Overwintering and Spring Emergence of Three Coccinellid Species in the Coastal Plain of South Carolina

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Environ. Entomol. 20(2): 540–544 (1991)

ABSTRACT Overwintering sites and spring emergence periods of three commonly occurring coccinellids were studied from 1984 to 1989 in the upper coastal plain area of South Carolina. In addition, experiments were conducted to determine the influence of temperature and photoperiod upon the feeding activity of overwintering *Hippodamia convergens* (Guérin-Méneville) when removed from hibernation sites. Feeding activity began shortly after removal from hibernation, increased with increasing temperatures and continued during both the photoperiod and the scotoperiod. Broomsedge, *Andropogon virginicum* L., was found to be an important overwintering site for *H. convergens*. *Coleomegilla maculata* (De Geer) and *Coccinella septempunctata* L. often shared the same overwintering habitat. Spring emergence of all three species was found to be controlled by temperature and all species began emergence at ≈50DD accumulated degree-days, with the emergence period extending from about the first week of March to the middle of April. A tendency for directional flight upon emergence was shown by all three species, with significantly more *H. convergens* and *C. septempunctata* flying to the east and south sides of the emergence cages, which was with the prevailing winds during the emergence period.

KEY WORDS Insecta, coccinellids, overwintering, habitats

SOME OF THE most visible and efficient predators in field and orchard crops are the Coccinellidae. Three dominant species in the South Carolina Coastal Plain are *Hippodamia convergens* (Guérin-Méneville), *Coleomegilla maculata* (De Geer), and *Coccinella septempunctata* L. *Coccinella septempunctata* was introduced from Europe (Angalet et al. 1979) and became established in South Carolina from 1984 to 1985 (S.H.R., personal observation). A tremendous amount of research and observation has been conducted on the ecology of these insects in the United States and wherever they are found. Several good reviews of this work are available (Hagen 1962, Hodek 1967). Overwintering habits of coccinellids are variable among species and over their geographical range. In different regions of the United States, *H. convergens* may produce one spring generation or several summer generations before estivohibernating or hibernating. *C. maculata* is reported to have several generations per year in the northeastern United States after hibernation (Andow & Risch 1985), or continuous generations in Venezuela without hibernation (Szumkowski 1952). In Europe and Asia, *C. septempunctata* ranges from one summer generation to continuous generations (see review by Hagen 1962); in the United States, it is reported to be almost entirely univoltine (Angalet et al. 1979).

Hibernating habits of various species of coccinellids range from large aggregations—*H. convergens*, *C. maculata*—to singly or small groups—*C. septempunctata; Olla-V-nigrum* (Mulsant). They may occur in a number of different habitats such as bare mountain peaks, leaf litter, and grass clumps (Fink 1919, Hawkes 1926, Sherman 1938, Yanes et al. 1982). The time of entry into and exit from hibernation by coccinellids may influence the amount and timing of predation that occurs on insect pests in crops. The primary purpose of this experiment was to determine the overwintering sites and periods of spring emergence by the three most numerous species of predaceous coccinellids in the South Carolina coastal plain.

Materials and Methods

Overwintering Sites and Feeding Activity. Beginning in the fall of 1984, various weed, grass, and wooded areas in the Pee Dee area of South Carolina were searched for overwintering coccinellids. Locations of beetle aggregations were noted and some were observed weekly for beetle activity throughout the winter and spring months.

During December 1984 and January 1985, *H. convergens* were removed from overwintering sites and brought into the laboratory to study their feeding behavior and activity as influenced by temperature. Three replicates of 20 beetles each were placed individually in clear plastic Petri dishes supplied with a distilled water-saturated cotton wick and 15 1-day-old *Heliothis zea* (Boddie) eggs. Rep-

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licates were set up between 0800 and 0900 hours EST and placed in controlled environment cabinets at 4.5, 10, 15.5, 21.1, and 26.5 ± 1°C, all set at photoperiods of (L:D) 12:12 (dawn, 0700, dusk 1900 hours). Observations on feeding and activity were made at 1000, 1200, 1400, and 1600 hours. Identical replicates were set up between 1500 and 1600 hours, placed in the cabinets and observed at 2100, 2400, and 0700 hours to determine feeding activity during the scoto-phase. An additional experiment was conducted in which three replications of 20 *H. convergens* each were held at 24 ± 1°C and supplied with a water source and five newly emerged first instar *H. zea*, and observed as before during the photophase for predatory feeding activity.

