host plants, and nymphs develop through five instars (Fenton and Hartzell 1923, Simonet and Pienkowski 1977). In Iowa, there are three overlapping generations of *E. fabae* per year (DeGooyer et al. 1998b).

Natural enemies of *E. fabae* have been identified, but little is known about their impact on *E. fabae* populations in alfalfa (Fenton and Hartzell 1923, Yadava and Shaw 1968, Lavallee and Shaw 1969, Wheeler 1977, Martinez and Pienkowski 1982, Rensner et al. 1983, Flinn et al. 1985). In laboratory studies, several coccinellid species prey upon *E. fabae* including *Coleomegilla maculata* (DeGeer), *Coccinella novemnotata* Herbst., and *Hippodamia convergens* (Guérin-Menéville) (Martinez and Pienkowski 1982, Weiser Erlandson and Obrycki 2010, Chasen et al. 2014). Weiser Erlandson and Obrycki (2010) observed

attack rates of 0.6 and 4.6 *E. fabae* per day by *C. maculata* adults and *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) larvae, respectively. Similarly, adult *Nabis roseipennis* (Reuter) (Hemiptera: Nabidae) consumed 4–5 *E. fabae* adults and 8–10 nymphs per day in the laboratory (Rensner et al. 1983). Other predatory species, such as *Nabis americoferus* Carayon and *Orius insidiosus* (Say) (Hemiptera: Anthoridae), locate and attack *E. fabae* eggs found in plant tissue (Martinez and Pienkowski 1982). Rensner et al. (1983) observed that nabid populations peak with *E. fabae* populations in Illinois alfalfa fields. In Virginia, *O. insidiosus* and *N. americoferus* were the most abundant predatory species, comprising 35% and 32% of predators collected in alfalfa (Martinez and Pienkowski 1982).

The objective of this study was to examine population dynamics of *E. fabae* and its relationship to associated predatory species in Iowa alfalfa fields.

Materials and Methods

Sampling Methods. *E. fabae* populations were sampled in two alfalfa fields in Ames, IA, in 1999 and 2000. Each field was sectioned into 10 25-m² quadrats. Samples were taken using a drop trap and a leaf blower with a suction attachment (WeedEater, Model BV1650, Shreveport, LA) and a mesh collection net (DeGooyer et al. 1998a). The drop trap consisted of a Plexiglas box (0.5 by 0.5 by 0.5 m = 0.125 m³) with an open bottom. The drop trap was randomly dropped over alfalfa foliage in each quadrat. Care was taken to ensure that there was no disruption of the foliage prior to dropping the trap. One suction sample was taken from each quadrat twice weekly from first harvest (late May to early June) until last harvest (August to September). Suction samples were collected by inserting the leaf blower through a 20-cm diameter hole on the top of the drop trap and vacuuming insects from within. Insects left on the top of the drop trap were counted directly. Samples were placed in plastic bags and

transported to the laboratory. The number of *E. fabae* nymphs, adults, and adult insect predators was recorded from each sample. Immature predators were excluded from the analysis due to labor constraints. The insects counted from the top of the drop box were added to the sample. Based on size and wing pad development, *E. fabae* nymphal stages were divided into three age groups: first–second, third–fourth, and fifth instars (Fenton and Hartzell 1923).

Data analysis. For comparison, partial life tables were calculated for only the last two growing periods of alfalfa during 1999 (second and third growing periods) and 2000 (third and fourth growing periods) to determine within-generation *E. fabae* population change. Data were not collected for the first growing period because *E. fabae* are migrating into Iowa and populations are not yet fully established. *E. fabae* age intervals used were first–second, third–fourth, and fifth instars; adult *E. fabae* were not used in life table analysis because of fluctuating

numbers due to immigration and emigration. *E. fabae* eggs were not included in analysis because of problems encountered in chemical clearing alfalfa stems for visual identification of eggs. Calculation of life table statistics followed Southwood (1978): $x =$ age interval of *E. fabae*, $l_x =$ number of *E. fabae* at the beginning of each age interval, $d_x =$ number dying during the age class x interval, $100q_x =$ percent mortality for age interval, $S_x =$ survival rate within age interval x. Estimates of l_x were determined by calculating the area under a curve method (Southwood 1978) using ENSTAT 4.0 (Pedigo and Zeiss 1996).

