Arrival, Establishment, and Habitat Use of the Multicolored Asian Lady Beetle (Coleoptera: Coccinellidae) in a Michigan Landscape

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ABSTRACT A monitoring system established within an array of cultivated and uncultivated habitats was used to characterize the first 5 yr of establishment of the exotic multicolored Asian lady beetle, *Harmonia axyridis* (Pallas), in an agricultural landscape of southwestern Michigan. Population trends over time were summarized for 11 species of resident coccinellids before and after the arrival of *H. axyridis*. In addition, annual population increase, habitat utilization patterns, and within-season population fluctuation for *H. axyridis* were analyzed. *H. axyridis* became a dominant coccinellid species in the landscape 4 yr after its arrival. Adults of this species were found in all habitats monitored, including early secondary succession, poplar plantation, alfalfa, soybean, corn, and winter wheat. Significant population peaks were observed early and late in the season, depending on the habitat. Resident species that appear affected by the establishment of *H. axyridis* are *Brachiacantha ursina* (F.), *Cycloneda munda* (Say), and *Chilocorus stigma* (Say). However, to attribute the decline on the numbers of those species to *H. axyridis* will require further assessment.

KEY WORDS *Harmonia axyridis*, environmental impact, biological control, exotic natural enemies

PUBLIC CONCERN REGARDING food safety and environmental integrity are changing how pest management is practiced in the United States. The indiscriminant use of pesticides that occurred during 1950-1960 has been replaced with ecological pest management systems (National Research Council 1996), a strategy that includes the use of biological control agents to promote natural regulation of pests. Typically, beneficial organisms from different parts of the world are imported into the United States, evaluated for biological control, and established in areas afflicted by pest outbreaks (Van den Bosch et al. 1982). Some of the introduced biological agents have successfully regulated pest populations (Caltagirone 1981, Haynes and Gage 1981). In recent years, however, there has been an increasing concern about the environmental impact of such introductions (Howarth 1991, Miller and Aplet 1993, Lockwood 1996, Thomas and Willis 1998). Exotic species can attack nontarget organisms, or compete with and eventually displace native beneficial fauna (Wheeler and Hoebeke 1995, Elliott et al. 1996). This likelihood increases as introduced species are able to disperse throughout the country. For example, the lady beetle *Coccinella septempunctata* (L.) was introduced several times into the United States after the 1950s and became established in the northeastern United States (Schaefer et al. 1987). Although this species may play an important role in the natural regulation of pests, evidence suggests that it is causing the extinction of native species of coccinellids (Wheeler and Hoebeke 1995, Elliott et al. 1996). More recently, the multicolored Asian lady beetle, *Harmonia axyridis* (Pallas), was 1st detected in the United States in 1988 (Chapin and Brou 1991). Although this exotic species was introduced several times into the country (Gordon 1985), it appears that its establishment should be attributed to an accidental introduction with commerce (Day et al. 1994). This species has received public attention because of its habit of aggregating in human dwellings in fall (Tedders and Schaefer 1994). However, evidence that this species is having an important impact on the species assemblages of resident coccinellids (LaMana and Miller 1996, Wheeler and Stoops 1996, Brown and Miller 1998) supports the recommendation of several investigators to monitor closely the establishment and spread of this organism (Wheeler and Hoebeke 1995, Coderre et al. 1995, Hoebeke and Wheeler 1996, McCorquodale 1998).

In 1989, a monitoring system for assessing habitat use patterns of insect predators in a row-crop agricultural landscape was established at the Kellogg Biological Station as part of the Long-term Ecological Research program. This system allowed us to detect the arrival of *H. axyridis* and monitor the establishment of this species in a complex agricultural landscape in southwestern Michigan. The results suggest that *H. axyridis* could play a dominant role among the predatory coccinellids currently present in these agricultural landscapes. The purpose of this article is to present results of the population trends of 11 species of resident coccinellids before and after the arrival of *H. axyridis*. In addition, we have documented the first 5 yr of population increase and habitat preferences of this exotic species. We believe these observations will set a framework for further studies to evaluate the

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potential impact of *H. axyridis* on the resident fauna of natural enemies in North America.

