

# Seasonal Changes in Habitat Preference by *Coleomegilla maculata*: Implications for Colorado Potato Beetle Management in Potato

Brian A. Nault<sup>1</sup> and George G. Kennedy

Department of Entomology, Box 7630, North Carolina State University, Raleigh, North Carolina 27695

Received April 20, 1999; accepted August 10, 1999

**Seasonal abundance, dispersal, and overwintering of the 12-spotted ladybird beetle, *Coleomegilla maculata* (DeGeer), in the mid-Atlantic states were investigated to assess the potential to manipulate the habitat of this predator to increase its impact on Colorado potato beetle, *Leptinotarsa decemlineata* (Say), management in commercial potato plantings. *C. maculata* populations were highest in corn fields through August, and overwintering aggregations were found most commonly in habitats adjacent to these fields. Although adult and larval populations of *C. maculata* were synchronized with first-generation potato beetle eggs and small larvae, they were concentrated in wheat rather than potato fields because most of the potato plants had not yet emerged when *C. maculata* adults dispersed from their overwintering sites. The subsequent generation of *C. maculata* tended to aggregate in corn rather than potato in late May and early June. Therefore, given the current mixture of crops as well as climatic and marketing limitations on planting date for potatoes, the potential for habitat manipulation to increase the impact of *C. maculata* on Colorado potato beetle management in potato in the mid-Atlantic states appears to be limited.** © 2000 Academic Press

**Key Words:** *Coleomegilla maculata*; *Leptinotarsa decemlineata*; overwintering; dispersal; seasonal abundance.

## INTRODUCTION

The Colorado potato beetle, *Leptinotarsa decemlineata* (Say), is the principal insect pest of Irish potato throughout the eastern United States (Hare, 1990). Conventional insecticides continue to play a dominant role in management of the potato beetle, despite this pest's history of rapidly developing resistance to insecticides used against it and increasing public concerns

about pesticide residues in the environment. Although a number of management strategies that minimize the use of conventional insecticides have been developed (see review in Zehnder *et al.*, 1994), the inclusion of a significant biological component to complement these strategies requires further investigation.

Recently, generalist predators have been identified as an important source of natural mortality to Colorado potato beetle eggs and small larvae in the United States, and these predators may have the potential to significantly suppress populations of this pest (Hough-Goldstein *et al.*, 1993; Hilbeck and Kennedy, 1995). Of these predators, the 12-spotted ladybird beetle, *Coleomegilla maculata* (DeGeer), was shown to be the most promising in this regard (Grodén *et al.*, 1990; Hazzard and Ferro, 1991; Hazzard *et al.*, 1991; Hough-Goldstein *et al.*, 1993; Hilbeck *et al.*, 1997). In Massachusetts and North Carolina, mortality of potato beetle eggs due to predation, primarily by *C. maculata*, was shown to be relatively high and consistent (MA = 30 to 50% and NC = 43%) throughout the egg-recruitment period, despite large increases in egg density (Hazzard *et al.*, 1991; Hilbeck *et al.*, 1997).

*C. maculata*'s diet includes both arthropods and pollen (Smith, 1960; Hodek, 1973). *C. maculata* was reported to feed on a variety of prey in a diversity of habitats. Some examples of its prey and habitats include the following: cereal leaf beetle, *Oulema melanopus* (Linné), in oats (Shade *et al.*, 1970); European corn borer, *Ostrinia nubilalis* (Hübner), corn leaf aphid, *Rhopalosiphum maidis* (Fitch), and pollen in corn (Conrad, 1959; Risch *et al.*, 1982; Andow and Risch, 1985; Coll and Bottrell, 1991); greenbugs, *Schizaphis graminum* (Rondani), in sorghum and wheat (Rice and Wilde, 1988); green peach aphids, *Myzus persicae* (Sulzer) and *L. decemlineata* in potatoes (Mack and Smilowitz, 1982; Grodén *et al.*, 1990; Hazzard *et al.*, 1991; Hazzard and Ferro, 1991); fall webworm, *Hyphantria cunea* (Drury), in pecan (Warren and Tadic, 1967); and corn earworm, *Helicoverpa zea* (Boddie), in cotton (Whitcomb and Bell, 1964).

<sup>1</sup> Present address: Eastern Shore Agricultural Research and Extension Center, Virginia Polytechnic Institute and State University, 33446 Research Drive, Painter, VA 23420.

*C. maculata* overwinters as an adult in aggregations beneath litter in protected areas such as fence rows and the edges of wooded areas. Overwintering aggregations often can be found at the base of prominent objects (e.g., trees) near open areas (Hagen, 1962; Benton and Crump, 1979; Wright and Laing, 1982; Coll *et al.*, 1994). Mortality during the winter can be quite variable among sites (range = 3 to 100%) (Benton and Crump, 1979; Wright and Laing, 1982).

Spring dispersal may span a month or longer and was documented to begin as early as late February in South Carolina (Roach and Thomas, 1991) and as late as early April in western New York (Benton and Crump, 1981). Roach and Thomas (1991) did not observe a preference in dispersal direction from overwintering sites. In North Carolina, early in the dispersal episode *C. maculata* adults were more concentrated along edges than in the interiors of wheat fields that bordered overwintering sites, suggesting that these insects exhibit short-range rather than long-range dispersal, at least when food (i.e., aphids) is abundant (B.A.N., unpublished results).

During the growing season, colonization of certain habitats by *C. maculata* is influenced by the presence of suitable prey and pollen or both. Maredia *et al.* (1992) reported that *C. maculata* populations moved from dandelion to wheat, to corn, and finally to alfalfa before emigrating to weedy vegetation along the edges of alfalfa fields prior to overwintering. They observed reproduction by *C. maculata* in each of the crop habitats. There are numerous reports of *C. maculata* concentrating in corn at the time of tasseling and pollen shed (Smith, 1971; Richerson and DeLoach, 1973; Benton and Crump, 1981; Groden *et al.*, 1990; Coll and Bottrell, 1991; Ferro, 1994).

*C. maculata* populations are well synchronized with Colorado potato beetle populations in potato in both Massachusetts and Rhode Island (Groden *et al.*, 1990; Hazzard *et al.*, 1991; Hazzard and Ferro, 1991). However, Groden *et al.* (1990) found that adult *C. maculata* populations in potato at the Kellogg Biological Station in Michigan were much lower later in the season, when second-generation potato beetle eggs are present, because this generation of potato beetles was small and alternative prey were abundant in adjacent crops. For this reason, they concluded that investigations of the dynamics of *C. maculata* must focus at the landscape rather than the individual crop level.