Regression analysis was performed for the relationship between each of the individual predator groups and combined predators, and each developmental stage of *E. fabae* and combined all stages of *E. fabae* using Excel data analysis tool (Excel 2010). Because of higher variation in field studies, statistical significance was set at $P \leq 0.055$.
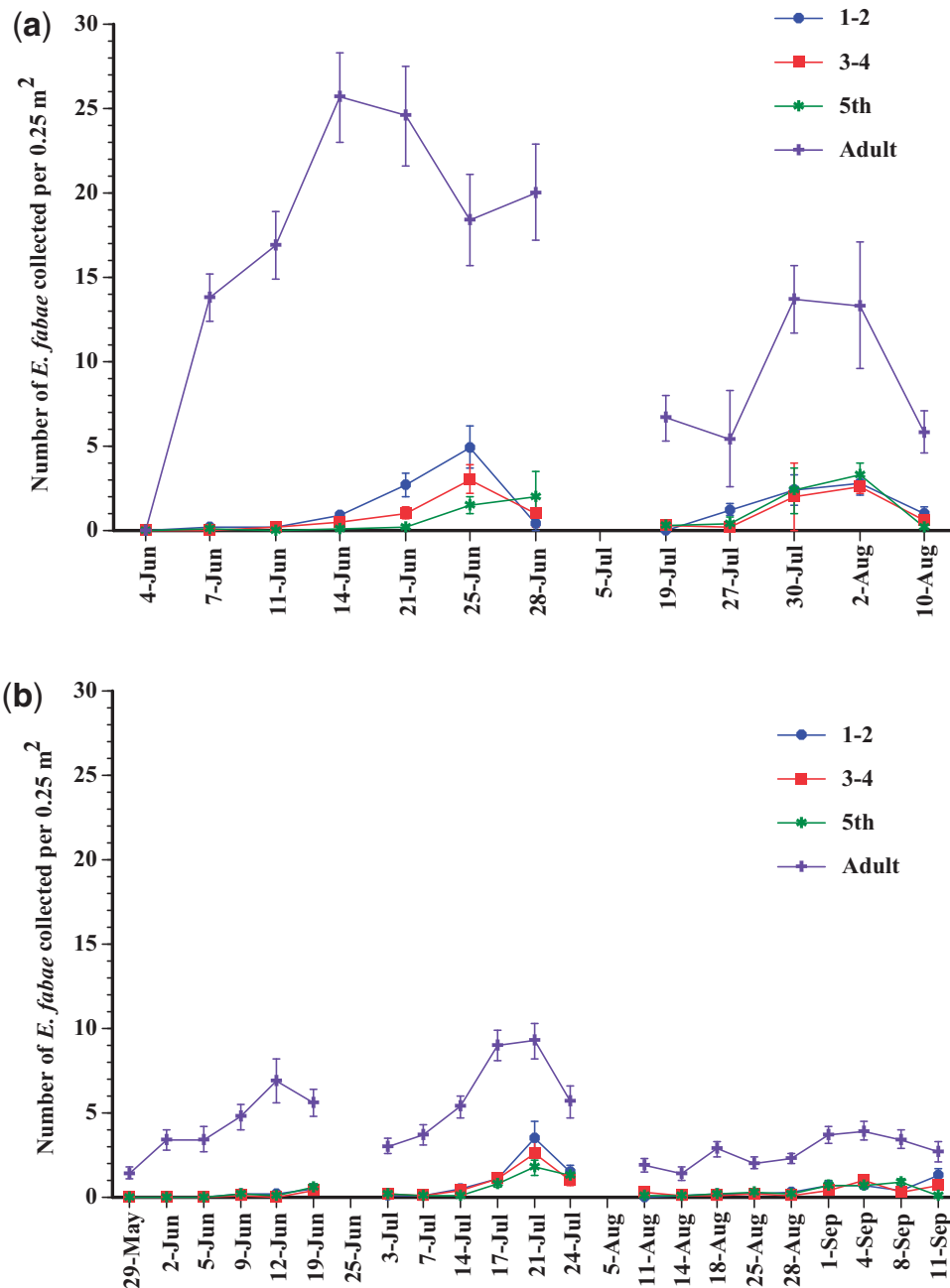