Materials and Methods

Study Area. This study was conducted at the Kellogg Biological Station, MI, from 1989 to 1998 as part of the Long-term Ecological Research program. The experimental design consisted of 7 treatments—1 early secondary succession, 2 perennial biomass plantations (alfalfa and poplar), and 4 agronomic treatments. All treatments were replicated 6 times using 1-ha plots as experimental units. Early secondary succession plots were tilled in 1989 and were left undisturbed for 8 yr. In 1997, before the growing season, young trees were cut and removed from the plots and the rest of the vegetation was burned to suppress woody seedlings. In another treatment, alfalfa, *Medicago sativa* L., was planted in 1989, and after a 5-yr cycle, a new stand of alfalfa was replanted in 1994. Insecticides were applied to alfalfa in 1990, 1991, 1994, and 1996 against the potato leafhopper, *Empoasca fabae* (Harris). In the perennial woody treatment, poplar, *Populus x euramericana)*, tree cuttings (15 cm high) were planted in spring of 1989, and red fescue, *Festuca rubra* L., was seeded as cover crop in 1990. Poplar plots remained undisturbed by management practices for the rest of the study. The 4 agronomic treatments were rotations of corn-soybean-winter wheat under the following conditions: (1) high chemical input with conventional tillage, (2) high chemical input with no tillage, (3) low chemical input with conventional tillage, and (4) zero chemical input with conventional tillage. Because *H. axyridis* was detected in 1994,the rotation scheme we followed was: soybean, *Glycine max* L., in 1994; winter wheat, *Triticum aestivum* L., in 1995; corn, *Zea mays* L., in 1996; soybean in 1997, and winter wheat in 1998. In the low- and zero-input treatments, cultivations and cover crops were used instead of herbicides and fertilizers. No insecticides were needed in these agronomic treatments during the course of the study.

Sampling Method. During May to August of each growing season since 1989, insects were sampled using double-sided, yellow cardboard sticky traps (22.5 by 14.0 cm) attached 1.2 m above the ground to a metal trap as described by Maredia et al. (1992a). Five traps per plot were placed at permanent geopositioned locations and sticky cardboards were replaced every 2nd wk. Coccinellid adults caught on traps were identified, counted, recorded, and removed every week.

Population Trends of Coccinellid Species. We compared the population trends of individual species of coccinellids before and after the arrival of *H. axyridis* to assess the potential for interaction between *H. axyridis* and resident coccinellids. Average seasonal trap captures (210 traps × 12 wk) for all 7 treatments in each experimental block were pooled to constitute 1 landscape sample (6 landscape samples total). Each sample was log transformed [$\log_{10}(x+1)$] and linear regression analyses were conducted to assess the population trend of each coccinellid species before and after the 1st observations of *H. axyridis* (1994). An analysis of variance (ANOVA) tested the statistical significance of the regression and hence the significance of the slope (β) in the linear regression equation abundance = a+β(year) to determine whether the population trend increased (>0), decreased (<0), or remained without change (=0) over time (Zar 1984).

***Harmonia axyridis* Population Establishment.** We assessed the degree of establishment of *H. axyridis* by estimating the increase in yearly population abundance and determining the habitats preferred in each year. Average trap capture per season for each treatment was computed and normalized using a $\sqrt{X + 0.001}$ transformation. ANOVA and the Tukey test were used to test for statistically significant differences between treatments within each year to evaluate habitat preferences. We also tested for statistically significant differences in the same treatment across different years to assess population increase over time.

***Harmonia axyridis* Temporal Dynamics Within a Season.** We estimated the seasonal population fluctuation of *H. axyridis* adults within each treatment. For each treatment, trap captures from all 4 yr were grouped in intervals of 200 DD (10°C). Average trap captures per 200-DD interval were computed and normalized before statistical analysis using a $\sqrt{X + 0.001}$ transformation. ANOVA and the Tukey test were used to test for statistically significant differences between degree-day intervals within each treatment.

