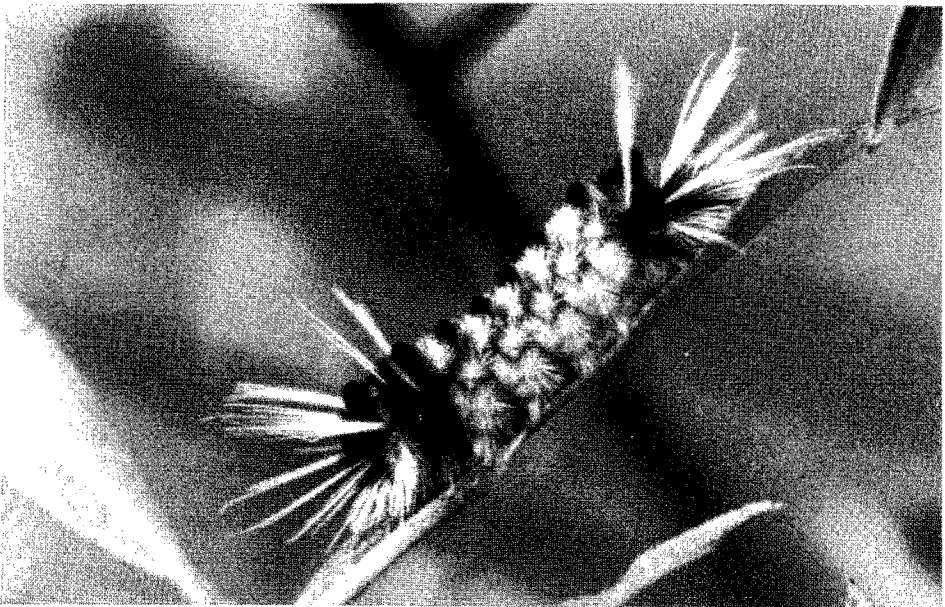


Vol. 25, No. 1

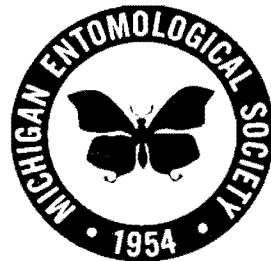
Spring 1992

THE
GREAT LAKES
ENTOMOLOGIST



PUBLISHED BY

THE MICHIGAN
ENTOMOLOGICAL
SOCIETY



APHIDOPHAGOUS COCCINELLIDS IN ALFALFA, SMALL GRAINS, AND
MAIZE IN EASTERN SOUTH DAKOTAR. W. Kieckhefer¹, N. C. Elliott^{1,2}, and D. A. Beck¹

ABSTRACT

In a 13-year study of aphidophagous coccinellids associated with alfalfa (*Medicago sativa*), maize (*Zea mays*), and small grain crops in eastern South Dakota, the following species were consistently associated with the crops: *Hippodamia convergens*, *H. tredecimpunctata tibialis*, *H. parenthesis*, *Colomegilla maculata lengi*, *Coccinella transversoguttata richardsoni*, *Cycloneda munda*, and *Adalia bipunctata*. All species except *A. bipunctata* were associated with each of the three crops, while *A. bipunctata* occurred only in maize. Relative abundances of each species varied among crops and among years. Although only seven species were associated with the crops, additional species were captured on sticky traps stationed adjacent to sampled fields. The species diversity of immature coccinellids did not differ among crops but did differ among years. The diversity of adults differed among crops and years. The site from which samples were taken had no influence on the diversity of immatures or adults. Species relative abundances in alfalfa and small grains were more similar to each other than they were to relative abundances in maize.