Fig. 1. Mean number $\pm$ SEM first–second instar, third–fourth instar and fifth instar, and adult *E. fabae* collected per 0.25 m² in Iowa alfalfa fields. (a) 1999. (b) 2000

Voucher specimens of all predators and *E. fabae* were deposited in the Department of Entomology Insect Collection, Iowa State University, Ames, IA.

Results

In 1999, *E. fabae* densities (±SE) ranged from 5.4 ± 2.9 to 25.6 ± 2.6 adults and 0.1 ± 0.1 to 3.3 ± 0.6 nymphs, collected per 0.25 m^2 (Fig. 1a). Percent mortality during the second growing period was 44% for first–second and 47% for third–fourth instars (Table 1). Total mortality from first to fifth instar was 70% (Table 1). During the third growing period, mortality was low for first to fifth instar resulting in a negative mortality (the number of fifth instars collected was greater than the number of first instars) (Table 1).

Compared with *E. fabae*, the number of predatory insects collected was relatively low (0–1 per 0.25 m^2) (Table 3). The only anthocorid species collected in this study was *O. insidiosus*; it also was the most numerous predatory species collected $(0.1 \pm 0.1–1.0 \pm 0.3$ per 0.25 m^2) (Fig. 2a). Nabid populations, including *N. roseipennis* and *N. americoferus*, ranged from 0 to 0.4 ± 0.2 adults per 0.25 m^2 (Fig. 2a). Coccinellid species collected were *C. maculata*, *H. convergens*, *Hippodamia tredecimpunctata* (Say), *Harmonia axyridis* (Pallas), *Cycloneda munda* (Say), *Hippodamia parenthesis* (Say), and *Coccinella septempunctata* L. Coccinellid densities ranged from 0 to 0.1 ± 0.1 per 0.25 m^2 (Fig. 2a). Neuropterans collected consisted of both Chrysopidae and Hemerobiidae. However, chrysopids, including *Ch. carnea* and *Chrysopa occulata* Say, were more abundant than Hemerobiidae. Densities of neuropterans ranged from 0 to 0.1 ± 0.1 per 0.25 m^2 (Fig. 2a). The only positive correlation of a predator group with *E. fabae* found during this year was that of the relationship between nabids and 3–4 instar *E. fabae* (Table 2; $F = 7.40$; df = 1, 4; $P = 0.053$).

In 2000, *E. fabae* densities collected per 0.25 m^2 ranged from 1.4 ± 0.4 to 9.2 ± 1.0 adults and 0 to 3.4 ± 1.0 nymphs (Fig. 1b). Percent mortality during the third growing period was 21% and 35% for first–second and third–fourth instars, respectively (Table 1). For this same growing period, total mortality for first to fifth instar was 49% (Table 1). During the fourth growing period, percent mortality was 23% for first to fifth instar (Table 1).

Although the same predatory species were collected in both years, predator numbers were higher in 2000 (Table 3). Densities of anthocorids (*O. insidiosus*) ranged from 0.1 ± 0.1 to 3.7 ± 0.6 adults per 0.25 m^2, with higher numbers occurring during the last growing period (Fig. 2b). *O. insidiosus* was the most numerous insect predator collected (Table 3). The second most abundant predatory group was Nabidae with densities ranging from 0 to 0.5 ± 0.2 adults per 0.25 m^2 (Fig. 2b). Coccinellids and neuropterans had similar densities of 0 to 0.4 ± 0.2 adults per 0.25 m^2 (Fig. 2b).

