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BIOLOGY AND ECOLOGY OF TWO PREDATERS, GEOCORIS PALLENS STAL AND G. BULLATUS
TAMAKI, G. ; WEEKS, R E 1 OF 1

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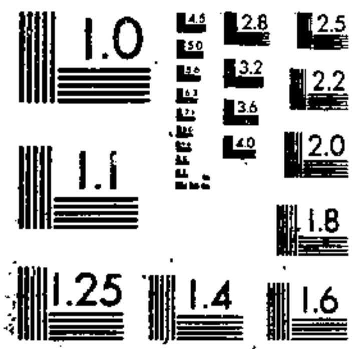

MICROCOPY RESOLUTION TEST CHART
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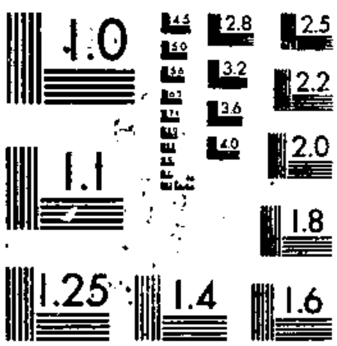

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ABSTRACT

Biology and ecology of *Geocoris pallens* and *G. bullatus*, two omnivorous predators, were studied. Laboratory-rearing and interbreeding tests were conducted to differentiate the life stages of both species. Eggs of *Geocoris* hatched at 21° to 41° C., and egg developmental rate varied with temperature and also with time of adult collection. Combination of sunflower seeds, insects, and green plant food was the best diet for the quickest developmental rate, highest egg production, and the greatest survival rate. Sunflower seed when placed in the field concentrated *Geocoris* and increased oviposition. Alfalfa as interplants in a mixed-culture experiment served as a breeding and reservoir site for *Geocoris*. *Geocoris* was also the most abundant predator in the predator complex in the mixed-culture experiment. Daily high temperatures above 24° appear to be correlated with the increase in *Geocoris* flight. In the seasonal-life-history studies on alfalfa *G. bullatus* overwintered in the adult and egg stage and had at least three generations per year, but *G. pallens* overwintered as adults and had at least two generations per year. Both species decline in September on cultivated crops, but *G. bullatus* is found in great abundance in orchardgrass in the fall.

ACKNOWLEDGMENT

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BIOLOGY AND ECOLOGY OF TWO PREDATORS, *Geocoris pallens* Stål and *G. bullatus* (Say)[1]

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INTRODUCTION

In the Yakima Valley of Washington, the two most common species of *Geocoris* are *G. pallens* Stål and *G. bullatus* (Say) (Lygaeidae: Geocorinae). *G. atricolor* Montandon is much less numerous. These insects are found in nearly all cultivated fields, orchards, residential yards, weedy areas, and even in meadows of the *Pinus ponderosa* zone about 3,000-foot elevation on the eastern slopes of the Cascade Mountains. Because of their great abundance and wide distribution, we undertook the study of comparative biology and ecology of *G. pallens* and *G. bullatus* for the better understanding of these predators and for the possibility of manipulating populations in an integrated control program.

A paper by McGregor and McDonough (*28*)[2] presented one of the earlier studies that used quantitative data to evaluate *Geocoris* as a predator. They reported that *G. punctipes* (Say) was an effective predator of the two-spotted spider mite, *Tetranychus urticae* Koch; but, as Usinger (*42*) has reported, early references, almost without exception, refer to *Geocoris* as destructive insects. These references were often based on superficial evidence of the occurrence of the insects on a given plant. After the mid-1930's, most of the literature established *Geocoris* as a beneficial insect; however, Goeden and Ricker (*15*) found that *G. pallens* was predaceous on species of weevils that were introduced into California for the control of puncturevine, *Tribulus terrestris* L.