Species diversity of coccinellids may vary within and among plant communities depending on a variety of factors including microclimate, prey density, annual changes in species abundance, the timing and rate of migration and dispersal, and geographic locality (Honek 1986). Coccinellid species diversity generally tends to be greater in stable vegetation, such as trees and shrubs, than in ephemeral crops (Honek 1982). Certain species show a decided preference for specific types of vegetation. For example, *Adalia bipunctata* (L.) is arboreal (Hodek 1966). Other species such as *Hippodamia convergens* Guerin-Meneville are more cosmopolitan (Hodek 1966). The age structure of plant communities can influence species composition. Gagne and Martin (1968) found that coccinellid species composition varied in coniferous forests of different ages. The presence of particular aphid species in the vegetation may partially determine the species composition of adults and larvae; some aphid prey may be more suitable than others, or may actually be toxic to certain coccinellids (Blackman 1967).

We recently reported on the long-term trends in coccinellid populations in small grain, alfalfa (*Medicago sativa*), and maize (*Zea mays*) fields in eastern South Dakota (Elliott and Kieckhefer 1990a, 1990b, Kieckhefer and Elliott

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1990). In this paper we compare species composition, relative abundances, and diversity of adult and immature coccinellids in the three crops.

MATERIALS AND METHODS

Coccinellid populations were sampled from fields of alfalfa, spring small grains, and maize throughout the growing seasons of 1968-1985. From 1973-1985, one field of each crop was sampled during each year at the following locations: south of Brookings (Brookings Co.); near Castlewood (Hamlin Co.); and east of Clear Lake (Deuel Co.). The same sites were sampled at these locations each year. From 1968-1972 a single field of alfalfa, spring small grain, and maize were sampled at two locations: south of Centerville (Clay Co.) and near Castlewood (Hamlin Co.).

Predator populations in alfalfa and small grains were sampled by collecting six subsamples each consisting of 50 pendular sweeps (total of 300 sweeps) taken along random transects into the field from the field edge with a 38 cm diameter sweepnet. Insect collections were chloroformed in the net, transferred to containers, and taken to the laboratory where we counted and identified them to species by comparison with specimens in a reference collection. Sampling in maize was done by collecting in an aspirator all adults and larvae seen on plants during four 15-min (total 1 h) inspections along field rows selected at random. Coccinellids were anesthetized, and returned to the laboratory for identification to species. Sampling in all crops was done in the late-morning or early afternoon on sunny days, after the ambient temperature had reached at least 15°C, wind velocity was under 24 kph, and foliage was dry. Each site was sampled at approximately weekly intervals.

Sticky traps were used to capture flying coccinellids adjacent to the sampled alfalfa, small grain, and maize fields during the growing seasons of 1968-1972. At each site, three traps were spaced approximately 20 m apart in a line along the edge of each sampled field (total of 9 traps per site). Traps were constructed by mounting six cylinders (30.5 cm ht. by 15.2 cm diam.) at 30.5 cm intervals on a 3.8 cm diameter by 3.7 m ht. aluminum pole (beginning at 30.5 cm above the ground), and coating the white cylinders with Tanglefoot³ (The Tanglefoot Co., Grand Rapids, Michigan). The trap assembly was held upright by sleeving the pole over a steel stake driven into the ground. Coccinellids caught on the traps were removed twice each week and returned to the laboratory where they were identified to species. Cylinder surfaces were cleaned and coated with Tanglefoot every two weeks.

The Berg-Parker dominance index (Southwood 1978) was used to measure species diversity. The Berg-Parker index (D) is simply the relative abundance of the most common species in the sample,

$$D = N_1 / \sum N_i, \quad i=1, \dots, T,$$

where T is the total number of species in the sample.

The degree of similarity of species relative abundances in alfalfa, maize, and small grains was evaluated using Kendall's tau rank correlation coefficients [PROC CORR³ (SAS Institute 1985)] as described by Southwood (1978: 433). The data from which Kendall's tau coefficients were calculated were the ranks of the relative abundances of each species averaged across samples from a particular crop within a year. Only data for species that occurred in all three crops were used in calculating rank correlations.

Analysis of variance [Proc GLM³ (SAS Institute 1985)] was used to determine if species diversity differed among years, sites, or crops. Auto- and cross

correlation coefficients [PROC ARIMA³ (SAS Institute 1984)] were calculated to determine if species diversity was correlated among years and if diversity of immatures was related to that of adults.