Results

Coccinellid Population Trend. Coccinellid species typical of early successional and arboreal habitats showed a decline in abundance after the arrival of *H. axyridis* (Table 1). That was true for *Brachiacantha ursina* (F.) (Fig. 1E) and *Cycloneda munda* (Say) (Fig. 1H). An analysis of the *Chilocorus stigma* (Say) population trend 5 yr after the arrival of *H. axyridis* showed an increase (Table 1). However, the population patterns of *C. stigma* depicted in Fig. 1B illustrates that its population is significantly declining ($F = 38.7$; df = 1, 16; $P < 0.001$) after the 3rd year of *H. axyridis* arrival. *Adalia bipunctata* (L.) (Fig. 1I), also an arboreal species, showed significant population decline before and after the arrival of *H. axyridis*. The coccinellid species *Coleomegilla maculata lengi* Timberlake (Fig. 1F), *Hippodamia convergens* Guérin-Méneville (Fig. 1K), and *Hyperaspis undulata* (Say) (Fig. 1J) showed a population decline before the arrival of *H. axyridis*, but later they maintained a stable population. Two other species—*Hippodamia parenthesis* (Say) (Fig. 1G) and *Coccinella trifasciata perplexa* Mulsant (Fig. 1L)—remained stable during the entire length of the study. Only 1 species, *Hippodamia glacialis glacialis* (F.) (Fig. 1D), showed a significant increase in its population after the arrival of *H. axyridis*. The exotic species *Coccinella septempunctata* (L.) (Fig. 1C) exhibited a declining population before the arrival *H. axyridis*. However, the population patterns of *C. septempuncatata* appear to fluctuate independently from the presence of *H. axyridis* with peaks in

Table 1. Regression statistics for the model [$\log_{10}$(adult abundance) = $\alpha + \beta$ (year)] used to assess population trends (increase or decrease) of 12 species of coccinellids before (1989–1993) and after (1994–1998) arrival of *Harmonia axyridis* in southwestern Michigan

Species name	Before *H. axyridis* arrival			After *H. axyridis* arrival		
	R^2	β (slope)	F	R^2	β (slope)	F
Harmonia axyridis	—	—	—	0.87	0.24***	190.72
Coccinella septempunctata	0.26	−0.15**	10.95	0.25	0.00	0.73
Brachiacantha ursina	0.42	0.30***	0.57	0.45	−0.18***	22.82
Hippodamia parenthesis	0.03	0.00	1.06	0.01	0.00	0.28
Adalia bipunctata	0.57	−0.23***	36.36	0.60	−0.16***	42.71
Hippodamia convergens	0.39	−0.18***	17.61	0.03	0.00	0.82
Chilocorus stigma	0.00	0.00	0.04	0.14	0.11*	4.63
Hippodamia glacialis glacialis	—	—	—	0.50	0.19***	27.78
Coleomegilla maculata lengi	0.15	−0.07*	4.90	0.07	0.00	2.00
Cycloneda munda	0.05	0.0	1.37	0.29	−0.12**	11.36
Hyperaspis undulata	0.22	−0.15**	7.68	0.02	0.00	0.57
Coccinella trifasciata perplexa	0.14	0.00	4.56	0.04	0.00	1.04

*, ≤ 0.05; **, ≤ 0.01; ***, ≤ 0.001; df = 1, 28 for all values.

abundance occurring every 5 or 6 yr. The species *Anatis labiculata* (Say) and *Hippodamia tredecimpunctata tibialis* (Say) were collected during the course of the study but were not considered in the analysis because of the low numbers of insects captured (19 and 7 adults, respectively).

***Harmonia axyridis* Establishment and Population Increase.** H. axyridis was first detected in the last week of July 1994 and accounted for 2.8% of the coccinellids captured that year. In 1995 and 1996 *H. axyridis* numbers accounted for 5.6 and 13.6%, respectively, of the coccinellids captured. In 1997, *H. axyridis* became the dominant species of the coccinellids measured in this study, accounting for 32.3% of the coccinellids captured. In 1998, *H axyridis,* representing 26.9% of the total coccinellids captured, was displaced from 1st place by *C. septempunctata.* This was caused by a rebound in the population of *C. septempunctata* (Fig. 1C). Yearly population increase by *H. axyridis* was significant in all treatments including high input-conventional tillage (F = 10.6; df = 4, 25; $P < 0.001$), high input-no tillage (F = 8.5; df = 4, 25; $P < 0.001$), low input-conventional tillage (F = 5.3; df = 4, 25; P = 0.003), zero input-conventional tillage (F = 9.6; df = 4, 25; $P < 0.001$), poplar (F = 37.8; df = 4, 25; $P < 0.001$), alfalfa (F = 24.4; df = 4, 25; $P < 0.001$), and secondary succession (F = 46.6; df = 4, 25; $P < 0.001$) (Fig. 2).