In addition, all predators were found to be positively correlated with the presence of *E. fabae* in 2000 during all periods sampled (Table 2). The relationship of *O. insidiosus* was strongest during the July sampling period, while neuropterans and nabids exhibited a strong relationship during the last sampling period (August to September) (Table 2).

Discussion

In 1999, *E. fabae* densities were 2–3 times higher than in 2000 (Fig. 1a). This is consistent with other studies that examined *E. fabae* populations in Iowa alfalfa fields from 1998 to 2000 (Weiser et al. 2003); *E. fabae* densities in Iowa alfalfa fields during 1999 were 3–10 times higher than those in 1998 and 2000. Adult *E. fabae* were consistently found in suction samples from the start of sampling and nymphs were first collected during the third week of sampling (11 June 1999). Flinn et al. (1990) observed that adult *E. fabae* usually do not colonize alfalfa regrowth until alfalfa reached a height of 5 cm, 10–15 d after alfalfa harvest. In contrast, we observed adult immigration somewhat earlier, at approximately 7 d after harvest. Early colonization of alfalfa regrowth may result in a higher number of *E. fabae* in the next generation. Adult *E. fabae* oviposit 2–3 eggs per day during their lifetime (DeLong 1938) which is, on average, 76–122 d for females depending on temperature (Sher and Shields 1991); and since *E. fabae* are continuously reproducing, there is the potential for rapid population growth (Hogg 1985).

E. fabae population peaks were synchronous for each age interval in all growing periods (Fig. 1). However, we did not observe successive density peaks for each age interval. This pattern was consistent for each growing period and year. Sampling intervals were relatively short (every 3–4 d) providing adequate resolution of changes in population dynamics.

Percent mortality of *E. fabae* was consistently higher in the first life tables constructed (second and third alfalfa growing periods in 1999 and 2000, respectively) than in the second life tables in the same years. For the second life table of each year, *E. fabae* percent mortality was relatively low (<25%) because higher numbers of older instar *E. fabae* were collected. This trend was not found in any of the other growing periods sampled and, therefore, is unlikely to be due to sampling error. There are two possible explanations for this observation. First, in 2000, we found a correlation in the number of predators with *E. fabae* (Table 2), especially with the nabids and neuropterans during the last growing period. These predators may have contributed to the mortality of *E. fabae* during this time. In addition, the number of *O. insidiosus* was correlated with all stages of *E. fabae* during the third growing period (Table 2) and its numbers in the alfalfa were highest during the last growing period (Fig. 2). Each of these predatory species feeds on *E. fabae* and may have contributed to the mortality of younger instars, causing the difference between age intervals (Weiser Erlandson and Obrycki 2010). In addition, Weiser Erlandson and Obrycki (2010) observed in laboratory studies that *O. insidiosus* feeds on proportionally more of the younger than the older instars of *E. fabae* nymphs and may prefer to prey upon smaller insects in the field. However, many of these predatory species are polyphagous and feed on other insects found in alfalfa. For example, coccinellids which are thought to be primarily aphidophagous will diversify their diet with other prey items, such as dipterans (Moser et al. 2011), as well as *E. fabae* (Weiser Erlandson and Obrycki 2010), when aphid availability is

Table 1. Partial life tables for *E. fabae* nymphs in alfalfa at Ames, IA, in 1999 and 2000

