CHANGES IN ABUNDANCE OF NATIVE AND ADVENTIVE COCCINELLIDAE (COLEOPTERA) IN ALFALFA FIELDS, IN NORTHERN NEW JERSEY (1993-2004) AND DELAWARE (1999-2004), U.S.A.[1]

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ABSTRACT: Weekly and biweekly sweep net collections were made near Blairstown, New Jersey, and Newark, Delaware (both in the U.S.A.), for 12 and 6 consecutive years, respectively. At Blairstown, only one non-native coccinellid [*Coccinella septempunctata* (L.)] was common when this research was started in 1993, one [*Propylea quatuordecimpunctata* (L.)] had recently appeared, and two others [*Harmonia axyridis* (Pallas), *Hippodamia variegata* (Goeze)] were detected later during the 12-year study. All of these four species were adventive, having established themselves through commerce, three species at inland ports, and one near a coastal seaport. The most numerous adult lady beetles at both locations were two native species, *Coleomegilla maculata* (F.) and *Hippodamia parenthesis* (Say), and three adventive species, *P. quatuordecimpunctata, C. septempunctata,* and *H. axyridis.* Six species were occasionally swept at Blairstown - one adventive species (*H. variegata*) and five native species [*Cycloneda munda* (Say), *Coccinella transversoguttata* Mulsant, *C. trifasciata* Mulsant, *Hippodamia convergens* Guerin, and *Brachiacantha ursina* (F.)]. All but the last species were also found at Newark. Lady beetle numbers varied considerably from year to year at both locations, demonstrating that long-term (10 years or more) research is required to correctly identify population trends. No coccinellid species decreased during the 12-year study at Blairstown—indicating that the once-common *H. convergens* and several species of *Coccinella* had become rare before the study started in 1993, and before three of the four adventive lady beetles had become numerous. The previous establishment of exotic parasites, previously reported to have reduced pea aphid numbers, was likely indirectly responsible for decreasing coccinellid diversity in alfalfa. Competition by the adventive *C. septempunctata* may also have reduced some coccinellid species prior to 1993, but such data for the northeastern U.S.A. have not been published, to our knowledge.

KEY WORDS: Coccinellidae, changes in abundance, native, adventive, New Jersey, Delaware, U.S.A.

Most aphid-feeding coccinellids are large and brightly colored, unlike most other predators and parasites of aphids, so they have been recognized as important natural enemies of pest aphids for more than 150 years (Kirby and Spence 1860). Recently, interest in these beetles has increased, as several once-common native lady beetles have become rare (e.g. Wheeler and Hoebeke 1995, Ellis et al. 1999). Because several foreign coccinellids have become established in North America through commerce since the early 1970s, some of these new arrivals have been considered responsible for displacing native lady beetles in some areas (Turnock et al. 2003, Wheeler and Hoebeke 1995), but not in others (Wright and DeVries 2000). Many major pest insects have become established in North America via shipping, and although it is less well known, this also has happened with predators and parasites of insects (Sailer 1978).

Changes in natural enemy dominance usually evolve over many years, requiring long-term studies to determine the eventual outcome (Day 2005). The research reported here was conducted in alfalfa, a relatively stable perennial crop, at two locations, over 6- and 12-year periods. The principal prey of lady

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beetles in alfalfa is the pea aphid [*Acyrthosiphon pisum* (Harris)], an adventive insect that had become so abundant by the late 1800s that it was a serious pest of peas (Sanderson 1900), and often was a significant pest of alfalfa for many years in North America (Kindler et al., 1971). In contrast, soon after the establishment of two parasites introduced by the USDA, damaging pea aphid populations in northeastern alfalfa became rare (Angalet and Fuester 1977, Day unpublished).

When this study was begun in 1993, two non-native coccinellid species were already present in the Blairstown, NJ, study area (NW New Jersey). Only one species was numerous, however, because the second species had only recently arrived (1991). Two more foreign lady beetles reached this area in 1994 and 1997, so a total of four non-native species were present there during the final seven years of the study.

This paper describes both the changes and the lack of changes in the coccinellid fauna of the piedmont area of northwestern New Jersey during this 12-year period. For comparison, data for the final six years of observations (1999-2004) are included from alfalfa at a second location - Newark, DE, located on the coastal plain in northern Delaware, 100 miles to the south.