Papers by York (*46*) and Sweet (*41*) contributed to better understanding of *Geocoris*. York found that *G. pallens* and *G. punctipes* required moisture as well as insect food and fed on plants as the primary source of moisture. Sweet reported on the seed-feeding habits of Lygaeidae and established the subfamily Geocorinae as definitely predaceous. He also found that *Geocoris uliginosus* (Say), *G. bullatus*, and *Hypogeocoris piceus* (Say) were by no means obligate predators because adults survived upon sunflower seeds and water for as long as 3 or 4 months. He hypothesized that "This apparent omnivorousness may well account for the high abundance of many geocorines, which has always puzzled students who have considered them strictly predatory. In view of the prevalence of seed feeding, it is very likely that Geocorinae and the Cleradini are derived from seed feeding ancestral forms."

A prey list of *Geocoris* species, their localities, and references are found in table 1. An attempt was made to list only the earliest reference to a particular prey species. Undoubtedly the list is incomplete. Table 1 definitely establishes *Geocoris* as omnivorous predators because of their wide prey range. *Geocoris* encompass a wide habitat range, including legumes, cotton, sugarbeet, vegetables, citrus, ornamentals, tobacco, and other cultivated and noncultivated plants, throughout most of the world.

[1] Published in cooperation with the College of Agriculture, Research Center, Washington State University, Pullman 99163.

[2] Italic numbers in parentheses refer to Literature Cited, p. 45.

TABLE 1.—*Prey list of* Geocoris *species*

Prey	Predator	Reference	Location
Hemiptera:			
Therioaphis maculata (spotted alfalfa aphid).	*G. pallens*	Smith and Hagen (1956)	California.
Do	*G. atricolor*	do	Do.
Do	*G. punctipes*	do	Do.
Nearctaphis bakeri (clover aphid).	*G. bullatus*	Smith (1923)	Idaho.
Acyrthosiphon pisum (pea aphid).	*G. atricolor*	Knowlton and Stains (1941)	Utah.
Myzus persicae (green peach aphid).	*G. decoratus*	Knowlton (1936)	Do.
Circulifer tenellus (beet leafhopper).	*G. pallens*	Essig (1926)	California.
Empoasca devastans (leafhopper).	*G. tricolor*	Subba Rao and others (1965)	India.
Do	*G. jucundus*	do	Do.
Empoasca solana	*G. punctipes*	Moffitt (1967)	California.
Aleyrodes spiraeoides (whitefly).	*G. pallens*	Landis and others (1958)	Washington.
Trialeurodes abutilonea (banded-winged whitefly).	do	do	Do.
Paratrioza cockerelli (potato psyllid).	*G. decoratus*	Knowlton (1933)	Utah.
Trioza maura (psyllid).	*G. atricolor*	Knowlton (1942)	Do.
Ferrisia virgata (striped mealybug).	*G. tricolor*	Otanes and Butac (1935)	Philippines.
Citrus red scale	*G. liolestes*	Hesse (1947)	South Africa.
Creontiades pallidus (mirid).	*G. amabilis*	Soyer (1942)	Africa.
Nysius ericae (false chinch bug).	*G. atricolor*	Knowlton (1935)	Utah.
Calocoris angustatus (mirid).	*G. tricolor*	Rangarajan and others (1964)	India.
Ragmus importunitus (mirid).	do	do	Do.
Psallus seriatus (cotton fleahopper).	*G. punctipes*	Isely (1927)	Arkansas.
Lygus pratensis (lygus bug).	do	do	Do.
Adelphocoris rapidus (rapid plant bug).	do	do	Do.
Coleoptera:			
Myllocerus viridanus (weevil).	*G. tricolor*	Rangarajan and others (1964)	India.
Amorphoidea lata (weevil).	do	Otanes and Butac (1935)	Philippines.
Lady beetle	*G. liolestes*	Hesse (1947)	South Africa.
Epitrix parvula (flea beetle).	*G. punstipes*	Chamberlin and Tenhet (1923)	Florida and Georgia.
Lepidoptera:			
Protoparce sp. (hornworm).	do	Gilmore (1936)	North Carolina.
Heliothis zea	*G. uliginosus*	Bell and Whitcomb (1964)	Arkansas.
H. virescens	do	do	Do.

TABLE 1.—*Prey list of* Geocoris *species*—Continued

Prey	Predator	Reference	Location
Acarina:			
Tetranychus urticae (two-spotted spider mite).	*G. punctipes*	McGregor and McDonough (1917)	South Carolina.
Paratetranychus indicus (cholam mite).	*Geocoris* sp.	Cherian (1933)	India.