In Massachusetts, *C. maculata* adults concentrate in corn during pollen shed and the populations increase in corn prior to overwintering at the base of trees adjacent to these fields. In this case, rotating potatoes with corn, or planting potatoes close to fields planted with corn the previous year results in elevated populations of *C. maculata* in potato and a significant suppression of

Colorado potato beetle populations in the spring (Ferro, 1994). In the mid-Atlantic states, corn begins to mature in late July and early August, well before the end of the growing season and well before *C. maculata* enters diapause (Deitz *et al.*, 1976). Therefore, it seems likely that *C. maculata* populations disperse from corn into other habitats before migrating to their overwintering sites. If this is the case, then planting potatoes following corn will not lead to enhanced *C. maculata* populations in potato and elevated levels of predation on Colorado potato beetle, as is observed in Massachusetts.

Under current management practices, overwintered Colorado potato beetle populations are typically so high that the naturally occurring levels of predation fail to prevent the development of damaging larval populations. Ferro (1994) pointed out that cultural practices that reduce the size of the overwintered potato beetle population should increase the effectiveness of natural enemies. However, a better understanding of the biology and ecology of predators such as *C. maculata* is needed to identify cultural tactics (e.g., crop rotation) that conserve and elevate predator populations to a level that has a practical impact on Colorado potato beetle management. This research was undertaken to determine the seasonal pattern of habitat use by *C. maculata* with the goal of identifying ways to concentrate populations of *C. maculata* in potato fields at the time eggs and small larvae of the Colorado potato beetle are present in the mid-Atlantic states. Our study had the following objectives: (1) determine whether *C. maculata* adult and larval populations are temporally synchronized with the most damaging Colorado potato beetle generation (first only) in potato, (2) identify crops that serve as nurseries for increases in *C. maculata* populations and that concentrate its populations prior to overwintering, and (3) characterize overwintering habitats for *C. maculata*.

## MATERIALS AND METHODS

### *Seasonal Abundance*

Seasonal abundance of *C. maculata* was investigated in the Tidewater region of eastern North Carolina in 1995 and 1996 by surveying populations in the most prevalent crops in the agroecosystem where potatoes are grown. One commercial field each of wheat, potato, corn, and early and late planted soybean was randomly selected from each of six farms ( $n = 6$ ) each year. Half of the farms were located in Pasquotank County and the other half in Washington County. Fields of the different crops within a farm were separated by no more than 1.6 km and fields were sampled weekly for *C. maculata* adults and larvae. Sampling periods in the various crops were as follows: wheat (mid-March

through early June), potato (late March or late April through mid- to late June), corn (late May to early June through late August), and early and late planted soybean (late June through late September or early October). One hundred fifty whole plant samples were taken in each field in a U-shaped pattern covering  $\approx 0.61$  ha. In wheat and soybean, each sample was 2 rows  $\times$  0.91 m (area = 0.32 m<sup>2</sup>), whereas in potato and corn each sample was 1 row  $\times$  0.91 m (area = 0.84 m<sup>2</sup>). Because the most difficult crop in which to sample *C. maculata* was corn, the sampling technique chosen for corn was used in all crops. Although an efficient sampling method for coccinellids in corn has not been identified, Michels and Behle (1992) reported that sampling visually for lady beetles in grain sorghum was significantly more efficient than sampling by sweep net, drop cloth, or pitfall traps. Therefore, all samples in all crops were inspected visually and all data were transformed to a per square-meter basis. Using the same sampling method in all crops enabled us to compare densities of insects among crops. For each crop on each farm, the average number of insects per sample was determined and this number was used in the analysis.

#### *Synchrony with Colorado Potato Beetle Populations*

In 1995 and 1996, the abundance of Colorado potato beetle egg masses and small larvae (first and second instars) was recorded in the same commercial potato fields that were sampled for *C. maculata*. Similarly, potato beetles were sampled weekly in these fields following the same procedure that was used for sampling *C. maculata*. In 1995, sampling of fields began shortly after potato plants emerged, whereas in 1996 sampling began prior to potato plant emergence.

#### *Movement of Adult C. maculata in the Fall*

Because few *C. maculata* were encountered in our samples between the time corn was harvested (beginning 15 August) and the time adults colonized overwintering sites (first half of October), their activity within the cropping system was monitored weekly from 8 August and 25 July through 7 and 3 November 1996 and 1997, respectively, using yellow sticky traps. Udayagiri *et al.* (1997) reported that yellow sticky cards were significantly more effective in trapping *C. maculata* adults than red, green, or white cards. Adults were monitored in Washington County, North Carolina, and Northampton County, Virginia, in 1996 and 1997, respectively. Sticky traps were double-sided (28 cm  $\times$  15 cm) and covered with Tanglefoot sticky material (The Tanglefoot Co., Grand Rapids, MI). On each of three farms, 5 traps each were placed at the interface of woods bordering corn or soybean, and 5 traps each were placed within corn or soybean fields at a distance of 50

m from woods that bordered these fields (4 treatments totaling 20 traps/farm). All of these traps were positioned 76 cm above ground and placed among weeds growing either along field borders or within fields between field sections. The experiment was a split-plot in which the treatments were arranged as a 2 (trap location)  $\times$  2 (crop) factorial in a complete block design replicated three times. The main plot factor was habitat (field edge or within field) and the subplot factor was crop (corn or soybean). Prior to colonization of overwintering sites, the total number of *C. maculata* adults per trap was recorded (in 1996, 8 August through 14 October; and in 1997, 25 July through 2 October). Additionally, the mean number of adults captured per day was determined for sampling intervals during peak migration to overwintering sites (in 1996, 15 through 29 October; and in 1997, 2 through 9 October). Differences among treatment means were calculated using the analysis of variance procedure PROC GLM and means were compared using LSMEANS at  $P < 0.05$  (SAS Institute, 1990). Data were transformed by a log ( $x + 1$ ) function prior to analysis, but untransformed means are presented.

#### *Characterization of C. maculata Overwintering Habitats*

A total of 21, 38, and 39 overwintering habitats for *C. maculata* adults were sampled one time during the winter (January through mid-March) of 1995, 1996, and 1997, respectively. In all 3 years, each habitat was classified according to the crops that it bordered the previous fall (i.e., corn, soybean, or both corn and soybean) and in 1996 and 1997 the habitat type was recorded (i.e., a "windbreak" or "trees along the forest edge"). A windbreak consisted of one to three rows of trees that were isolated from other trees, were growing in a line parallel to a field margin, and were situated between the field and a ditchbank or a road. Trees along the forest edge consisted of trees within the first 20 ft of a forest.

Twenty potential overwintering sites (equal to an approximately 30-cm band of leaf litter around the base of a single tree) were sampled per habitat, and the mean number of adults per site was used in the analyses. In 1995, only differences among the mean number of adults per tree per habitat location (soybean only, corn only, or corn and soybean) were determined using an analysis of variance (PROC GLM), and means were compared using LSMEANS at  $P < 0.05$  (SAS Institute, 1990). In 1996 and 1997, the number of adults per tree per adjacent crop (i.e., soybean only, corn only, or corn and soybean), habitat type (i.e., windbreak or trees along the forest edge), and their interaction were compared.