METHODS

Coccinellid adults were collected in alfalfa fields using a sweep net, near Blairstown, New Jersey (41º 00' N, 74º 54' W, elevation 160-290m), and at Newark, Delaware (39º 40' N, 75º 44' W, elev. 33m). Three alfalfa fields were sampled each week (May-July), or biweekly (August-October) for 12 years at Blairstown, and one alfalfa field was sampled each week (May-October) for six years at Newark. Each sweep sample consisted of 100 half-cycles. If a field had recently been mowed, another adjacent or nearby alfalfa field was sampled until the original field had regrown. When a field was rotated to another crop, which occurred at 5-8 year intervals, an adjacent or nearby alfalfa field was substituted. The Blairstown data are averages of three fields.

Contents of the sweep nets were emptied into a glass-topped sleeve cage, to prevent escape of the coccinellids as they were being aspirated into clear plastic vials for counting and identification to species. All lady beetle species were identified by the authors. Voucher specimens are in the reference collection at the USDA Newark laboratory.

To reduce bias at each location, all samples at Blairstown were collected by the first author, and all Newark sampling was done by the second author.

RESULTS AND DISCUSSION

Non-native species. Four non-native coccinellid species were collected in the sampled fields at both locations. The years and locations of first detection and the methods of entry of these species are summarized in Table 1. Although two of these species, *C. septempunctata* (L.) and *H. axyridis* (Pallas), had been previ-

ously released in North America, a careful comparison of published and quarantine records indicate (Gordon 1985, Table 2; Day et al., 1994, Table 2) that neither species became established where it had been released, and that all four species became established accidentally elsewhere, at or near seaports. These species are referred to in this paper as "adventive," to differentiate them from "introduced" species, because the latter term implies establishment by intentional importation and release.

Although *C. septempunctata* (*7-punctata,* hereafter) had reached both study areas in the 1970s, the other three species (Table 1) did not arrive until the 1990s. Two additional adventive coccinellids, *Coccinella undecimpunctata* L. (Wheeler and Hoebeke 1981) and *Harmonia quadripunctata* (Pontoppidan) (Hoebeke and Wheeler 1996), have been found elsewhere in the northeastern U.S., but were not detected at either of our study locations.

Major species in alfalfa. The most commonly collected coccinellid species over all years are listed in Table 2. It is interesting that the five most numerous species were the same at both locations, despite the latitude and elevation differences mentioned earlier. Because three of the five most numerous species at both locations are adventive, it is probable that additional lady beetle species (as reported for alfalfa by Angalet and Fuester 1977, Ellis et al., 1999, Wheeler and Hoebeke 1995, and others) were abundant before these new arrivals appeared, but unfortunately prior data from our two study locations have not been published, to our knowledge.

A bar graph (Fig. 1) of these data shows the numerical relationships more clearly. A native coccinellid, *Coleomegilla maculata* (F.), was the most abundant species at both locations—strikingly so at Newark, perhaps because of nearby field corn, which was absent from two of the three Blairstown farms. This beetle has long been a dominant species in corn (Forbes, 1883; Wright and DeVries 2000), probably because it can survive there on pollen and fungus spores, so is less dependent on availability of aphids (Forbes 1883). Moreover, Day (unpubl.) once observed an adult inside a corn kernel, eating the contents.

All of the three most numerous lady beetle species [*C. maculata, P. quatuordecimpunctata* (L.), *H. parenthesis* (Say)] (Fig.1) are small (mean length 4.8mm), about 1/3 smaller than the two less numerous species (*C. 7-punctata, H. axyridis*; mean length 7.0mm). Perhaps more small coccinellids can be produced from a given number of aphids than large coccinellids, contributing to the observed greater abundance of the smaller species.

Table 1. Adventive coccinellids: first detection dates and locations in eastern North America, the United States, and at the two study sites, 1968-1997.