DISCRIMINATORY CHARACTERISTICS

During the summer, when *Geocoris* were found in great abundance in the Yakima Valley, the genus was generally represented by two species, *G. pallens* and *G. bullatus*. Except for the apparent size and color differences between the two species—*G. bullatus* is larger and darker than *G. pallens*—we were unable to find any distinguishing morphological differences between them. Therefore, specimens of both species were sent to two taxonomists to confirm our indentification. The taxonomists did not agree with each other on the identification of these species. In 1967, a personal communication with P. D. Ashlock, University of Kansas, clarified the taxonomic status of these species. He informed us that besides the size differences between the two species, no apparent external morphological or genitalial differences have been reported that would distinguish these species throughout their geographic range. Stater and Knop (*38*) found similar difficulties in the same family (Lygaeidae) in which species of *Lygaeus kalmii* Stål and *L. reclivatus* Say both exhibited geographic variation with an intergrade zone.

Interbreeding

To determine if two separate species existed in the Yakima Valley, we conducted an interbreeding experiment. Fifth instar nymphs of *G. pallens* and *G. bullatus* were collected from a field of alfalfa. All individuals were kept separately in small plastic cages to make certain that all emerging adults were virgin. When the adults emerged, four mating combinations were established as follows: Male and female of *G. pallens*; male of *G. pallens* with female of *G. bullatus*; male of *G. bullatus* with female of *G. pallens;* and male and female of *G. bullatus*. Each pair was placed in a cylindrical plastic cage (15 cm. in diameter and 6 cm. deep) with sugarbeet leaves, green peach aphids (*Myzus persicae* (Sulzer)), and chopped sunflower seeds (*Helianthus annus* L.) for food. Each paired combination was replicated five times. These cages were kept in the laboratory under 16-hour-day length and an average temperature of 24° C. Every 2 to 3 days, new food was added to the cages and the eggs were removed for incubation.

In cages with combinations of *G. pallens* and *G. bullatus*, either male or female, no copulation was observed and no fertile eggs were laid. However, with presumably pure species lines, copulation was observed and many fertile eggs were laid (table 2). These results biologically substantiated our separation of the two species.

Description of Life Stages

To differentiate the nymphal instars of *G. pallens* and *G. bullatus*, we separated the eggs from field-collected adults of both species. These eggs were incubated in the laboratory at an average temperature of 24° C. (range 17°–29°). After eclosion, 20 nymphs of each species were measured and described. This procedure was repeated after each successive molt. From these data, we were able to distinguish the instars of both species. Thus, field-collected *Geocoris* of all stages were separated into their respective instars and species on the basis of data from laboratory specimens.

The following descriptions of life stages are sufficient to differentiate between the two species in this region. They will not necessarily provide separation for the species throughout their distributions.

TABLE 2.—*Results of the interbreeding of* Geocoris pallens *and* G. bullatus *in the laboratory*

Mating pairs Female	Male	Average number eggs/female/day	Total number of observed matings	Total number eggs hatched
G. pallens	*G. bullatus*	1.3	0	0
G. pallens	*G. pallens*	5.2	5	160
G. bullatus	*G. pallens*	2.8	0	0
G. bullatus	*G. bullatus*	5.3	7	113

Adult

Length, width, and interocular measurements of field- and laboratory-reared *Geocoris* indicated that females of *G. bullatus* are the larger of the two species (tables 3 and 4). The males of *G. bullatus* are equivalent in size to females of *G. pallens*, and males of *G. pallens* are the smallest adults. Besides size, color differences are distinct between the two species. The legs of both sexes of *G. pallens* are light tan or straw colored, and on some this is interspersed with tiny brown spots. Legs of *G. bullatus* females are entirely dark brown, and those of males are spotted with dark brown against a lighter background. The ventral abdominal sclerites of *G. pallens* are light to dark tan, but those of *G. bullatus* are dark brown to black.