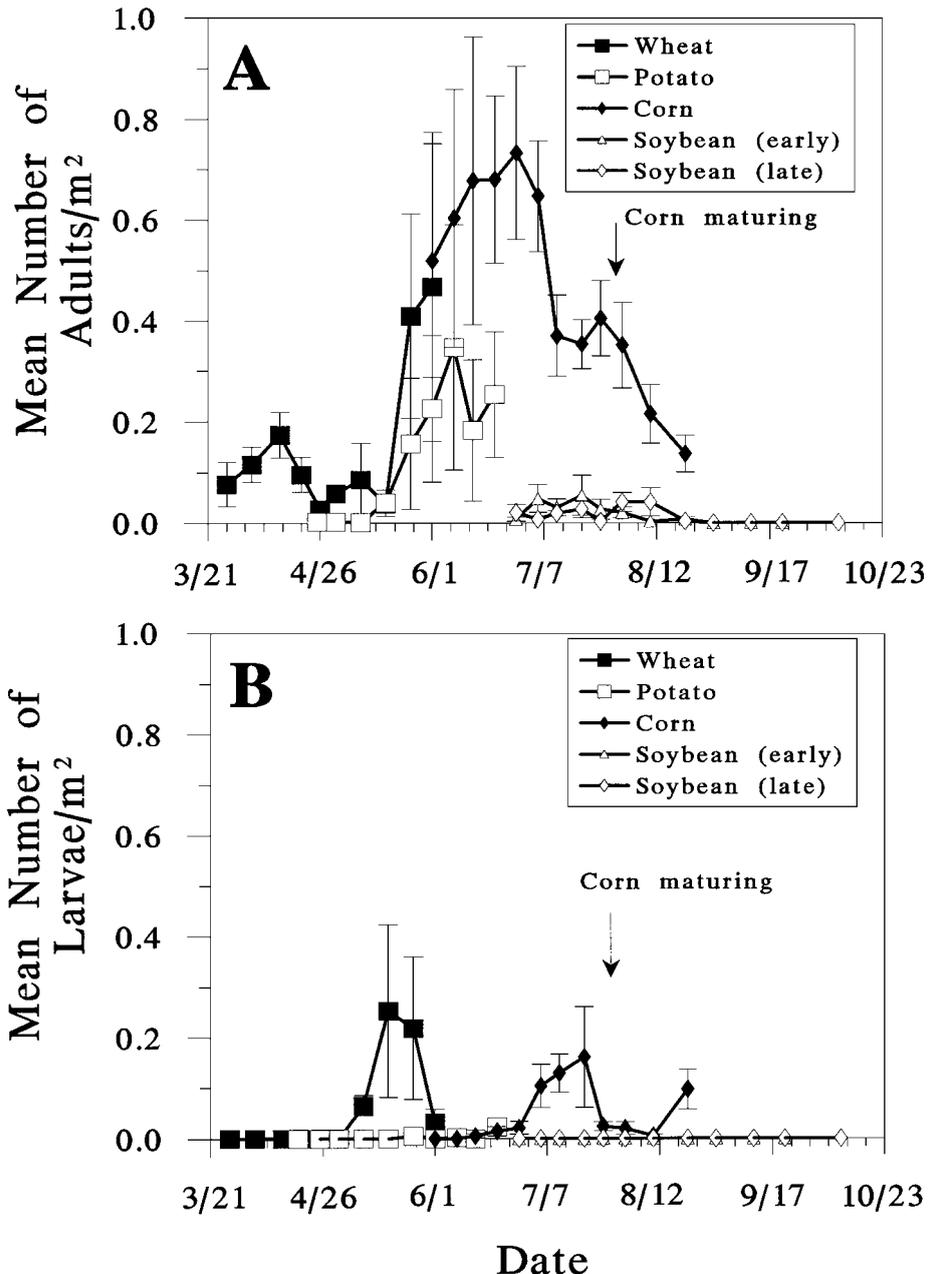
In 1997, the influence that tree size had on the

number of *C. maculata* adults that overwintered at its base was investigated. Tree size was quantified by measuring its girth 1 m above its base and these values were used in the analysis. Habitats were selected that had at least one *C. maculata* adult by at least three trees ( $n = 19$  habitats). Within each habitat, a total of nine trees were randomly selected and the number of adults was recorded. A simple linear regression model (PROC GLM) was used to identify a relationship between tree size and number of overwintered beetles  $P < 0.05$  (SAS Institute, 1990).