	1st OBSERVED IN EASTERN NORTH AMERICA[a]			1st OBSERVED IN UNITED STATES			1st detected	
Species	**Year**	**Location**	**Reference**	**Year**	**Location**	**Reference**	**NJ**	**DE**
Coccinella 7-punctata (L.)	1973 1973	E. Rutherford[b], NJ Repentigny, Quebec	Angalet and Jacques 1975 Larochelle 1979	1973	E. Rutherford, NJ	A. and J. 1975	1975[c]	1977
Propylea 14-punctata (L.)	1968	Quebec City, Quebec	Chantel 1972	1984	Grande Isle, VT	Dysart 1988	1991	1997[e]
Harmonia axyridis (Pallas)	1988	near New Orleans, LA	Chapin and Brou 1991	1988	Abita Springs, LA	C. and B. 1991	1994	1993
Hippodamia variegata (Goeze)	1984	Montreal, Quebec	Gordon 1987	1992	NY and VT	Wheeler 1993	1997[d]	1994[e]

[a] All four species were first detected near major seaports. Four of the five locations (except East Rutherford, near Elizabeth, NJ) are inland ports. Two species had never been released in North America; the other two species had never been detected at any of their release locations, which were 80-360 km from their first recovery sites (details are in Day et al., 1994, Table 2).

[b] This is the closest town to the first detection site — some references refer to the "Hackensack meadowlands," a large marsh which extends through several New Jersey towns.

[c] This is the only adventive species that was numerous when observations were started in NJ in 1993.

[d] First recorded collection at Blairstown; this species was found in an adjacent county (Sussex) much earlier (1993).

[e] Apparently undocumented in the literature: these two dates are from unpublished USDA-Newark records.

Table 2. Major[a] coccinellid species collected in alfalfa at two locations

Locations	Species	$\bar{x}$ no. /100 sweeps	years present
Blairstown, NJ (1993-2004)	*Coleomegilla maculata* (F.)	1.27	12
	Propylea 14-punctata[b] **(L.)**	1.13	12
	Hippodamia parenthesis (Say)	0.51	12
	Coccinella 7-punctata[c] **(L.)**	0.30	12
	***Harmonia axyridis* (Pallas)**	0.22	11
Newark, DE (1999-2004)	*Coleomegilla maculata* (F.)	3.47	6
	Hippodamia parenthesis (Say)	0.83	6
	Propylea 14-punctata[b] **(L.)**	0.76	6
	***Harmonia axyridis* (Pallas)**	0.65	6
	Coccinella 7-punctata[c] **(L.)**	0.43	6

[a] Average number was more than 0.2 adults per 100-sweep sample, calculated over all collection dates and fields (Fig. 2), during the 1993-2004 (Blairstown), and 1999-2004 (Newark) growing seasons (May-October).
[b] The full species name is *quatuordecimpunctata.*
[c] The full species name is *septempunctata.*
The two abbreviated species names are used in this paper for brevity. Adventive species are in **bold** type.

Minor species in alfalfa. Six to seven additional coccinellid species (Table 3) were usually present in small numbers, during the 6- and 12-year observation periods. *H. convergens* Guerin, an abundant native species in alfalfa in some locations (Elliott et al., 1996, Turnock et al., 2003), was never numerous at Blairstown or Newark, nor was *H. variegata* (Goeze), an adventive species. Details on other seldom-collected species are also in Table 3. If any of the native coccinellids had been reduced by the arrival of adventive lady beetles at Blairstown prior to the initiation of this study in 1993, only *C. 7-punctata* could have been responsible, because other adventive species were not yet numerous, or had not yet become established (Table 1).

Changes in coccinellid species following arrival of adventive lady beetles. Because *C. 7-punctata* was first detected at Blairstown 16 years before this study was started, and three other coccinellids arrived two years prior to four years after this study began, we recognized that it would be difficult to determine the causes of all changes that might be observed, and their significance. We also recognized that the six years of data from Newark, while useful for comparisons to Blairstown, are insufficient to detect changes in abundance of coccinellids, which vary considerably from year to year (Wheeler 2003). "Before-after" comparisons were therefore only made for Blairstown, comparing two, five-year time periods—before most adventive coccinellids were abundant (1993-1997), and

after (2000-2004). Figure 2 compares "before" to "after" abundances for both native and adventive lady beetles. There was an unexpected increase in the total number of native coccinellids (2A), nearly all of which was an increase in *C. maculata,* but this change was not statistically significant. Similarly, there was an increase in the total number of all adventive lady beetles (also not statistically significant), that was nearly entirely composed of a large increase in *P. quatuordecimpunctata* (*P. 14-punctata,* hereafter) (2B, which was significant at the 1% level).