RESULTS

Consistency of Sampling Methods. The sampling methods used in our study differed among crops, and therefore, the possibility exists that the efficiency with which species were sampled may have differed among crops. Differences in sampling efficiency would result in biased estimates of species relative abundances, and consequently also biased estimates of species diversity. We cannot provide undisputable proof that our sampling methods provided unbiased estimates of species relative abundances within each crop. However, results of previous studies indicate that sweepnet sampling provides accurate estimates of coccinellid species relative abundances in alfalfa (Fenton and Howell 1957, Pruess et al. 1977) and small grains (Elliott et al. 1991, Elliott and Kieckhefer unpublished data). Our sampling in maize was accomplished by complete enumeration of coccinellids on maize plants, and therefore should have provided unbiased representation of species relative abundances. The available evidence suggests that our sampling methods provided accurate estimates of species relative abundances in each crop.

Differences in sampling intensity could also bias estimates of species diversity, with the magnitude of the bias depending on the characteristics of the particular diversity index and its sensitivity to sampling intensity (Southwood 1978). Comparisons of species diversity indices among crops would be unreliable in the presence of such bias. Since we had no prior knowledge as to which of several diversity indices described in the literature would be best for use on our data, the Berg-Parker dominance index (D) was used because it is relatively insensitive to sample size and is considered to be a reliable descriptor of species diversity (Southwood 1978).

In order to minimize the potential for bias due to small sample size we chose to perform analysis of variance on diversity indices estimated using average annual species relative abundances in each crop at a site. Estimates of species relative abundances each year at a site were based on a minimum of six 300-sweep samples in small grains, ten 300-sweep samples in alfalfa, and five 1-hour searches in maize fields. The resultant increase in sample size obtained by using annual averages should have minimized bias in estimates of diversity indices due to small sample size.

Coccinellid Species Composition. Adult coccinellids are highly mobile and move freely among fields (Kieckhefer and Olson 1974, Ives 1981), whereas immature coccinellids are essentially restricted to the field in which they are born. Furthermore, adults of some species utilize habitats for feeding and other activities in which they seldom reproduce (Elliott and Kieckhefer 1990a, 1990b, Kieckhefer and Elliott 1991). Therefore, we felt that it would be useful to examine species relationships of immatures and adults separately. Adults of seven coccinellid species regularly occurred in the crops (Table 1): *Hippodamia convergens*; *H. tredecimpunctata tibialis* (Say); *H. parenthesis* (Say); *Colomegilla maculata lengi* Timberlake; *Coccinella transversoguttata richardsoni* Brown; *Cycloneda munda* (Say); and *Adalia bipunctata*. All species except *A. bipunctata* were associated with each of the three crops, while *A. bipunctata* occurred only in maize. Other coccinellids were collected in

³Mention of a proprietary product does not constitute endorsement by the USDA.

Table 1.—Relative abundances of adult and immature coccinellids in three crops in eastern South Dakota from 1973-1985.

Life Stage/Species	Crop		
	Alfalfa	Small Grains	Maize
Adult			
<i>Hippodamia convergens</i>	0.45	0.46	0.43
<i>H. tredecimpunctata tibialis</i>	0.23	0.33	0.27
<i>H. parenthesis</i>	0.21	0.10	0.01
<i>Coleomegilla maculata lengi</i>	0.09	0.09	0.26
<i>Cycloneda munda</i>	0.01	0.01	0.01
<i>Coccinella transversoguttata richardsoni</i>	0.01	0.01	0.01
<i>Adalia bipunctata</i>	0.00	0.00	0.01
Immature			
<i>H. convergens</i>	0.48	0.48	0.35
<i>H. tredecimpunctata tibialis</i>	0.20	0.30	0.28
<i>Hippodamia parenthesis</i>	0.26	0.06	0.01
<i>Coleomegilla maculata lengi</i>	0.06	0.16	0.36
<i>Cycloneda munda</i>	0.00	0.00	0.00
<i>Coccinella transversoguttata richardsoni</i>	0.00	0.00	0.00
<i>Adalia bipunctata</i>	0.00	0.00	0.00

Table 2.—Relative abundances of coccinellids on sticky traps placed adjacent to fields of alfalfa, small grains, and maize, and relative abundances of coccinellids in samples from alfalfa, small grain and maize fields from 1968-1972.