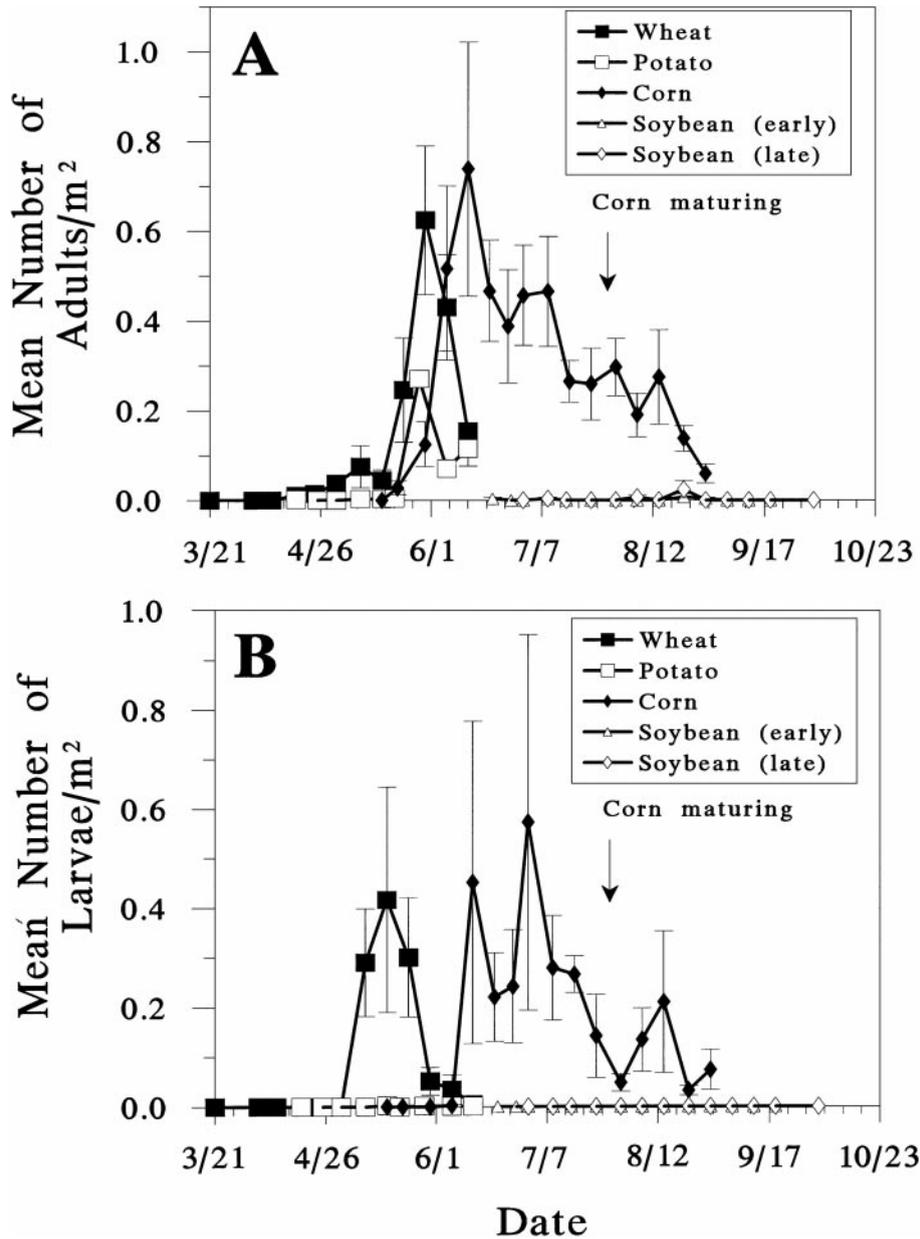
**RESULTS**

*Seasonal Abundance*

Overwintered *C. maculata* adults colonized wheat fields from mid-March through April (Figs. 1A and 2A). Adults were observed feeding on English grain aphids, *Macrosiphum avenae* (Fabricius), bird cherry-oat aphids, *Rhopalosiphum padi* (L.), and eventually pollen. *C. maculata* adults mated and laid eggs in wheat as early as mid-April, but larvae were not observed until 9 May, and larval populations did not peak until 16 May



**FIG. 1.** Seasonal abundance (mean  $\pm$  SEM) of *C. maculata* adults (A) and larvae (B) in the most prevalent crops in the Tidewater region of eastern North Carolina in 1995. The arrow denotes an approximation of the beginning of corn maturation. For each mean,  $n = 6$ .

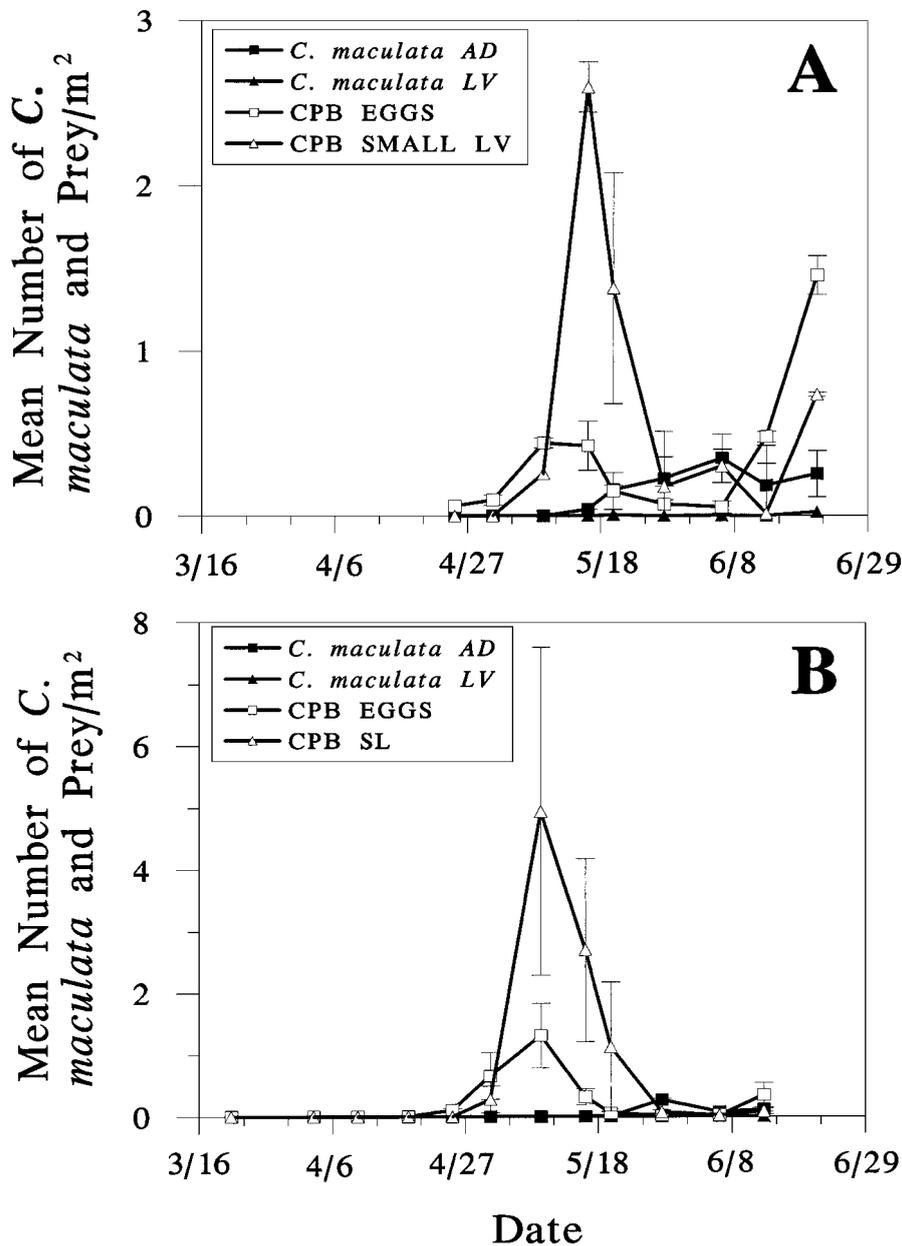


**FIG. 2.** Seasonal abundance (mean  $\pm$  SEM) of *C. maculata* adults (A) and larvae (B) in the most prevalent crops in the Tidewater region of eastern North Carolina in 1996. The arrow denotes an approximation of the beginning of corn maturation. For each mean,  $n = 6$ .

in both years (Figs. 1B and 2B). First-generation adults began to emerge from wheat in early May and populations in wheat peaked at the end of May in both years (Figs. 1A and 2A).