Males of both species can be easily distinguished from the ventral and dorsal views. Ventrally, differences in the external genitalia are visible, males having periphallic lobes and females showing their ovipositors. Dorsally, males of both species have white pigmentation covering the dorsal surface of the antennae but females lack the white coloring.

Egg

Eggs of *Geocoris* are ovoid or spheroidal with chorionic processes that are seen under magnification. These chorionic processes consist of a circle of notches around the blunt end of the egg. The eggs of *G. bullatus* averaged 7.9 (range 6–10) processes in the ring and eggs of *G. pallens* averaged 6.3 (range 6–8). Because of the overlapping range in the numbers of chorionic processes on the eggs, these processes cannot be used to separate the eggs of the two species. However, color and size can be used to separate the eggs. Eggs of *G. pallens* are tan, and the eggs of *G. bullatus* are light pink; the eggs of *G. pallens* are smaller than the eggs of *G. bullatus* (table 4).

First Instar

Nymphs are very difficult to locate in large numbers in the field, because of their small size and cryptic behavior of living under duff and crowns of plants. Only a few first instars of *Geocoris* were collected; therefore, no measurements or descriptions of the field-collected first instars are given (table 4). However, from our laboratory rearing, many first instars were available for study (table 3). There were differences in length and width of the two species, with *G. bullatus* being larger, but no difference existed for interocular measurements of the two species.

Second Instar

A pronounced thoracic plate generally marked with brown spots running laterally across the pronotum distinguishes the second from the first instar. Other differences that distinguish the second from the first instar nymphs are the appearance of red pigmentation in the abdomen of the second instar and size differences (tables 3 and 4). Species differentiation between the second instars are based on color and size. The legs of *G. pallens* are light tan and its abdomen is light red. The legs of *G. bullatus* are colored with light to dark brown blotches and its abdomen is dark red. *G. bullatus* is longer and wider than *G. pallens*, but still no apparent size differences existed in their interocular distances.

Third Instar

Besides the size differences between the second and third instars (tables 3 and 4), the rudimentary wing pads are first visible in the third instar. The species differ in coloring in this in-

TABLE 3.—*Measurements of* Geocoris *spp. reared (on green peach aphids, sunflower seeds, and sugarbeet leaves) in the laboratory*

Stage	Number		Mean ±SD., mm. Length		Width		Interocular	
	G. bullatus	*G. pallens*	*G. pallens*	*G. bullatus*	*G. pallens*	*G. bullatus*	*G. pallens*	*G. bullatus*
First nymph	20	23	1.08 ±0.08	1.19 ±0.06	0.43 ±0.08	0.54 ±0.06	0.26 ±0.00	0.26 ±0.01
Second nymph	29	18	1.35 ± .09	1.53 ± .08	.66 ± .05	.76 ± .06	.31 ± .02	.31 ± .02
Third nymph	18	15	1.64 ± .12	1.91 ± .18	.80 ± .10	.97 ± .12	.37 ± .01	.40 ± .02
Fourth nymph	18	20	2.18 ± .15	2.34 ± .18	1.06 ± .12	1.15 ± .13	.48 ± .03	.52 ± .03
Fifth nymph (male)	25	20	2.84 ± .16	3.27 ± .13	1.28 ± .10	1.49 ± .09	.59 ± .03	.67 ± .04
Fifth nymph (female)	10	20	3.04 ± .16	3.48 ± .18	1.66 ± .06	1.71 ± .11	.62 ± .02	.67 ± .04
Adult (male)	19	20	3.10 ± .16	3.66 ± .15	1.25 ± .06	1.55 ± .09	.60 ± .03	.71 ± .04
Adult (female)	19	20	3.50 ± .20	4.07 ± .19	1.53 ± .11	1.94 ± .09	.68 ± .02	.78 ± .03

TABLE 4.—*Measurements of* Geocoris *spp. collected from a field of alfalfa on August 1, 1969*