Species	Sticky trap	Field
<i>Adalia bipunctata</i>	0.041	0.000
<i>Coccinella novemnotata</i>	0.004	0.000
<i>Coccinella transversoguttata richardsoni</i>	0.002	0.003
<i>Coleomegilla maculata lengi</i>	0.069	0.043
<i>Cycloneda munda</i>	0.011	0.044
<i>Hippodamia convergens</i>	0.508	0.535
<i>H. glacialis</i>	0.004	0.000
<i>H. tredecimpunctata tibialis</i>	0.292	0.264
<i>H. parenthesis</i>	0.069	0.111

samples from the three crops, however their occurrence was so sporadic that it is unlikely that they were regular inhabitants of the crops. Adults of more species occurred in the crops than immatures; immatures of only four species (*H. convergens*, *H. tredecimpunctata tibialis*, *H. parenthesis*, and *C. maculata lengi*) were collected (Table 1).

Although adults of seven species were collected from the three crops, other species were caught on sticky traps stationed adjacent to fields (Table 2). *Adalia bipunctata* was frequently caught on sticky traps adjacent to small grain and alfalfa fields throughout the spring and summer, but was not captured in alfalfa and small grain fields during that time.

With the exception of *A. bipunctata*, the adults of the same species inhabited each crop; however, their species relative abundances varied among crops (Table 1). For example, *H. parenthesis* was the third most abundant species in alfalfa, but was nearly absent from maize. *Coleomegilla maculata* comprised a greater percentage of the coccinellid fauna in maize, but was of less importance in small grains and alfalfa. *Hippodamia convergens* and *H. tredecimpunctata* were the two most abundant species overall, and were among the dominant species in each crop.

Table 3. — Mean (SE) Berg-Parker diversity indices (D) for adult and immature coccinellids in three crops. Diversity indices were calculated from species average annual relative abundances in each crop from 1973–1985.

Life Stage	Crop		
	alfalfa	small grains	maize
Immature	0.76 (0.04) ^a	0.75 (0.03) ^a	0.75 (0.03) ^a
Adult	0.57 (0.02) ^a	0.58 (0.02) ^b	0.63 (0.02) ^a

Means within a row followed by the same letter are not significantly different ($P > 0.05$) based on the least significant difference test.

Patterns in relative abundances of immatures generally paralleled those of adults, however, some differences were evident (Table 1). For example, *C. maculata lengi* formed a higher proportion of the total immature coccinellid fauna of maize and small grains than that represented by adults. The results suggest that oviposition requirements may differ among species.

Species Diversity. Preliminary three-stage nested analyses of variance of species diversity indices (D) calculated from individual samples yielded no evidence of differences in species diversity among sites for either immatures ($F=0.86$; $df=24,185$; $0.50 < P < 0.75$) or adults ($F=0.91$; $df=24,668$; $0.50 < P < 0.25$). Furthermore, Pearson correlation coefficients calculated for all possible pairs of sites (three pairs) indicated that species diversity at a site within a year was uncorrelated with diversity at other sites. Therefore, we felt that it was appropriate to use sites as replicates in analyses of variance of diversity statistics calculated from average annual abundances.

For immatures, analysis of variance yielded no evidence of differences in species diversity among crops ($F=0.04$; $df=2,60$; $P=0.96$). However, D differed significantly among years ($F=2.22$; $df=12, 60$; $P=0.02$). For adults, analysis of variance indicated that species diversity differed among crops ($F=3.46$; $df=2, 71$; $P=0.03$) and years ($F=6.51$; $df=12, 71$; $P < 0.01$). There was no evidence for year by crop interaction in species diversity for immatures ($F=1.27$; $df=22,60$; $P=0.23$) or adults ($F=1.64$; $df=22,71$; $P=0.08$). The absence of interaction suggests that factors causing annual variation in species diversity were nearly independent of those affecting variation in species diversity among crops.