Spring Emergence. From 1984 to 1987, a 2-m^2 plot of broomsedge (*Andropogon virginicum* L.) was established at the Pee Dee Research and Education Center (PDREC) by transplanting 8–10 large plants containing overwintering beetles into the plot, usually in December on a day when temperatures remained between 1 and 5°C during the day. In 1988, six plots of broomsedge were established at different field sites at the PDREC as previously described. In each year and at all locations in 1989, the sedge clump plots were covered with a screen cage (3 by 3 by 2 or 2 by 2 by 2 m) during the last week of February. One green (John Deere green, John Deere Company, Moline, Ill.) and one white enamel wood panel, each 0.5 by 0.5 m and coated with Tanglefoot (Tanglefoot Company, Grand Rapids, Mich.) were suspended on each side of the interior of the cages. The panels were examined daily (except weekends) for beetles that left the sedge clumps and flew to the panels. To test whether the coccinellid species flew in a particular direction, we calculated an *F* value using the following equation:

$$F = \frac{\chi^2 \text{ direction totals/df}}{\chi^2 \text{ directions} \times \text{years/df}}.$$

We used the cumulative Weibull function to describe the probability distribution of emergence from overwintering for each coccinellid species. A SAS program developed by Wagner et al. (1984) was used to fit a cumulative Weibull function to the emergence data, as a function of accumulated degree-days (DD). The three-parameter Weibull function has the form:

$$F_{(x)} = 1 - exp(-[x - \gamma)/\eta]^{\beta})$$

where $F_{(x)}$ is the probability of complete emergence at time x (DD), and γ, β, and η are parameter estimates.

Degree days were calculated as follows:

$$\text{DD} = \Sigma\ ([max + min/2]) - 12.0$$

DD, accumulated degree days above a threshold of 12°C; *max*, maximum temperature; *min*, minimum temperature. DD were accumulated beginning on 1 January. Air temperature values were obtained from a weather station located at the USDA–ARS, Coastal Plains Soil and Water Conservation Research Center, Florence, S.C.

This SAS program (Wagner et al. 1984) was designed to handle data from constant temperature experiments. Because temperature has such a strong influence on developmental rate, the cumulative probability distributions are displaced in time. Each distribution is normalized by multiplying the developmental times of each distribution by that distribution median rate. Normalizing each distribution results in the distributions at all experimental temperatures falling on top of each other. This results in one standard curve for all temperatures, which can be used to predict developmental time of individuals in a population under variable temperatures.

Since these data were collected under variable temperatures, the normalization of the distributions was eliminated and the Weibull function was fitted to the original data set. Cumulative degree-days was substituted for developmental time and the number of individuals of each species emerging from overwintering at each cumulative degree-day was entered.

Results and Discussion

Overwintering Sites and Feeding Activity. Overwintering habitats of *H. convergens*, *C. maculata*, and *C. septempunctata* generally differ in the coastal plain area; however, they were found to cohibernate in broomsedge. The primary species in broomsedge was *H. convergens*, whereas the other two species were usually found in limited numbers in the sedge clumps. Sedge clumps of 15 cm or greater base diameter, unburned and in full-day sunlight, were the most preferred overwintering sites. However, only a few sedge clumps in any field site were used as overwintering sites by *H. convergens*, and in some years, few beetles were found in any site in the sampling area. Because this species is noted for its migratory habits, there is a possibility that certain unknown fall weather conditions may promote long-range movement to overwintering sites while others may force local aggregation. This question needs further research.

Occasional aggregations of *H. convergens* were found in smut grass, *Sporobolus poiretic* (Roem & Schult); in a partially cut pile of Coastal Bermuda grass (*Cynodon* spp.); and in limited numbers in tufts and piles of plant debris along fence lines. One large aggregation of over 200 *H. convergens* beetles was discovered on the underside of a small pine tree that was bent to the ground and surrounded by common Bermuda grass.