Year	Growing period[a]	x[b]	l_x[c]	d_x[d]	$100q_x$[e]	S_x[f]
1999	2	1–2 instars	38.02	16.77	44.11	55.89
1999	2	3–4 instars	21.25	9.99	47.01	52.99
1999	2	5 instars	11.26			
1999	2	Total		26.76	70.38	29.62
1999	3	1–2 instars	34.79	4.14	11.9	88.1
1999	3	3–4 instars	30.65	−4.21	−13.74	113.74
1999	3	5 instar	34.86			
1999	3	Total		−0.07	−0.2	100.2
2000	3	1–2 instars	36.21	7.59	20.96	79.04
2000	3	3–4 instars	28.62	10.07	35.19	64.81
2000	3	5 instars	18.55			
2000	3	Total		17.66	48.77	51.23
2000	4	1–2 instars	14.28	4.5	31.51	68.49
2000	4	3–4 instars	9.78	−1.29	−13.19	113.19
2000	4	5 instars	11.07			
2000	4	Total		3.21	22.48	77.52

[a] In 1999, first growing period May–6 June, second growing period 7 June–28 June, third growing period 29 June–10 August; and in 2000, first growing period May–27 May, second growing period 28 May–18 June, third growing period 19 June–27 July, and fourth growing period 28 July–10 September

[b] x, age interval of *E. fabae*.

[c] l_x, number of *E. fabae* at the beginning of each age interval.

[d] d_x, number dying during the age class x interval.

[e] $100q_x$, percent mortality for age interval.

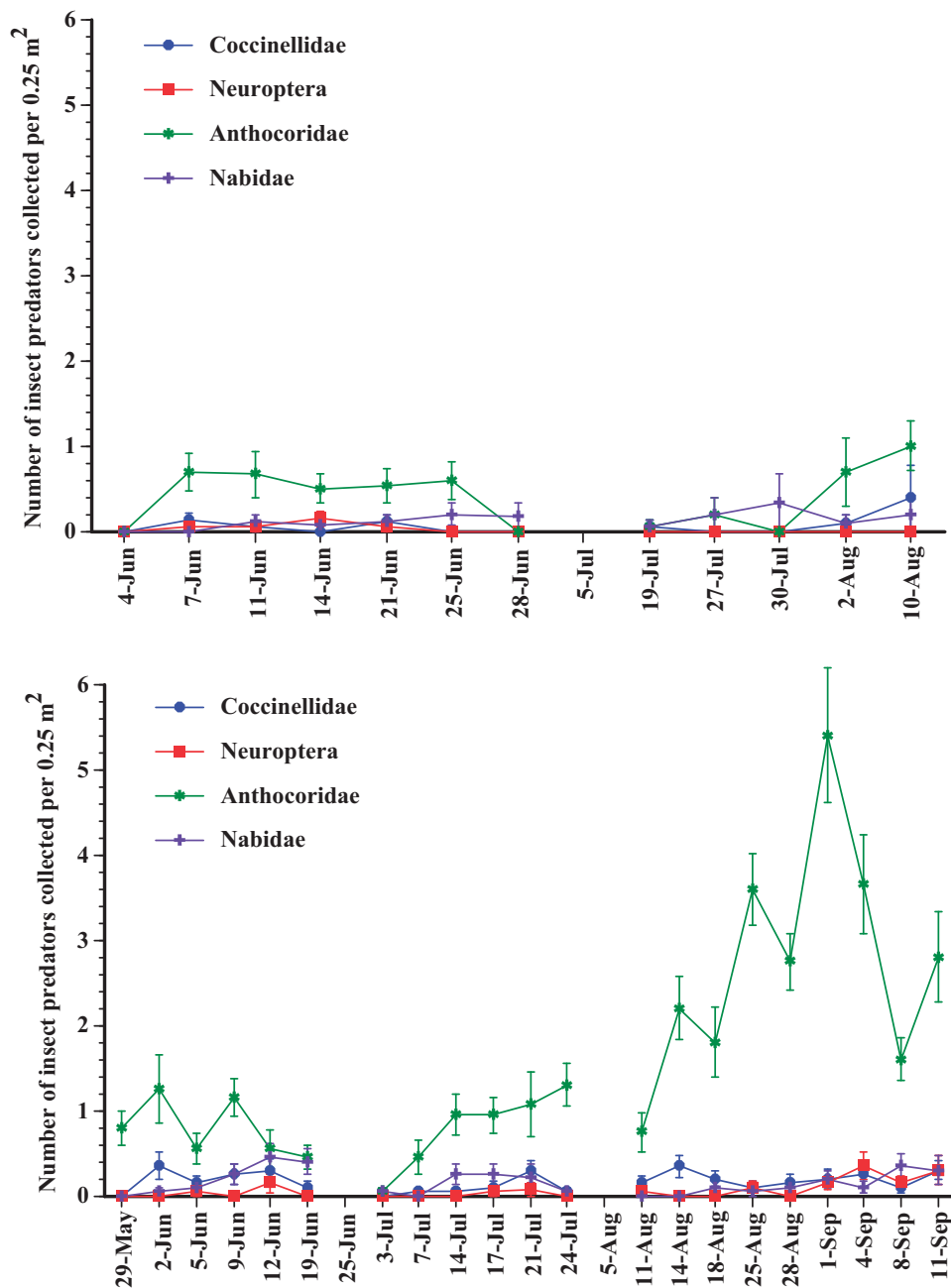[f] S_x, survival rate within age interval