Species diversity of adults was lower in corn than in alfalfa or small grains (Table 3). Examination of Table 1 provides insight into factors accounting for the lower species diversity in corn compared to alfalfa and small grains. Three species account for nearly all coccinellids in maize; and, as indicated by ranges in relative abundances, two species, *H. convergens* and *C. maculata lengi*, can at times dominate. In alfalfa and small grains, other species consistently comprise a greater proportion to the total coccinellids. Thus, both species number and equitability are often greater in these crops than in maize.

Because crop and year were statistically independent in their effects on species diversity we pooled data across crops to further analyze annual variation in species diversity. Species diversity in the pooled data varied among years (Fig. 1); adult species diversity varied from 0.42 in 1984 to 0.75 in 1981. Species diversity of immature coccinellids was similarly variable among years. Examination of the pooled data suggests that diversity in a particular year was unrelated to diversity in the previous year (Fig. 1). This was confirmed by calculating autocorrelation coefficients for time lags of one year; autocorrelation coefficients for both adults and immatures did not differ significantly from zero. Diversity of adults appeared to be related to diversity of immatures within years (Fig. 1). The relationship was confirmed by calculat-

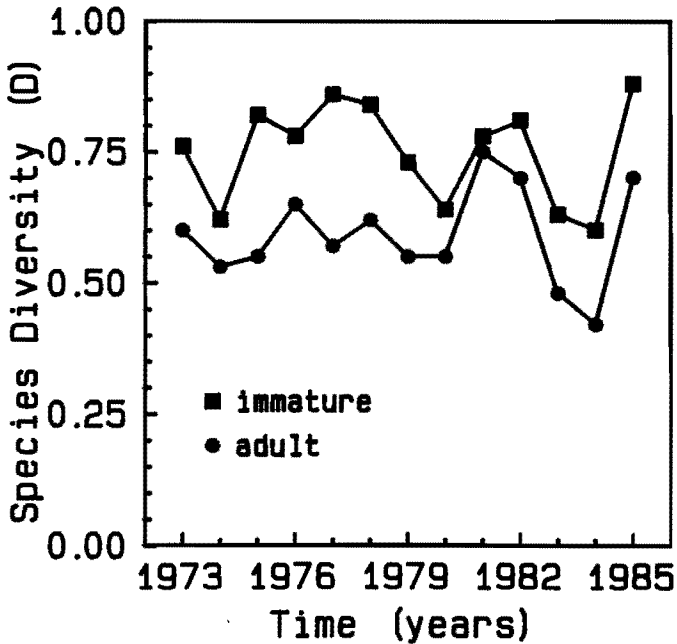


Figure 1. Species diversity (D) of adult (circles) and immature (squares) coccinellids in three crops in eastern South Dakota from 1973 through 1985.

ing the cross correlation coefficient for a time lag of zero years from time series of diversity indices for adults and immatures. The coefficient differed significantly from zero ($r=0.82$; $P=0.02$). Similarity in diversity of adults and immatures within years would be expected if factors stimulating oviposition were similar for coccinellid species inhabiting the crops or if immatures that developed to maturity in the fields remained there for relatively long periods of time after adult eclosion.

Similarity in Species Abundances in Crops. Data for *A. bipunctata* were excluded from calculations of rank coefficients because it occurred only in maize. Thus, each correlation coefficient for comparing adult coccinellids in any two crops was calculated from 78 pairs of data-points consisting of the ranks of the relative abundances of six species in each of 13 years in the two crops. Similarly, each coefficient for comparing similarity of immatures consisted of 52 paired ranks because three species were excluded.