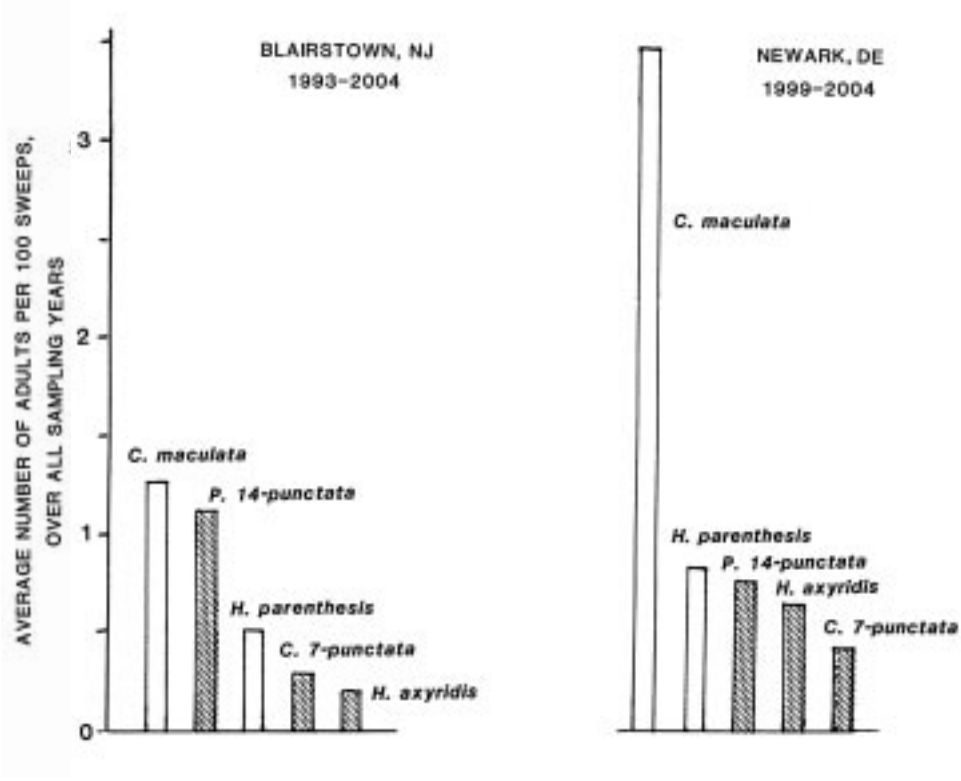

Figure 1. Average abundance of the 5 major coccinellid species in alfalfa at 2 locations, over all years. Shaded bars = adventive species.

Table 3. Minor[a] coccinellid species collected in alfalfa at two locations

Locations	Species	spp.	$\bar{x}$ no. /100 sweeps	Years
Blairstown, NJ (1993-2004)	*Hippodamia s*pp.[b]	2	0.091	8, 12
	Cycloneda munda (Say)	1	0.037	12
	Brachiacantha ursina (F.)	1	0.023	12
	Coccinella spp.[c]	3/7	0.007	12
Newark, DE (1999-2004)	*Hippodamia* spp.[b]	2	0.343[d]	6
	Cycloneda munda (Say)	1	0.023	6
	Coccinella spp.[c]	3	0.000	6
		6		

[a] "Minor" lady beetle species were, on average, much less numerous than the "major" five species in Table 2.

[b] Includes ***H. variegata* (Goeze)** (an adventive species present for 8 years at Blairstown and all 6 years at Newark) and *H. convergens* Guerin, a native species that was uncommon at both locations.

[c] Includes *C. transversoguttata* Mulsant, *C. 9-notata* Herbst, and *C. trifasciata* Mulsant. The once-common ***C. 11-punctata* (L.)** was not detected at either location.

[d] Listed as "minor" because this genus was abundant in only one year (2002), and at only one of the two locations. Adventive species are in **bold** type.