Fig. 2. Mean number ± SEM Coccinellidae, Neuroptera, Anthocoridae, and Nabidae collected per 0.25 m² in Iowa alfalfa fields. (a) 1999. (b) 2000

low. Smaller *E. fabae* populations were observed in 2000 than in 1999 (Figs. 1a and b) while higher populations of predators were observed in 2000 than in 1999 (Fig. 2a and b). Although these predatory species may not be significant mortality factors in this study, we did not collect their immature stages and, collectively with the adults, they may be important in maintaining low *E. fabae* population densities in the field.

Another factor that may have affected our data is that *E. fabae* begin their reproductive diapause before their southward migration in late summer to fall (Taylor et al. 1995). Taylor et al. (1995) determined that in New York, mid-July, only 50% of late instar *E. fabae* females would become reproductively mature. This coincides with decreasing photoperiod (e.g., 15:9 [L:D] h). By mid-August and September, the number of late instar females predicted to become reproductively mature drastically dropped to about 25% and 9%, respectively. In Iowa, daylight hours decrease to about 14 h around mid-August and to about

13 h by early September. The decrease of the number of early instars shown in our data supports the induction of reproductive diapause beginning in late July.

Population dynamics may fluctuate from year to year based on environmental conditions and how many alfalfa growing periods occur in a particular season. Although we found the same population trend in each year, population numbers of adult *E. fabae* were higher in 1999 compared with those found in 2000. Hogg (1985) observed that temperature affected *E. fabae* developmental time, natality, and mortality in laboratory studies; reproductive rates were higher and generation times were shorter at higher temperature regimes. We did not find a substantial difference in average temperatures between 1999 and 2000, but rainfall was much higher in 1999 during the months of May, July and, August (www.wunderground.com). The higher rainfall in 1999 may have contributed to faster alfalfa growth and larger plants

Table 2. Significant R^2 values obtained for relationships between predators and various stages of *E. fabae* in Iowa alfalfa fields in 1999 and 2000