***Harmonia axyridis* Habitat Preferences.** Significant differences among treatments for *H. axyridis* abundance were found in 1994 (F = 5.8; df = 6, 35; $P < 0.001$), 1995 (F = 4.5; df = 6, 35; P = 0.002), and 1998 (F = 20.2; df = 6, 35; $P < 0.001$). In 1994, when *H. axyridis* arrived, it was more abundant in secondary succession (Fig. 2). In 1995, significant differences were found among the zero-input wheat, poplar, alfalfa, and early secondary succession study sites. During the following 2 yr (1996 and 1997), no significant differences were found between treatments. However, in 1998, *H. axyridis* showed strong preferences for secondary succession, poplar, and alfalfa habitats (Fig 2).

***Harmonia axyridis* Seasonal Dynamics.** Significant patterns of temporal abundance of *H. axyridis* were observed in secondary succession, zero input-conventional tillage, alfalfa, and poplar. In poplar, a population peak of this exotic species occurred early in the season (400 DD) with a gradual decline thereafter (Fig. 3). In alfalfa, 2 population peaks were observed early and late in the season (200 and 1,400 DD). In secondary succession the peak of this coccinellid occurred late in the season (1,200 DD). In the zero input-conventional tillage treatment, a significant peak was observed early in the season (Fig. 4). In the remainder of the agronomic treatments, population levels of *H. axyridis* remained constant during most of the season (Fig. 4).

Discussion

H. axyridis is the 2nd exotic species of coccinellids that immigrated into and became established in Michigan in recent years. Its arrival in southern Michigan, as measured by our monitoring system, coincided with its detection in the Montreal region of Canada (Coderre et al. 1995). The landscape in southern Michigan is characterized by the presence of agricultural and old fields interspersed with deciduous and conifer plantations (Burbank et al. 1992). *H. axyridis,* a widely polyphagous species (Hodek 1993, Coderre et al. 1995), seems well adapted to exploit the resources provided by this mixture of habitats. *H. axyridis* is primarily an arboreal species that inhabits orchards and forest stands as well as old-field vegetation (Chapin and Brou 1991, Tedders and Schaefer 1994, LaMana and Miller 1996, Brown and Miller 1998). Our observations in the poplar stands and in early secondary succession habitats are consistent with the literature. This species also can be present in agricultural habitats such as forage crops (LaMana and Miller 1996, Buntin and Bouton 1997), corn, soybean, and wheat (this study). This broad habitat use by *H. axyridis* can allow this species to maintain high populations in a mixed agricultural-forest landscape, enabling it to play a dominant role in the community of beneficial coccinellids in the region. In fact, *H. axyridis* has become a dominant coccinellid in this southern Michigan landscape only 4 yr after its detection. Previous to