It is important to note that only one (*P. 14-punctata*) of the four adventive coccinellid species became more numerous between these two time periods (Fig. 2), while the other three immigrant species remained at low levels. This included *C. 7-punctata,* which had become the dominant lady beetle in Manitoba alfalfa by 1992 (Turnock et al., 2003), in S. Dakota alfalfa by 1988-1992 (Elliott et al., 1996), and at its initial New Jersey establishment locale in the 1970s (Angalet et al., 1979). However, it was a minor coccinellid species in Nebraska alfalfa in 1992-1995 (Wright and DeVries 2000). These major differences in coccinellid species rankings within the same crop grown in widely separated areas indicate that the eventual importance of "new" coccinellid species, whether introduced intentionally or accidentally, is not predictable. Moreover, the outcomes in alfalfa are not necessarily the same as in other crops, such as apple trees (Brown and Miller 1998) and corn (Elliott et al., 1996).

Possible causes of changes in abundance of some coccinellid species. Because three of the five most numerous lady beetle species were adventive species (Fig. 1), other native coccinellids may have been more numerous prior to the arrival of the invading species. The "competitive displacement" that apparently caused the scarcity of many native lady beetles [including *Coccinella*

novemnotata Herbst (*C. 9-notata,* hereafter), *C. transversoguttata* Mulsant, *C. trifasciata* Mulsant, *Hippodamia convergens,* and *H. tredecimpunctata*] has been widely discussed as a possible result of the establishment of *C. 7-punctata* (e.g. Angalet and Fuester 1977, Brown and Miller 1988, Ellis et al., 1999, Elliott et al., 1996, Stephens 2002a, Wheeler and Hoebecke 1995, Wheeler and Stoops 1996). However, it is well to keep in mind the following points: "correlation does not prove causation" (a similar caution was made by Wheeler and Hoebeke 1995), *C. 7-punctata* was not a dominant species (it was 4th or 5th in numbers) in the present study, and native coccinellids were first and second (Newark) to first and third (Blairstown) in abundance (Fig. 1) in this study.

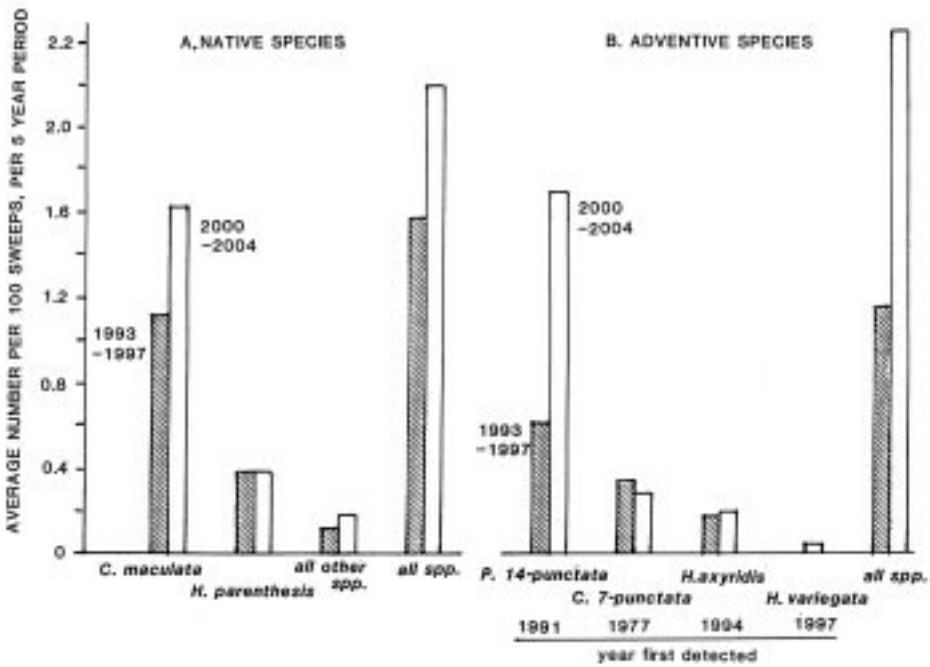

Figure 2. Comparative abundance of native and adventive coccinellid species during two 5-year periods (1993-1997 vs. 2000-2004), in northern New Jersey. The only statistically – significant change was the increase in *P. 14-punctata* (ANOVA: F=16.9; d.f. 8, 1; P=0.01).