Year	Growing period[a]	Predator (adult)	Stage of *E. fabae*	R^2	F (df)	F	P	Line equation
1999	2	Nabidae	3–4 instars	0.649	1, 4	7.40	0.053	$Y = 0.0520x + 0.0627$
2000	2	Nabidae	1–2 instars	0.707	1, 4	9.67	0.036	$Y = 0.8895x + 0.0897$
2000	2	Nabidae	Adult	0.918	1, 4	44.53	0.003	$Y = 0.0941x - 0.1885$
2000	2	Nabidae	All stages	0.958	1, 4	90.50	0.000	$Y = 0.3270x - 0.1650$
2000	3	Orius	1–2 instars	0.594	1, 5	7.32	0.043	$Y = 0.2467x + 0.5339$
2000	3	Orius	3–4 instars	0.583	1, 5	6.98	0.046	$Y = 0.3141x + 0.5300$
2000	3	Orius	5 instars	0.553	1, 5	6.18	0.055	$Y = 0.5452x + 0.4846$
2000	3	Orius	Adult	0.618	1, 5	8.10	0.036	$Y = 0.1432x - 0.0307$
2000	3	Orius	All stages	0.654	1, 5	9.47	0.028	$Y = 0.2729x + 0.2223$
2000	3	All predators	1–2 instars	0.606	1, 5	7.69	0.039	$Y = 0.0725x + 0.1730$
2000	3	All predators	3–4 instars	0.597	1, 5	7.40	0.042	$Y = 0.0926x + 0.1717$
2000	3	All Predators	5 instars	0.612	1, 5	7.89	0.038	$Y = 0.1671x + 0.1533$
2000	3	All predators	Adult	0.764	1, 5	16.16	0.010	$Y = 0.0464x - 0.0208$
2000	3	All predators	All stages	0.736	1, 5	13.93	0.014	$Y = 0.0842x + 0.0713$
2000	4	Neuroptera	1–2 instars	0.657	1, 7	13.40	0.008	$Y = 0.2559x + 0.0142$
2000	4	Neuroptera	3–4 instars	0.950	1, 7	133.29	0.000	$Y = 0.4129x - 0.0131$
2000	4	Neuroptera	All stages	0.688	1, 7	15.46	0.005	$Y = 0.2648x - 0.1252$
2000	4	Nabidae	1–2 instars	0.447	1, 7	5.67	0.049	$Y = 0.2027x + 0.0477$
2000	4	Nabidae	All stages	0.453	1, 7	5.80	0.047	$Y = 0.2063x - 0.0595$

[a]In 1999, first growing period May–6 June, second growing period 7 June–28 June, third growing period 29 June–10 August; and in 2000, first growing period May–27 May, second growing period 28 May–18 June, third growing period 19 June–27 July, and fourth growing period 28 July–10 September.

Table 3. Predator minimum and maximum densities ($\pm$SE) per 0.25m^2 found in Iowa alfalfa fields in 1999 and 2000

	1999		2000	
Predator	Min	Max	Min	Max
Coccinellidae	0.00 (0.0)	0.10 (0.1)	0.00 (0.0)	0.40 (0.2)
Neuroptera	0.00 (0.0)	0.10 (0.1)	0.00 (0.0)	0.40 (0.2)
Anthocoridae	0.01 (0.1)	1.00 (0.3)	0.10 (0.1)	3.70 (0.6)
Nabidae	0.00 (0.0)	0.40 (0.2)	0.00 (0.0)	0.50 (0.2)

that may have attracted more adult *E. fabae* to the alfalfa fields. Adult *E. fabae* adults colonized alfalfa regrowth about 1 wk after harvest (DeGooyer et al. 1998b, this study), which may contribute to higher numbers of *E. fabae* and possibly more generations. However, this may not be as significant during the second growth of alfalfa due to high nymphal mortality (70% in 1999 and 49% in 2000).

This study offers further insight to the population dynamics of *E. fabae* and predatory species in alfalfa. Several predatory species occur simultaneously with *E. fabae* in alfalfa including *O. insidiosus*, nabids, neuropterans, and coccinellids. We found their numbers to be positively correlated with those of *E. fabae* once in 1999 and many times in 2000 (Table 2). These data show that these predators may have an effect on the percent mortality of *E. fabae* (especially the younger instars) in alfalfa fields. While some pest management programs discount the impact that natural enemies have on maintaining lower populations of pest species, such as *E. fabae*, we believe that collectively these natural enemies have an impact on *E. fabae* populations.

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