Stage	Number		Mean ±SD., mm. Length		Width		Interocular	
	G. pallens	*G. bullatus*	*G. pallens*	*G. bullatus*	*G. pallens*	*G. bullatus*	*G. pallens*	*G. bullatus*
Egg	100	100	0.88 ±0.03	0.92 ±0.03	0.37 ±0.01	0.42 ±0.02	---------	---------
Second nymph	20	20	1.43 ± .09	1.60 ± .07	.64 ± .06	.74 ± .06	0.31 ±0.03	0.32 ±0.02
Third nymph	20	20	1.84 ± .12	2.06 ± .10	.83 ± .08	1.01 ± .08	.36 ± .01	.43 ± .02
Fourth nymph	20	20	2.40 ± .10	2.67 ± .15	1.12 ± .09	1.35 ± .15	.47 ± .03	.57 ± .02
Fifth nymph (male)	20	20	2.96 ± .16	3.30 ± .25	1.25 ± .12	1.64 ± .10	.59 ± .03	.66 ± .03
Fifth nymph (female)	20	10	3.22 ± .15	3.64 ± .15	1.55 ± .11	1.91 ± .12	.63 ± .02	.71 ± .04
Adult (male)	30	30	3.23 ± .06	3.70 ± .11	1.23 ± .06	1.49 ± .08	.62 ± .03	.71 ± .04
Adult (female)	30	30	3.71 ± .19	4.31 ± .22	1.50 ± .10	1.85 ± .08	.70 ± .04	.81 ± .04

star. The abdomen of *G. pallens* is light red and silverish or whitish pigments cover parts of the head and thorax. The legs are light tan and some have a brown blotch at the distal end of the femur. In contrast, the abdomen of *G. bullatus* is dark red with blotches of brown on the head and thorax and its legs are dark brown. At this stage there is a significant difference in the interocular distance between the two species. *G. bullatus* having the greater spread (table 4).

Fourth Instar

In this instar, the wing pads are slightly longer than half the width of the thorax. There are four major features in the fourth instar that separate the two species. In *G. pallens* these are: (1) legs are light tan with a few brown spots; (2) scutellum is light tan with small, light brown spots on the anterior lateral part; (3) wing pads are tan except for the laboratory-reared *G. pallens*, which has a median-brown longitudinal stripe on each side; and, (4) the background color of the abdomen is light red with silverish pigmentation extending to the head and thorax. In *G. bullatus* these are: (1) legs are heavily pigmented with brown and black spots; (2) scutellum has a pair of black blotches on the anterior lateral part almost meeting at the medial line; (3) wing pads are brown at the apex or the entire wing pad is brown; and (4) abdomen is dark red and head and thorax are heavily pigmented with brown blotches.

Fifth Instar

The last nymphal instar is easily distinguished from all other instars because the wing pads are almost as long as the width of the thorax. Also, in this instar, the sexes can be separated because the females of both species have a membraneous window on the ventral tip of the abdomen that exposes parts of the valvulae. Also, the female of *G. bullatus* is the longest of all fifth instar nymphs (tables 3 and 4). The male of *G. bullatus* and the female of *G. pallens* are similar in size, and both are larger than the male of *G. pallens*.

Legs of *G. pallens* are uniformly light tan and its abdomen has yellow specks on a light-red background. Its head, thorax, and wing pads have a silvery appearance. Rarely do the wing pads of *G. pallens* have dark pigmentation. *G. bullatus* differs from *G. pallens* by having spots and blotches of brown on its legs and by having its abdomen covered with greenish-blue specks on a dark-red background with the specks more heavily concentrated on the margin of the abdominal segments. The apex of the wing pad is dark brown or black.

LIFE HISTORY AND BIOLOGY

Comparative life history and biology studies of both species were conducted in the laboratory.

The primary objectives were to study the effects of temperature on the development of eggs and the effects of different foods, especially sunflower seeds, on the developmental time, survival rate, and reproductive rate of the different life stages.

Egg Development and Temperature

A series of experiments were conducted to study the effects of temperature on the developmental rate of eggs of both species. Champlain and Sholdt's (*6*) methods of analysis of the effects of temperature on eggs were used to compare their species (*G. punctipes*) with our two *Geocoris* spp. (*G. bullatus* and *G. pallens*).