An additional complicating factor may be the large reductions in pea aphid numbers that occurred in the 1960s and 1970s following the USDA biocontrol program which resulted in the widespread establishment in the U.S. of the parasites *Aphidius smithi* Sharma and Subba Rao and *A. ervi* Haliday (Angalet and Fuester 1977). The resulting lower food supply (much reduced pea aphid populations in alfalfa and pea crops over 21 years: Angalet and Fuester 1977) would be expected to reduce coccinellid numbers (fewer aphids was one of the hypotheses also advanced by Wheeler and Hoebeke 1995), and could affect some species more than others, but to our knowledge these effects have not been documented by published field studies. We were able to find one example of unpublished data: during the period when the introduced *Aphidius* parasites of the pea aphid were spreading rapidly over the United States and Canada (Angalet and Fuester 1977), G. W. Angalet (USDA–Moorestown, New Jersey) collected 137 samples of coccinellids in alfalfa fields in several states, during 1966-1969. A recent compilation of his data by Stephens (2002b) showed that *Coccinella 9-notata* had become scarce (0-1% of all lady beetles) by 1968-1969. Because this occurred 4-5 years before *C. 7-punctata* was first detected (1973) in a small area in coastal New Jersey, competition by the latter adventive coccinellid could not have been involved.

Changes in the total number of coccinellids over time. When the total of all species per sample, each year, was tabulated (Fig. 3), several interesting patterns emerged. First, the year to year variations in beetle numbers during the 12-year period at Blairstown confirms Wheeler's (2003) statement about the considerable amount of variability from one year to another. And, the usually alternating "high-low" fluctuations suggest that, when very numerous, these beetles depressed the numbers of their aphid prey, so the aphids were usually much less abundant in the next year, which in turn reduced the coccinellids.

The third pattern was the unexpected gradual increase in total lady beetle numbers from 1993 to 2002, which was shown above to have been due to increases in two small coccinellid species (Fig. 2) – one native (*C. maculata*) and one adventive (*P. 14-punctata*).

Finally, because the high numbers of beetles in 2002 in northern New Jersey (Blairstown) also occurred in Delaware (Newark) (Fig. 3), and the population fluctuations from 1997-2004 were surprisingly similar at both locations, there appears to be an as yet unknown regional influence on aphid and/or lady beetle numbers – perhaps due to weather effects, directly on these insects or indirectly through the host plant.

Life cycle observations. When the total number of each of the five major coccinellid species over all years at Blairstown was plotted for each month (Fig. 4), it was evident that only *H. axyridis* appeared to produce two generations during the year, as evidenced by two population peaks. This graph also suggests temporal differences – *C. 7-punctata* and *P. 14-punctata* were most numerous in early summer, while *C. maculata* appeared in late summer, possibly after its aphid prey had declined on corn.

Significant Findings. During this 12-year field study, only five coccinellid species (two native and three adventive) were abundant in alfalfa. One native and one adventive species became more numerous during the study; both are smaller than the other three species. Although *Coccinella 7-punctata* was the only adventive lady beetle that had been present for many years before these observations were started, it was not one of the dominant species before or after the other three adventive coccinellids became well established. Five species of lady beetles previously recorded from alfalfa in other areas were absent or rarely sampled in northwestern New Jersey alfalfa, even in the early 1990s when three of the four adventive species were uncommon or absent. These findings indicate that long-term (over a decade) field studies, in the same crop and area, are necessary to document and understand the changes that occur.