As wheat began to ripen in mid-May, populations of adult *C. maculata* increased in corn and potato. It is likely that adults began to disperse from wheat into corn and potato fields at this time (Figs. 1A and 2A). Prior to this time, very few adults and virtually no larvae were observed in either corn or potato. Adults fed on bird cherry-oat aphids and eventually pollen in corn, whereas they fed on second-generation Colorado

potato beetle egg masses and small larvae in potato (Figs. 3A and 3B). *C. maculata* adults tended to aggregate more in corn than in potato and reproduced in corn in both years (Figs. 1B and 2B). Few *C. maculata* egg masses (B.A.N., unpublished results) and larvae were observed in potato and reproduction occurred well after the first-generation potato beetle egg and small larval populations had peaked (Figs. 3A and 3B). Hazzard *et al.* (1991) reported that the peak abundance of adult *C. maculata* in a Massachusetts potato field was two to four times greater than we observed in our surveys during 1995 and 1996. Several additional overlapping



**FIG. 3.** Mean number ( $\pm$ SEM) of *C. maculata* adults and larvae and its prey, *L. decemlineata* eggs and small larvae (first and second instars), in potato fields in eastern North Carolina in (A) 1995 and (B) 1996. CPB refers to Colorado potato beetle, whereas AD, LV, and SL refer to adult, larvae, and small larvae, respectively. For each mean,  $n = 6$ .

generations of *C. maculata* occurred in corn in July and August, but the size of the populations in corn tended to decrease as corn matured (Figs. 1A and 2A). There were fewer *C. maculata* adults and larvae observed in soybean fields than in other fields throughout the season (Figs. 1 and 2).

#### Synchrony with Colorado Potato Beetle Populations

*C. maculata* adult and larval populations first peaked in mid- to late April and in mid-May, respectively (Figs.

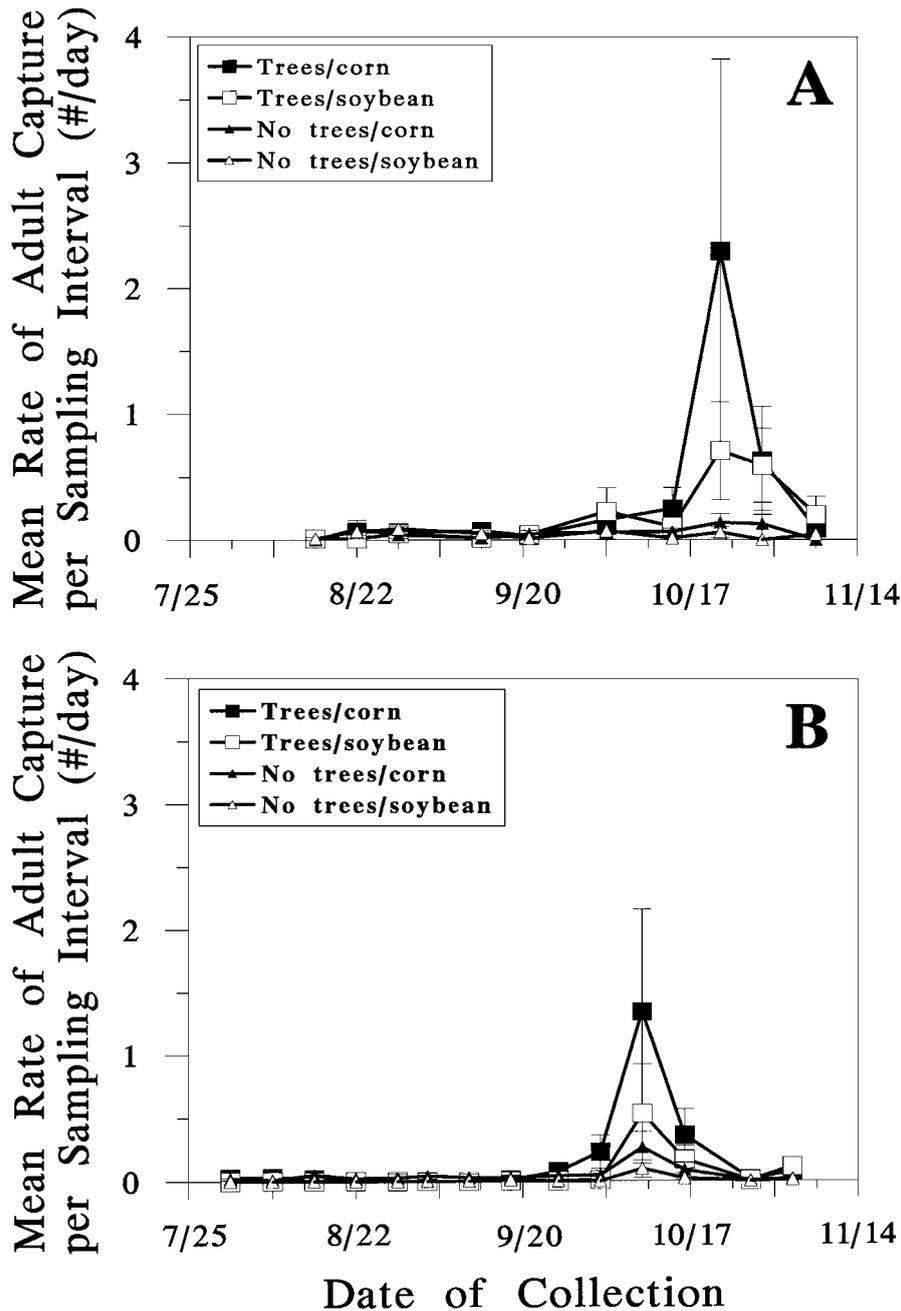
1 and 2) and were temporally synchronous with peak populations of first-generation Colorado potato beetle eggs and small larvae (Fig. 3). However, during these periods *C. maculata* adult and larval populations in potatoes were low because most were concentrated in wheat (Figs. 1A, 1B, 2A, and 2B). The numbers of *C. maculata* adults and larvae in potatoes began to increase as wheat dried, approximately 3 weeks after first-generation potato beetle egg and small larval populations peaked (Figs. 3A and 3B).

All potato fields were treated one to three times with

an insecticide during the last half of May to manage European corn borer, *Ostrinia nubilalis* (Hübner), and Colorado potato beetle infestations. Because the timing of the first insecticide application in these fields rarely occurs before early third instar Colorado potato beetles become abundant (at least 4 to 7 days after small potato beetle larval populations peak), insecticides were not a limiting factor in *C. maculata* population establishment in potato early in the season.