Coleomegilla maculata was found primarily around large trees such as pecan in open areas near fields, and in forest leaf litter along the sides of fields. These areas were characterized by a deep layer of largely decomposed organic matter. Several thousand beetles were present in some areas

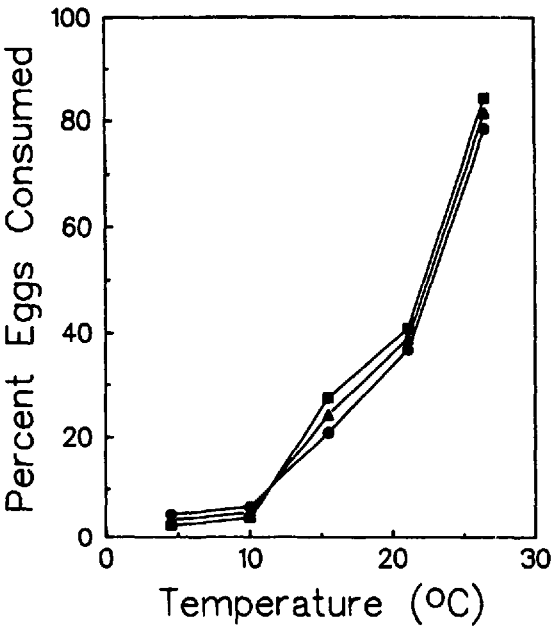

Fig. 1. Consumption of *H. zea* eggs by overwintering *Hippodamia convergens* during photoperiod (L:D 12:12) at different temperatures. ■—■, night; ●—●, day; ▲—▲, mean.

while only a few were present in others. The limited numbers of *C. maculata* found in broomsedge were mainly in large clumps that were growing in moist, high organic soil locations.

Coccinella septempunctata was not found in large aggregations in any sampled habitat, but they were usually scattered singly or two to three individuals in broomsedge clumps, in tree bark crevices, in living pine needle clusters, and in other grass and weed clumps in and around open fields. This species has apparently become established in the Coastal Plain area and is often the most prevalent species collected in field samples by the authors (unpublished data).

When overwintering *H. convergens* were removed from hibernation and brought into the laboratory, their movement increased dramatically within 1–2 h at 24 ± 2°C. Beetles usually drank water avidly and rapidly walked about the holding containers after warming up. The availability of water was previously shown to increase longevity in *Coccinella trifasciata perplexa* Muls. (Smith 1965) and is evidently a requirement for *H. convergens*.

Hippodamia convergens placed in different temperatures and given *H. zea* eggs showed significant temperature-related feeding responses (Fig. 1). Little feeding occurred between 4.5 and 10°C, but increased rapidly at temperatures >15.5°C, exceeding 80% in 24 h at 26.5°C. The same feeding activity was noted during light and dark periods, which indicates a high degree of activity throughout the 24-h cycle under the conditions of these experiments. The maximum number of eggs consumed by individual beetles and time of feeding to satiation was not determined, but satiation evidently was not reached in 24 h because the beetles continued to consume eggs at the higher temperatures. In somewhat similar experiments, Shands & Simpson (1972) reported that aphid consumption was greater by nondiapausing than by diapausing female *C. septempunctata*, and aphid consumption increased with increasing temperature.

When newly emerged first-instar *H. zea* larvae were given to *H. convergens*, satiation may have affected the number of larvae consumed. Between 0900 and 1230 hours EST, 65% of the larvae were eaten by the beetles while from 1230 to 1800 hours

Table 1. Collection of emerging overwintered Coccinellids flying to colored sticky panels on each side of screen cages located on the Pee Dee Research and Education Center, Florence, S.C. 1985–1989