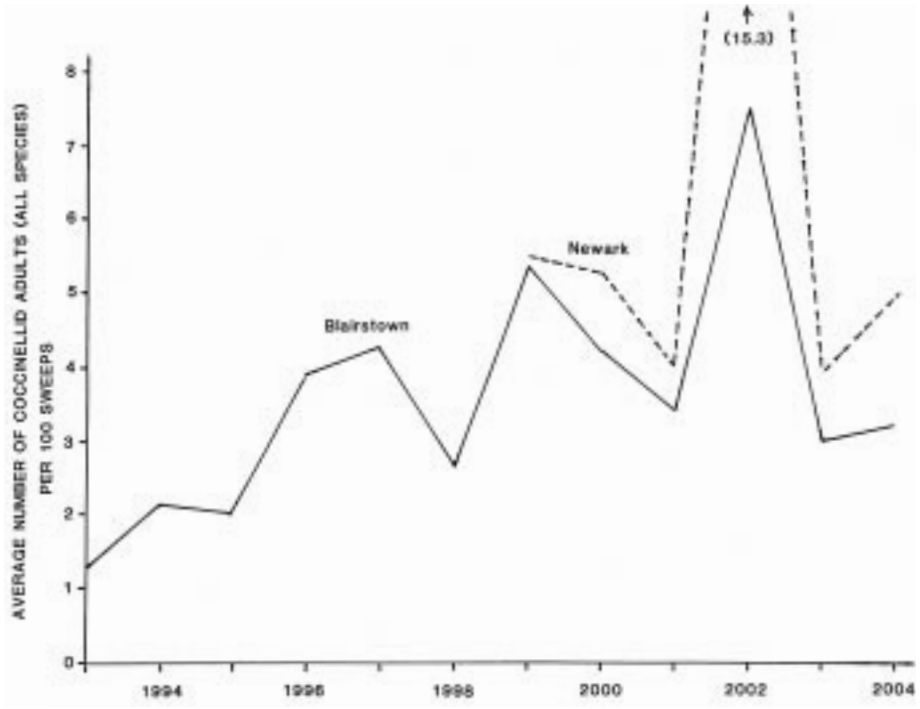

Figure 3. Total number of coccinellid adults (all species) swept in alfalfa, at Blairstown, NJ (1993-2004) and Newark, DE (1999-2004).

Unanswered questions. It is unclear whether the five native coccinellid species that were seldom collected during this study had been previously reduced by competition with *Coccinella 7-punctata,* or by the reduction in pea aphids which followed the establishment of two introduced *Aphidius* parasites. The causes of the similar and nearly cyclic fluctuations of all coccinellid species at both study locations are also unknown.

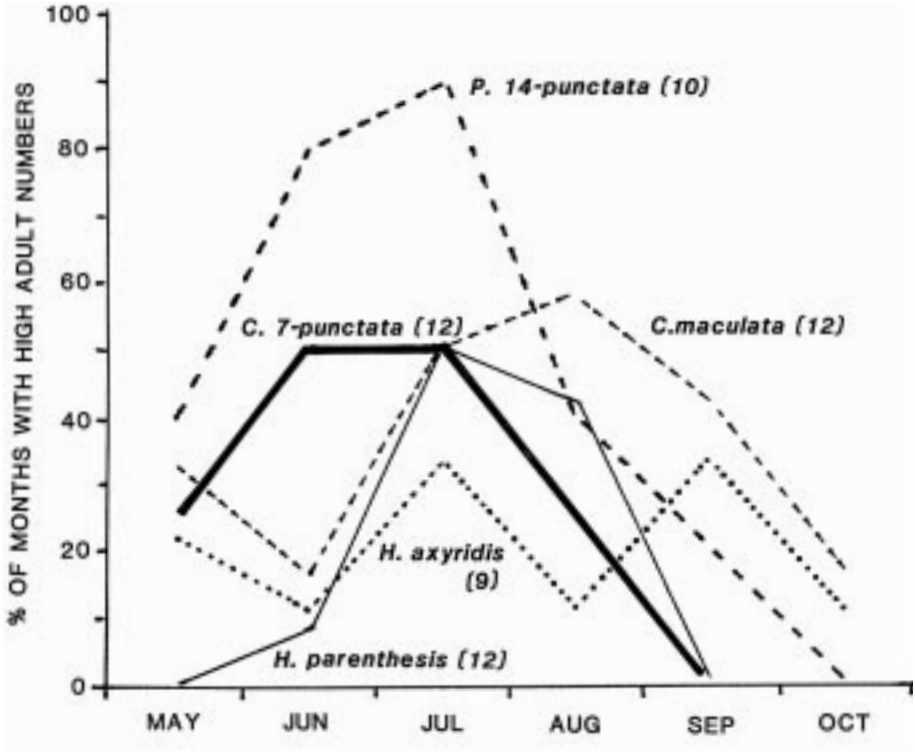

Figure 4. Estimated number of generations: percentages of months with high numbers of coccinellid adults at Blairstown, NJ 1993-2004. The number of years with data sufficient to include are in parentheses.

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