#### Movement of *C. maculata* Adults in the Fall

Some *C. maculata* adults were active near corn and soybean between the time corn was harvested and the time of migration to overwintering habitats (early to mid-October) (Figs. 4A and 4B). During this interval in 1996 (8 August through 14 October), neither crop, nor habitat, nor an interaction between the two significantly affected the total number of adults captured per trap (Crop,  $F = 0.06$ ;  $df = 1, 4$ ;  $P = 0.8226$ ; Habitat,



**FIG. 4.** Mean ( $\pm$ SEM) rate of capturing *C. maculata* adults per trap per sampling interval between the time corn was harvested and the end of migration to overwintering habitats in (A) Washington County, North Carolina in 1996 and (B) in Northampton County, Virginia in 1997. Means for each sampling interval are shown on the last day of that interval.

$F = 1.34$ ;  $df = 1, 4$ ;  $P = 0.9007$ , and Crop  $\times$  Habitat,  $F = 0.01$ ;  $df = 1, 4$ ;  $P = 0.9118$ ) (see Table 1). During this interval in 1997 (25 July through 2 October), neither habitat nor an interaction between crop and habitat significantly affected the total number of adults captured per trap (Habitat,  $F = 0.82$ ;  $df = 1, 4$ ;  $P = 0.4599$ ; and Crop  $\times$  Habitat,  $F = 0.24$ ;  $df = 1, 4$ ;  $P = 0.6489$ ); however, there were significantly more adults captured near corn than by soybean (Crop,  $F = 11.83$ ;  $df = 1, 4$ ;  $P = 0.0263$ ) (see Table 1). These results suggest that between corn harvest and the time they migrate to overwintering habitats, *C. maculata* adults may be found near corn fields rather than near woodlands, windbreaks, or soybean fields in some years.

*C. maculata* adults began migrating to overwintering sites from early to mid-October through early November. On 22 and 29 October 1996, significantly more adults were captured per trap per day per sampling interval adjacent to trees than at a distance of at least 50 m into corn or soybean fields from these trees (22 October,  $F = 31.62$ ;  $df = 1, 4$ ;  $P = 0.0302$ ; and 29 October,  $F = 31.50$ ;  $df = 1, 4$ ;  $P = 0.0303$ , respectively) (Figs. 4A and 4B). On 9 October 1997, more adults were encountered adjacent to trees than within corn or soybean fields, but this difference was not significant ( $F = 3.73$ ;  $df = 1, 4$ ;  $P = 0.1932$ ). In both 1996 and 1997, *C. maculata* adults tended to migrate to overwintering habitats (i.e., trees) that were adjacent to corn rather than soybean, but variance was too high to

TABLE 1

Comparison of the Total Number of *C. maculata* Adults Captured per Yellow Sticky Trap when Traps Were Placed Adjacent to Either a Forest Edge or at Least 50 m from That Edge within Either a Corn or Soybean Field

Source	1996		1997	
	<i>n</i>	Total no. of adults captured per trap (mean $\pm$ SEM)	<i>n</i>	Total no. of adults captured per trap (mean $\pm$ SEM)
Habitat				
No trees	6	3.2 $\pm$ 0.7 a	6	1.1 $\pm$ 0.5 a
Trees	6	5.5 $\pm$ 1.7 a	6	1.4 $\pm$ 0.8 a
Crop				
Corn	6	4.7 $\pm$ 1.4 a	6	2.5 $\pm$ 0.6 a
Soybean	6	4.1 $\pm$ 1.5 a	6	0.1 $\pm$ 0.0 b
Habitat $\times$ Crop				
No trees/corn	3	3.3 $\pm$ 1.0 a	3	2.1 $\pm$ 0.4 a
No trees/soybean	3	3.0 $\pm$ 1.2 a	3	0.1 $\pm$ 0.1 b
Trees/corn	3	6.0 $\pm$ 2.5 a	3	2.8 $\pm$ 1.2 a
Trees/soybean	3	5.1 $\pm$ 2.9 a	3	0.1 $\pm$ 0.1 b

Note. Data represent collection sites in Washington County, NC, and Northampton County, VA, from 8 August 1996 through 14 October 1996 and from 25 July 1997 through 2 October 1997, respectively. Means followed by the same letter within the same column and source do not differ significantly [ $P > 0.05$ ; LSMEANS (SAS Institute, 1990)].

TABLE 2

Comparison of the Mean Number of *C. maculata* Adults Overwintering at the Base of Trees in Habitats Adjacent to Certain Crops Planted the Previous Season

Habitat type	Adjacent crop	No. of locations sampled ( <i>n</i> )	Mean no. of adults per tree <sup>a</sup>
Winter of 1995			
—	Soybean only	4	6.3 a
—	Corn only	7	70.3 b
—	Both <sup>b</sup>	10	85.2 b
Winter of 1996			
Forest	Soybean only	9	0.4 a
Hedgerow	Soybean only	3	0.0 a
Forest	Corn/both	12	2.5 a
Hedgerow	Corn/both	14	27.3 b
Winter of 1997			
Forest	Soybean only	11	1.4 a
Hedgerow	Soybean only	3	0.0 a
Forest	Corn/both	10	5.3 a
Hedgerow	Corn/both	15	12.3 b

<sup>a</sup> Means followed by the same letter do not differ significantly [ $P > 0.05$ ; LSMEANS (SAS Institute, 1990)].

<sup>b</sup> Both denotes soybean + corn.

detect significant differences (1996 Crop  $\times$  Habitat,  $F = 0.46$ ;  $df = 1, 4$ ;  $P = 0.5363$ ; and 1997 Crop  $\times$  Habitat,  $F = 6.76$ ;  $df = 1, 4$ ;  $P = 0.0600$ ).

#### Characterization of Overwintering Sites

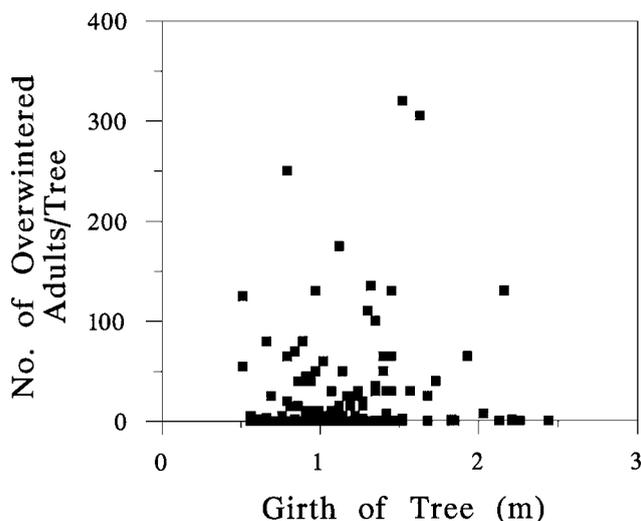
In 1995, there were significantly more overwintered *C. maculata* adults per tree in habitats adjacent to either corn only or both corn and soybean than in habitats bordering soybean only ( $F = 6.22$ ;  $df = 2, 18$ ;  $P = 0.0089$ ) (Table 2). In 1996, many more overwintered adults per tree were found along windbreaks adjacent to corn than along forest edges next to corn, whereas the numbers of overwintered adults per tree along windbreaks and forest edges adjacent to soybean only were low and did not differ [i.e., significant interaction between habitat type and adjacent crop ( $F = 8.21$ ;  $df = 1, 34$ ;  $P = 0.0071$ )] (Table 2). Adults were found in only 1 of 12 locations where the overwintering habitat was adjacent to soybean only and in only 6 of 12 locations where the habitat was a forest edge next to corn. In contrast, adults were found in 14 of 14 locations where a habitat was a windbreak adjacent to corn.