Year	Species	Direction[a]				Color	
		N	E	S	W	Green	White
1985	*H. convergens*	44	31	60	57	78	114
	C. maculata	0	0	2	3	3	2
	C. septempunctata	0	1	0	0	0	1
1986	*H. convergens*	0	1	0	0	1	0
	C. maculata	6	20	14	3	21	22
	C. septempunctata	0	0	0	0	0	0
1987	*H. convergens*	138	509	707	140	529	965
	C. maculata	58	102	133	26	130	189
	C. septempunctata	0	1	6	2	4	5
1988	*H. convergens*	72	96	120	51	108	231
	C. maculata	2	1	1	0	1	3
	C. septempunctata	1	2	8	1	4	8
1989	*H. convergens*	57	63	90	83	144	149
	C. maculata	11	9	27	58	31	74
	C. septempunctata	9	10	50	21	46	44
Totals[a]	*H. convergens*	311	700	977	331	860	1,459
	C. maculata	77	129	176	89	186	287
	C. septempunctata	10	20	58	24	54	58

[a] F-test for direction effects: *H. convergens* ($P = 0.03$); *C. maculata* ($P = 0.26$); *C. septempunctata* ($P = 0.01$).

Table 2. Estimated parameters and asymptotic standard errors (in parentheses) for the cumulative Weibull function for emergence of coccinellids from overwintering

Species	γ	η	β	R^2
Hippodamia convergens	51.89 (1.11)	31.32 (1.73)	1.03 (0.08)	0.983
Coleomegilla maculata	50.64 (19.68)	69.62 (20.22)	2.97 (0.91)	0.968
Coccinella septempunctata	90.67 (0.07)	6.89 (0.91)	0.54 (0.06)	0.943

EST, only 16% of the larvae were consumed. Overall, 81% of the larvae supplied to beetles removed from hibernation were consumed within 8 h at 24° ± 2°C. These feeding results were in contrast to observations made by Rankin & Rankin (1980), who indicated that *H. convergens* (obtained from California) removed from low temperature storage and placed in 24°C in December would not feed, even if given live aphids, for 4 d. However, by May they would feed within 1 d after removal from low temperature storage.

Earlier experiments with *H. convergens* conducted by Davis & Kirkland (1982) showed that overwintering beetles that had been removed from hibernation and fed attained ovarian maturity within 8 d. Before ovarian maturity, beetles displayed various levels of flight activity and temperature was found to be instrumental in controlling flight activity. In contrast to dispersal behavior, feeding behavior was initiated early in the day at much lower temperatures and unfed beetles showed significantly greater total flight activity than fed beetles. In our studies, little flight tendency was noted during the 24-h holding periods after removal from hibernation. Solbreck (1974) reported that in *C. maculata* there is a successive maturation of flight behavior in the spring that is largely controlled by temperature acting over an extended period, and temperatures >15° are necessary for flight maturation to take place.

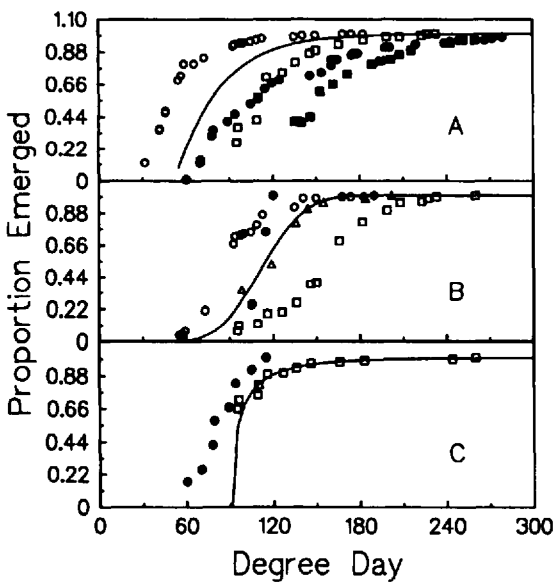

Fig. 2. *A.* Capture of emerging overwintered *Hippodamia convergens* on sticky panels vs. degree day temperature accumulation above 12°C. *B.* Capture of emerging overwintered *Coleomegilla maculata* on sticky panels vs. degree day temperature accumulation above 12°C. *C.* Capture of emerging overwintered *Coccinella septempunctata* on sticky panels vs. degree day temperature accumulation above 12°C. Circles indicate observed emergence; solid line indicates predicted emergence. ■, 1985; △, 1986; ○, 1987; ●, 1988; □, 1989; ——, predicted.