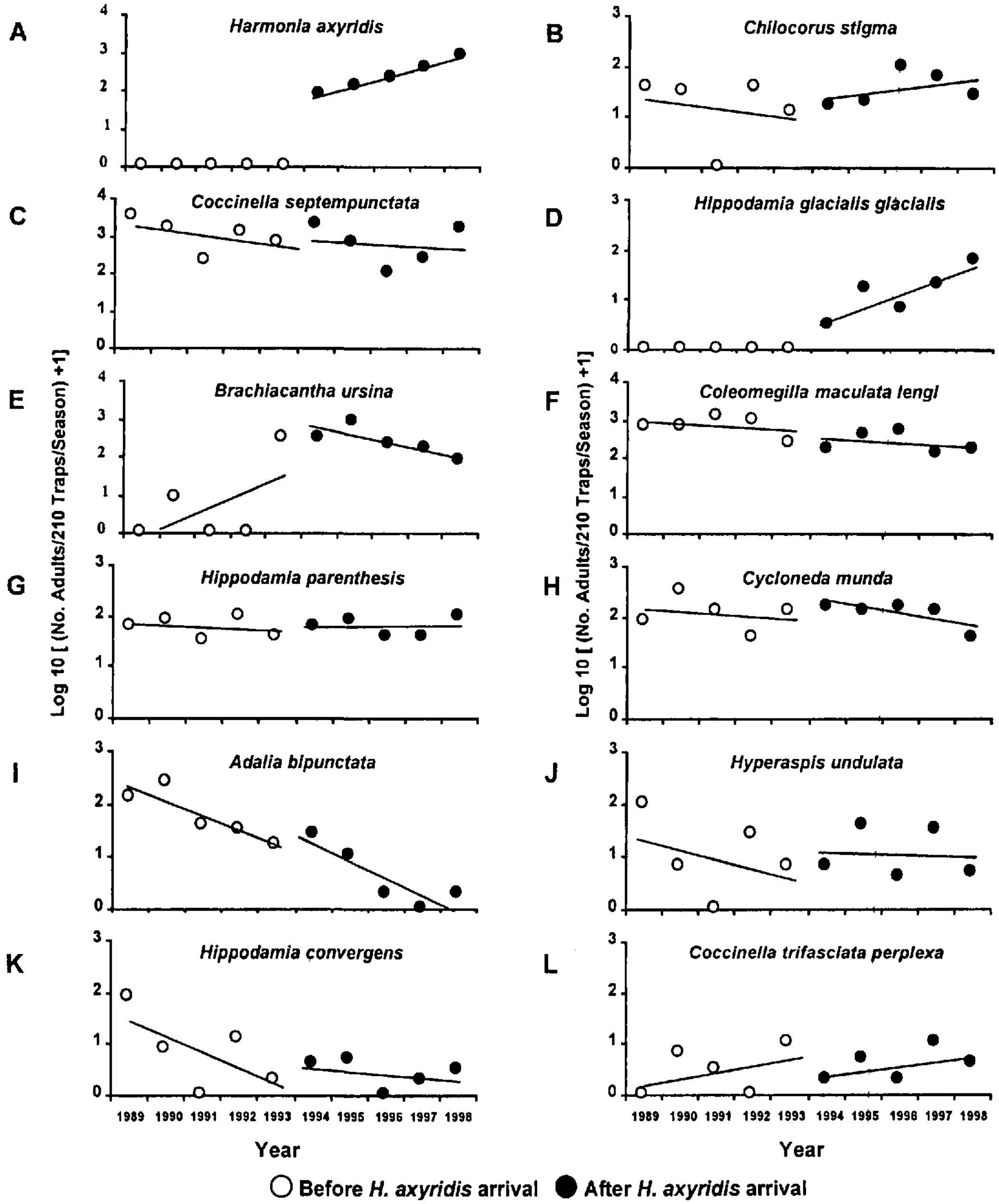

Fig. 1. Annual population trends of twelve species of coccinellids before and after the arrival of *H. axyridis* in an agricultural landscape at the Kellogg Biological Station Hickory Corners, MI.

its arrival, the dominant coccinellids in the agricultural landscape were another exotic species, *C. septempunctata*, and the native *C. maculata lengi*. During the summer, both *C. septempunctata* and *C. maculata lengi* inhabit primarily wheat, alfalfa, and corn, but also forage on some herbaceous plants in old-field habitats (Honek 1985, Maredia et al. 1992b, Ostrom et al. 1997). Neither of these 2 species forage in arboreal habitats during the summer. Coccinellid species that foraged in deciduous trees in the Michigan landscape before the arrival of *H. axyridis* include *B. ursina*, *C. stigma*, and *C. munda* (Maredia et al. 1992b), although *C. munda* also can be found in agricultural crops such as corn, wheat, and alfalfa (Colunga-Garcia et al. 1997). This situation indicates that most resident species of coccinellids occupy only part of the habitats that *H. axyridis* can potentially use. Whether *H. axyridis* will be able to outcompete resident species of coccinellids is an issue for further investigation. However, a decline in the population of the arboreal species *B.ursina*, *C.*