In 1997, overwintered adults per tree were found most commonly adjacent to corn than soybean ( $F = 8.93$ ;  $df = 1, 35$ ;  $P = 0.0051$ ) (Table 2). Although there were over twice as many overwintered adults encountered along windbreaks adjacent to corn than encountered at forest edges adjacent to corn and no differences existed between the number of adults in habitats adjacent to soybean, the habitat type  $\times$  crop interaction was not

significant ( $F = 2.39$ ;  $df = 1, 35$ ;  $P = 0.1310$ ). Adults were found in only 3 of 14 locations where the overwintering habitat was adjacent to soybean only, in 7 of 10 locations where the habitat was a forest edge next to corn, and in 14 of 15 locations where the habitat was a windbreak next to corn. Taken together, these results indicate that adults are more likely to be concentrated by trees within windbreaks that bordered corn during the fall than in other locations that were sampled. There was no relationship between the size of tree and the number of *C. maculata* adults that chose to overwinter at its base ( $F = 3.29$ ;  $df = 1, 152$ ;  $P = 0.0718$ ) (Fig. 5).

## DISCUSSION

Only one Colorado potato beetle generation typically completes development on potato in the mid-Atlantic region before the crop is harvested in June and early July. If *C. maculata* is to play an important role in significantly reducing Colorado potato beetle populations in the mid-Atlantic states, its adult and larval populations, or both, must be temporally synchronized with first-generation potato beetle eggs and small larvae (late April through early May) as well as occur in abundance in potato fields. Our results indicated that the latest emerging *C. maculata* adults from the overwintering population and those earliest emerging from the first-generation were temporally synchronized with first-generation potato beetle eggs and small larvae; however, they were concentrated in wheat rather than potato. Similarly at the Kellogg Biological Station in Michigan, *C. maculata* populations were temporally synchronous with first- and second-generation potato



**FIG. 5.** Relationship between the number of *C. maculata* adults per tree and the size of the tree in which they were found. The sample included all individuals in leaf litter within a 30-cm band around the base of each tree. Tree size was measured by its girth 1 m above the ground.

beetle eggs and small larvae, but densities of *C. maculata* were much lower in potatoes when second-generation potato beetle eggs were present because this generation of potato beetles was small and there were abundant sources of prey in adjacent crops (Grodén *et al.*, 1990).

Our results indicate that *C. maculata* emerged from overwintering sites from mid-March to early April and then colonized wheat fields. During this period, most potato plants either had not emerged or were very small. Adults fed on aphids and pollen and reproduced in wheat. When most of the first-generation *C. maculata* adults emerged from wheat in late May to early June, some colonized potatoes at the time second-generation potato beetle eggs and small larvae were present, but most colonized corn. In North Carolina, Hilbeck and Kennedy (1995) and Hilbeck *et al.* (1997) reported that peak densities of *C. maculata* and the highest levels of predation on potato beetle eggs and small larvae occurred in late May and early June.

Wheat and corn were the only abundant crops in which significant reproduction by *C. maculata* occurred, probably because these crops contained an abundance of aphid prey and pollen. *C. maculata* were difficult to find in the crops we sampled and in weeds adjacent to them between the time corn was harvested and the time immediately prior to overwintering. It is possible that during this period adults estivate in corn residue or along field margins or that they dispersed to habitats we did not sample. It is also possible that their populations were low and widely distributed. Few *C. maculata* adults were captured near corn and soybean fields during the fall prior to aggregation at overwintering sites. These results contrast with those obtained in northern areas where *C. maculata* populations remain abundant in crops such as late planted corn (Ferro, 1994) and alfalfa (Maredia *et al.*, 1992) late in the season and disperse from these crops to their overwintering sites when the critical photoperiod for diapause induction is reached.

Although *C. maculata* adult activity adjacent to corn and soybean was low and did not differ in the fall prior to 14 October, overwintering adults occurred most commonly and in the greatest numbers in habitats, especially windbreaks, that were adjacent to corn fields. In Massachusetts, overwintering *C. maculata* populations also have been shown to concentrate in habitats adjacent to corn fields. Further, rotating potatoes to these fields the following spring led to elevated populations of *C. maculata* in potato, which in turn resulted in a significant reduction in the size of Colorado potato beetle populations (Ferro, 1994). Currently in the mid-Atlantic states, growers often rotate corn with potato/late-planted soybeans, which also should position the largest *C. maculata* overwintering populations adjacent to potato fields. Yet, *C. maculata* populations have had much less impact on suppressing first-generation

Colorado potato beetle populations in commercial potato fields in the mid-Atlantic states than they have had in Massachusetts. It is likely that a major reason for this difference is that *C. maculata* populations in the mid-Atlantic states concentrate in wheat fields rather than potato fields at the time first-generation Colorado potato beetle eggs and small larvae are present.

#### ACKNOWLEDGMENTS

We thank B. Bumgarner, M. Campbell, C. Cheshire, K. Coward, V. Covington, H. Doughty, R. Groves, M. Hanzlik, J. Speese, and N. Storer for their assistance in the field. This project was funded by Grant 94-37312-0628 from the USDA CSRS NRI CGP, entitled "Enhanced Biological Control of the Colorado Potato Beetle."