Spring Emergence. The numbers of each species of coccinellids emerging from the sedge clumps and flying to the sticky panels in the cages are given in Table 1. Considerable differences in numbers of each species occurred each year when only one cage was used to record emergence (1985–1988). The variation between numbers of each species each year in the cages made analysis for direction and color difficult. There were no significant differences in number of coccinellids caught on white compared with green panels. However, there was a significant tendency for the *H. convergens* to fly east or south when leaving the sedge clumps. *C. septempunctata* showed a similar tendency, flying significantly more often to panels on the south or east sides of the cages. No significant difference was found for flight direction by *C. maculata*.

The significance of directional flight by beetles leaving hibernation sites is unclear, because all

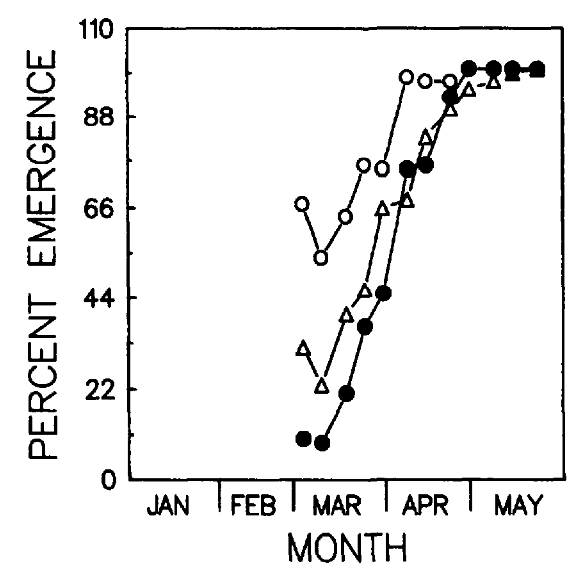

Fig. 3. Cumulative spring emergence of *Hippodamia convergens, Coleomegilla maculata,* and *Coccinella septempunctata* from broomsedge clumps during 1985–1989 at Florence, S.C. △, *Hippodamia;* ○, *Coccinella;* ●, *Coleomegilla.*

cages were located in open field areas, subject to full-day sunlight and largely unobstructed wind currents. Prevailing winds during flight initiation may have been responsible for this directional flight. On the 24 observation collection dates in 1989 (22 February–19 April), the prevailing winds were out of the northeast (11 times) and northwest (12 times). A higher proportion of captures of all three species was on panels on the south, east, and west sides of the cages. Thus, it is probable that beetles leaving the sedge clumps and taking flight move with the wind initially before orienting to whatever direction they may chose to begin their post-hibernation activities.

The spring emergence patterns of the three species of coccinellids were found to be closely related to environmental temperatures. To predict the emergence of coccinellids, a cumulative Weibull function (Wagner et al. 1984) was fit to the proportion emerged as a function of degree-days. Estimates of the parameters γ, β, and η are given in Table 2. The observed and predicted cumulative emergence from overwintering for each coccinellid species are given in Fig. 2. The γ parameter estimates the number of degree-days just before overwintering emergence begins. All three species began emergence at $\approx$50 DD. The estimated γ parameters for *H. convergens* and *C. maculata* were 51.89 and 50.62, respectively. The estimated γ parameter for *C. septempunctata* was larger (90.67) because of the rapid emergence in 1989, when 66% of the population emerged on 22 February. In 1988, the emergence curve was similar to that of the other two species. Using air temperature to calculate degree-days did not result in a close fit between observed and predicted emergence. This could have been caused by the temperature within the sedge clumps being different from air temperature. Fye (1971) found that the temperature within the cotton plant canopy is $\approx$2°C less than air temperature. Using temperatures measured within the sedge clumps instead of using air temperature may result in a better estimate of coccinellid emergence.

Cumulative spring emergence recorded for the three species of coccinellids over the 5-yr period of this study is shown in Fig. 3. *C. septempunctata* began emergence in late February and all had emerged by the last of March. The other two species, *H. convergens* and *C. maculata*, normally began emergence at the end of February or during the first week of March, but *Hippodamia* seemed to emerge a little earlier and more uniformly than *Coleomegilla*. In any case, all three species were generally gone from the grass clumps by mid April of each year.

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Received for publication 5 March 1990; accepted 1 October 1990.