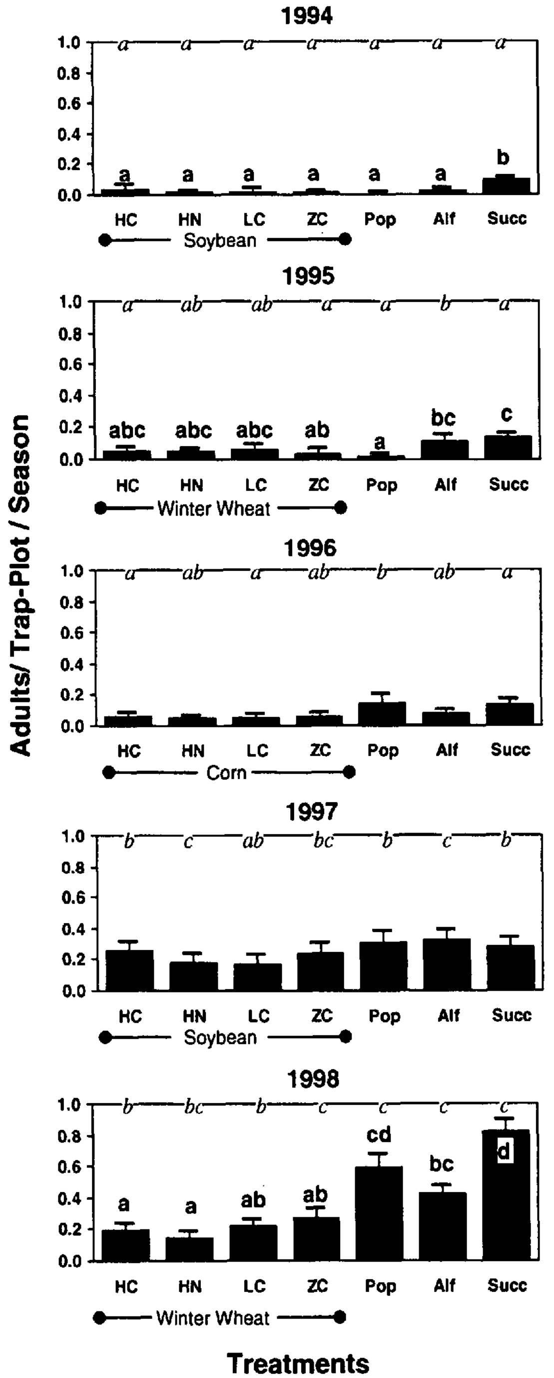

Fig. 2. Annual mean trap captures (±SE) of *H. axyridis* sampled using yellow sticky traps in poplar (Pop), alfalfa (Alf), early secondary succession (Succ), high fertilizer and herbicide input, conventional tillage (HC), high fertilizer and herbicide input, no tillage (HN), low fertilizer and herbicide input, conventional tillage (lethal concentration), and zero fertilizer and herbicide input, conventional tillage (ZC). Treatments within the same year followed by different letters (bold) are statistically different (Tukey test; $P \leq 0.05$; df = 6, 35 in each comparison). Same treatments across different years followed by different letters (italics) are statistically different (Tukey test; $P \leq 0.05$; df = 4, 25 in each comparison).

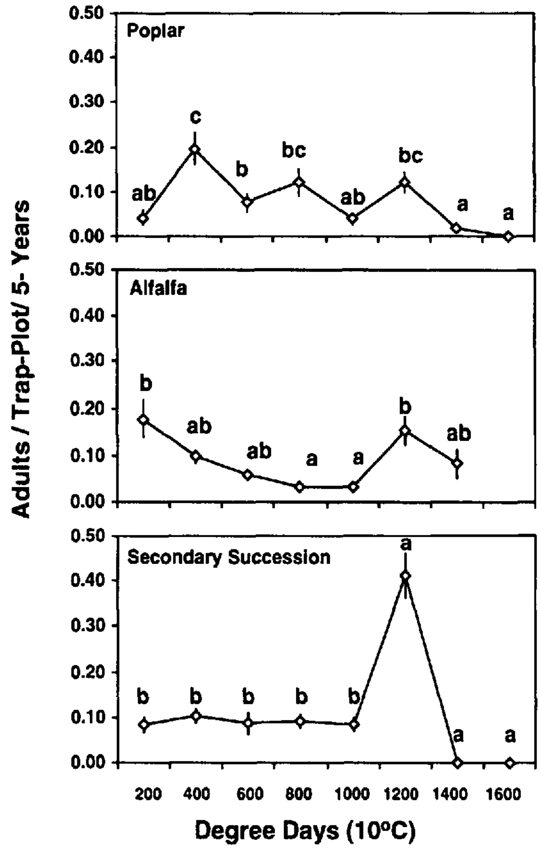

Fig. 3. Mean trap captures (±SE) of *H. axyridis* at 200 DD (10°C) intervals sampled using yellow sticky traps in perennial plantations (poplar and alfalfa) and early secondary succession. Time intervals followed by different letters are statistically different (Tukey test; $P \leq 0.05$; df = 7, 40 in each comparison).

munda, and *C. stigma* could be an indication that competitive displacement by *H. axyridis* already may be occurring.