#### REFERENCES

- Andow, D. A., and Risch, S. J. 1985. Predation in diversified agroecosystems: Relations between a coccinellid predator *Coleomegilla maculata* and its food. *J. Appl. Ecol.* **22**, 357-372.
- Benton, A. H., and Crump, A. J. 1979. Observations on aggregations and overwintering in the coccinellid beetle *Coleomegilla maculata* (DeGeer). *J. N.Y. Entomol. Soc.* **87**, 154-159.
- Benton, A. H., and Crump, A. J. 1981. Observations on the spring and summer behavior of the twelve-spotted ladybird beetle, *Coleomegilla maculata* (DeGeer) (Coleoptera: Coccinellidae). *J. N.Y. Entomol. Soc.* **84**, 102-106.
- Coll, M., and Bottrell, D. G. 1991. Microhabitat and resource selection of the European corn borer (Lepidoptera: Pyralidae) and its natural enemies in Maryland field corn. *Environ. Entomol.* **20**, 526-533.
- Coll, M., Garcia de Mendoza, L., and Roderick, G. K. 1994. Population structure of a predatory beetle: The importance of gene flow for intertrophic level interactions. *Heredity* **72**, 228-236.
- Conrad, M. S. 1959. The spotted lady beetle, *Coleomegilla maculata* (DeGeer), as a predator of European corn borer eggs. *J. Econ. Entomol.* **52**, 843-847.
- Deitz, L. L., Van Duyn, J. W., Bradley, J. R., Jr., Rabb, R. L., Brooks, W. M., and Stinner, R. E. 1976. "A Guide to the Identification and Biology of Soybean Arthropods in North Carolina," North Carolina Agricultural Experiment Station Technical Bulletin No. 238.
- Ferro, D. N. 1994. Biological control of the Colorado potato beetle. In "Advances in Potato Pest Biology and Management" (G. W. Zehnder, M. L. Powelson, R. K. Jansson, and K. V. Raman, Eds.), pp. 357-375. APS Press, St. Paul, MN.
- Groden, E., Drummond, F. A., Casagrande, R. A., and Haynes, D. L. 1990. *Coleomegilla maculata* (Coleoptera: Coccinellidae): Its predation upon the Colorado potato beetle (Coleoptera: Chrysomelidae) and its incidence in potatoes and surrounding crops. *J. Econ. Entomol.* **83**, 1306-1315.
- Hagen, K. S. 1962. Biology and ecology of predaceous coccinellidae. *Annu. Rev. Entomol.* **7**, 289-326.
- Hare, J. D. 1990. Ecology and management of the Colorado potato beetle. *Annu. Rev. Entomol.* **35**, 81-100.
- Hazzard, R. V., and Ferro, D. N. 1991. Feeding responses of adult *Coleomegilla maculata* (Coleoptera: Coccinellidae) to eggs of Colorado potato beetle (Coleoptera: Chrysomelidae) and green peach aphid (Homoptera: Aphididae). *Environ. Entomol.* **20**, 644-651.
- Hazzard, R. V., Ferro, D. N., Van Driesche, R. G., and Tuttle, A. F. 1991. Mortality of eggs of Colorado potato beetle (Coleoptera: Chrysomelidae) from predation by *Coleomegilla maculata* (Coleoptera: Coccinellidae). *Environ. Entomol.* **20**, 841-848.
- Hilbeck, A., and Kennedy, G. G. 1995. Predators feeding on the Colorado potato beetle in insecticide-free plots and insecticide-treated commercial potato fields in eastern North Carolina. *Biol. Control* **6**, 273-282.
- Hilbeck, A., Eckel, C., and Kennedy, G. G. 1997. Predation on Colorado potato beetle eggs by generalist predators in research and commercial potato plantings. *Biol. Control* **8**, 191-196.
- Hodek, I. 1973. "Biology of Coccinellidae." Junk, The Hague/Academia, Prague.
- Hough-Goldstein, J. A., Heimpel, G. E., Bechmann, H. E., and Mason, C. E. 1993. Arthropod natural enemies of the Colorado potato beetle. *Crop Protect.* **12**, 324-334.
- Mack, T., and Smilowitz, Z. 1982. Using temperature-mediated functional response models to predict the impact of *Coleomegilla maculata* (DeGeer) adults and third instar larvae on green peach aphids. *Environ. Entomol.* **11**, 46-52.
- Maredia, K. M., Gage, S. H., Landis, D. A., and Worth, T. M. 1992. Ecological observations on predatory coccinellidae (Coleoptera) in southwestern Michigan. *The Great Lakes Entomol.* **25**, 265-270.
- Michels, G. J., Jr., and Behle, R. W. 1992. Evaluation of sampling methods for lady beetles (Coleoptera: Coccinellidae) in grain sorghum. *J. Econ. Entomol.* **85**, 2251-2257.
- Rice, M. E., and Wilde, G. E. 1988. Experimental evaluation of predators and parasitoids in suppressing greenbugs (Homoptera: Aphididae) in sorghum and wheat. *Environ. Entomol.* **17**, 836-841.
- Richerson, J. V., and DeLoach, C. J. 1973. Seasonal abundance of *Perillus coccinellae* and its coccinellid host and degree of parasitism in central Missouri. *Environ. Entomol.* **2**, 138-141.
- Risch, S. J., Wrubel, R., and Andow, D. 1982. Foraging by a predaceous beetle, *Coleomegilla maculata* (Coleoptera: Coccinellidae), in a polyculture: Effects of plant density and diversity. *Environ. Entomol.* **11**, 949-950.
- Roach, S. H., and Thomas, W. M. 1991. Overwintering and spring emergence of three coccinellid species in the coastal plain of South Carolina. *Environ. Entomol.* **20**, 540-544.
- SAS Institute 1990. "SAS/STAT User's Guide." Version 6.12. SAS Institute, Cary, NC.
- Shade, R. E., Hansen, H. L., and Wilson, M. C. 1970. A partial life table of the cereal leaf beetle, *Oulema melanopus*, in northern Indiana. *Ann. Entomol. Soc. Am.* **63**, 52-59.
- Smith, B. C. 1960. A technique for rearing coccinellid beetles on dry foods, and influence of various pollens on the development of *Coleomegilla maculata* Lengi Timb. (Coleoptera: Coccinellidae). *Can. J. Zool.* **38**, 1047-1049.
- Smith, B. C. 1971. Effects of various factors on the local distribution and density of coccinellid adults on corn (Coleoptera: Coccinellidae). *Can. Entomol.* **103**, 1115-1120.
- Udayagiri, S., Mason, C. E., and Pesek, J. D., Jr. 1997. *Coleomegilla maculata*, *Coccinella septempunctata* (Coleoptera: Chrysomelidae), *Chrysoperla carnea* (Neuroptera: Chrysopidae), and *Macrocentrus grandii* (Hymenoptera: Braconidae) trapped on colored sticky traps in corn habitats. *Environ. Entomol.* **26**, 983-988.
- Warren, L. O., and Tadic, M. 1967. Biological observations on *Coleomegilla maculata* and its role as a predator of the fall webworm. *J. Econ. Entomol.* **60**, 1492-1496.
- Whitcomb, W. H., and Bell, K. 1964. "Predaceous Insects, Spiders and Mites of Arkansas Cotton Fields," Arkansas Experimental Station Bulletin 690.
- Wright, E. J., and Laing, J. E. 1982. Stage specific mortality of *Coleomegilla maculata* lengi Timberlake on corn in southern Ontario. *Environ. Entomol.* **11**, 32-37.
- Zehnder, G. W., Powelson, M. L., Jansson, R. K., and Raman, K. V. (Eds.) 1994. "Advances in Potato Pest Biology and Management," APS Press, St. Paul, MN.