Rank correlations for immatures are listed in Table 4. Species relative abundances in maize and alfalfa appear to be least similar, while those in small grains and alfalfa were most similar. Similarity coefficients for adults reveal a pattern consistent with that for immatures, although coefficients for adults were generally greater (Table 4). Variation in similarity among crops appears to be related to variation in the relative abundances of less common species. In particular, *C. maculata lengi* and *H. parenthesis* more often had similar ranks in relative abundance in alfalfa and small grains than they did in maize.

Table 4.—Kendall's tau rank correlation coefficients calculated from relative abundances of adult (upper triangle) and immature (lower triangle) coccinellids sampled from three crops. Rank correlations were calculated from average annual relative abundances in each crop from 1973–1985.

	Alfalfa	Small grains	Maize
Alfalfa	—	0.63	0.39
Small grains	0.45	—	0.51
Maize	0.29	0.36	—

DISCUSSION

Only six coccinellid species were associated with the three major agricultural crops grown in of the eastern South Dakota; even fewer species reproduced in the crops. The aphidophagous coccinellid fauna in agricultural crops typically exhibits low species diversity (Honek and Rejmanek 1982). Interception trap data indicated that there were several species active near fields of agricultural crops that did not colonize them, apparently because the crops do not provide appropriate habitat for colonization. For example, even though *A. bipunctata* is a relatively common coccinellid in eastern South Dakota, it is primarily arboreal (Hodek 1966) and does not colonize most crops.

The two most abundant species in alfalfa, maize, and small grains, *H. convergens* and *H. tredecimpunctata tibialis* comprised a high proportion of the coccinellid fauna in all crops; these species and *C. maculata lengi* feed and reproduce in virtually the entire spectrum of plant communities comprising the landscape, from old-fields and crops, to areas dominated by trees and shrubs (Warren and Tadic 1967, Gagne and Martin 1968, Weber and Holman 1976). Several of the less abundant species appear to be more closely associated with non-crop habitats. *Coccinella transversoguttata richardsoni* is primarily an old-field species, especially those in which woody vegetation is establishing, whereas *C. munda* often inhabits and reproduces in mature and senescing trees (Gagne and Martin 1968); *H. parenthesis* is usually associated with grasses and sedges (Palmer 1914).

Some of the coccinellids observed in association with alfalfa, maize, and small grains in this study have been observed in these crops by authors studying coccinellid faunas in other regions of North America (Foott 1971, Smith 1971, Havnvik and Frye 1969, Neuenschwander et al. 1975, Schiefelbein and Chaing 1966, Wheeler 1977). Coccinellid species diversity in these studies was roughly similar to that we observed, however faunal compositions differed and may to be related to the geographic region in which the study was conducted.

The generally greater species diversity in alfalfa compared to small grains and maize may be partially attributable to the extended growing season for this crop, during which it is inhabitable by aphids and aphidophagous coccinellids, or perhaps to the extended crop cycle of alfalfa compared to small grains and maize (typically at least three years) which may permit development of more complex plant and animal communities. Perhaps because of the high mobility of adult coccinellids and likely species differences in requirements or preferences for oviposition, immatures portray a different picture of diversity relationships. Immatures of species were equally diverse in all crops, though species relative abundances varied markedly among crops.

Levels of annual variation in species diversity observed in this study may have resulted from a variety of sources. Variation in cultural practices within sampled fields among years can influence species abundance. Abundances of aphidophagous insects in crops are influenced by both weed density and spe-

cies composition (Smith 1976, Horn 1981, Powell et al. 1986). Radwan and Lovei (1983) employing methods of analysis similar to ours demonstrated that coccinellid species diversity varied among fields in which maize was grown continuously and those in which it was rotated with other crops. Annual fluctuations in aphid populations in crops could also influence species diversity. Coccinellid species exhibit differential responses to variation in aphid density; some species prefer high and others low aphid densities (Honek 1983, 1985). Environmental factors that influence overwintering survival and the timing of migrational flights from overwintering sites could influence species diversity. Honek (1982) found that regional populations of *Coccinella septempunctata* L. varied by two orders of magnitude over a four year period. Variation in plant phenology among fields in relation to seasonal patterns of dispersal by coccinellids could also influence species relationships.

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