An additional important consideration is the potential outcome that the interaction between the 2 exotic species *C. septempunctata* and *H. axyridis* may have on native populations of coccinellids. *C. septempunctata* is an aggressive species able to impact local populations of coccinellids (Wheeler and Hoebeke 1995, Elliott et al. 1996). Although we do not have records on coccinellid abundance before the appearance of *C. septempuncatta* in Michigan, there is a high possibility that this species caused the decline in the population levels of *Adalia bipunctata* and *Hippodamia convergens* observed in this study (Wheeler and Hoebeke 1995, Elliott et al. 1996). *C. septempunctata* appears to be at a disadvantage when competing against *H. axyridis* (Hironori and Katsuhiro 1997). Although this seem to be the case in arboreal habitats (Brown and Miller 1998), that may not be true for crop habitats (Buntin and Bouton 1997). Moreover, populations of *H. axyridis* in Michigan peak early or late in the season, depending on the habitat (this study), whereas popula-

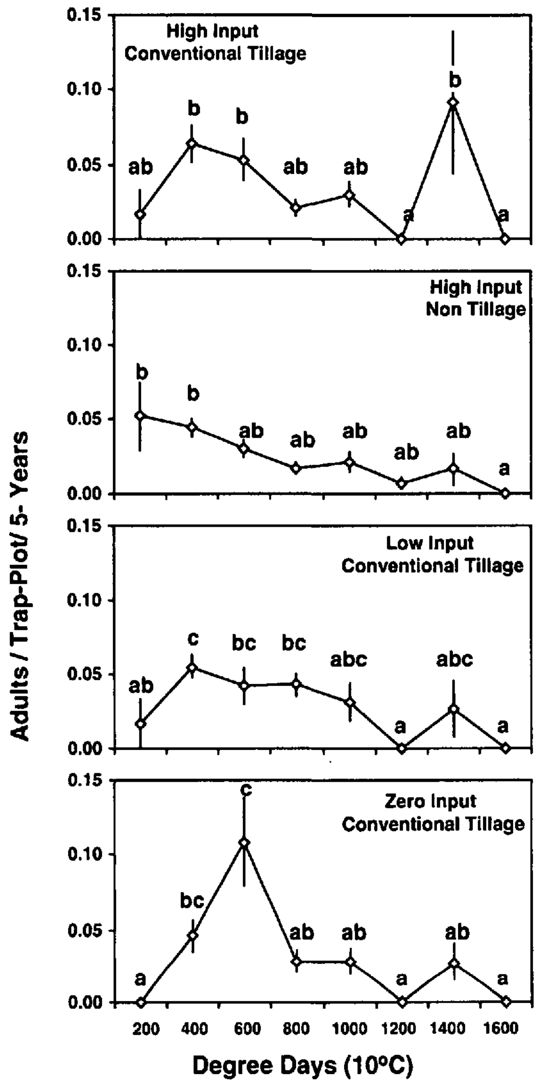

Fig. 4. Mean trap captures (±SE) (n = 6) of *Harmonia axyridis* at 200 DD (10°C) intervals sampled using yellow sticky traps in a soybean-winter wheat-corn rotation under 4 different management practices (tillage and fertilizer-herbicide inputs). Time intervals followed by different letters are statistically different (Tukey test; $P \leq 0.05$; df = 7, 40 in each comparison).

tions of *C. septempunctata* peak at midseason (Maredia et al. 1992c). Both differences in habitat preference and time of occurrence may contribute to avoid competition between both exotic species in the mixed agricultural–forest landscapes of southwestern Michigan.

Currently, the potential environmental impact of *H. axyridis* in agricultural habitats does not seem to be of major concern, perhaps because of its mainly arboreal habits. However, if *H. axyridis* dominates arboreal habitats and *C. septempuncatata* and *H. axyridis* dominate crop habitats, the available niche for the rest of the resident species in this predator complex may be dramatically reduced (Elliott et al. 1996). We believe that this species has the potential to alter the community structure of predatory coccinellids in forest-agricultural landscapes. Also, we agree with other investigators that the impact of *H. axyridis* on resident beneficial fauna should be studied carefully. Because *H. axyridis* is a newcomer in many areas, this is a unique opportunity to gain important information useful in any overall assessment of the environmental impacts of introduced exotic beneficial insects on the native beneficial fauna in North America.

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