In all experiments, eggs of *G. bullatus* and *G. pallens* were obtained from field-collected adults. One egg was placed in each vial and covered with muslin cloth. About 18 to 21 vials with eggs of each species were placed into a larger open container that was then placed in a gallon jar. Before sealing the jar, a color change humidity indicator card was placed on the inside wall of each jar and humidity readings were adjusted to temperature following the method of Blinn (*3*). One jar was placed in each of six cabinets, each with different constant temperatures.

In a preliminary test, eggs of both species did not hatch at 38° C. In all subsequent tests we added 200 g. of calcium nitrate in 100 ml. of water, with an approximate range of 50 to 70 percent relative humidity at each temperature.

With the addition of the salt solution, 95 to 100 percent of the eggs hatched at 40.6° (table 5). Howe (*20*) mentioned that moisture may influence the resistance to high temperatures of eggs that need to absorb water during embryogenesis. In 1969 the experiment was repeated again with higher temperatures, but no egg hatch occurred at 43° and 49°. Champlain and Sholdt (*6*), using eggs of *G. punctipes*, found that about 61 percent of the eggs hatched at 35° but no eggs hatched at 40°. They made no mention of adjusting humidity for higher temperatures and estimated 50 percent relative humidity for the experiment. If the average RH was 50 percent for all temperatures and no special attention was given to maintaining humidity at higher temperatures, humidity in the higher temperature cabinets would probably be much lower than 50 percent.

At a temperature of 15.6° C. no egg hatch occurred, but at 21°, 85 to 95 percent of the eggs hatched in all experiments for both species. No further test was conducted to determine the low-temperature threshold for successful egg hatch. Champlain and Sholdt (*6*) reported 4 percent egg hatch for *G. punctipes* at 15°, but most of these died within one day after hatching. At 20° they reported about 85 percent egg hatch for *G. punctipes*. From their findings and ours, the low temperature range for 50 percent egg hatch lies between 16° to 20° for all three species.

The mean developmental time decreased with increase in temperature within the range 21° to 41° C. (table 5). The mean development time of eggs of both species from adults field-collected on June 2, 1969, corresponded more closely to data from *G. punctipes* than with eggs obtained from adults field-collected on July 15, 1968. To substantiate this observation, we calculated the regression equation $Y=a+bX$, where Y is the reciprocal of the number of days and X is the temperature.

Table 6 compares the regression equations and r values of *G. pallens* and *G. bullatus* with that of *G. punctipes* (*6*). The slope of *G. punctipes* was given as 0.00751 by Champlain and Sholdt (*6*). The range of slopes for both *G. pallens* and *G. bullatus* was 0.00706 to 0.00783, or 94 to 104 percent of that of *G. punctipes*. Although all species appeared to have similar rates of development per unit of temperature, a covariance analysis to test the homogeneity of regres-

TABLE 5.—*Mean hatching time for eggs of* Geocoris pallens *and* G. bullatus *at various constant temperatures*

[Eggs from adults collected in 1968 and 1969]

Date adults collected and temperature, ° C.	*Geocoris pallens*			*Geocoris bullatus*		
	Initial number of eggs	Number eggs hatched	Hatching time (days) mean ±SD	Initial number of eggs	Number eggs hatched	Hatching time (days) mean ±SD
July 15, 1968:						
10.0	21	0	----------	21	0	----------
15.6	21	0	----------	21	0	----------
21.1	21	17	22.3 ±0.99	21	19	22.3 ±0.50
26.7	18	18	11.7 ± .57	21	20	12.2 ± .42
32.2	20	20	8.2 ± .37	21	21	8.1 ± .30
40.6	20	19	5.5 ± .54	21	21	5.1 ± .30
June 2, 1969:						
21.1	20	19	15.3 ± .67	20	20	15.4 ± .49
26.7	20	19	7.8 ± .54	20	20	8.4 ± .50
33.9	20	17	6.0 ±0	20	19	6.0 ±0
37.2	20	20	5.5 ± .51	20	19	5.5 ± .51
43.3	20	0	----------	20	0	----------
48.9	20	0	----------	20	0	----------

TABLE 6.—*Regression equations and r values for egg development of* Geocoris pallens, G. bullatus, *and* G. punctipes *at various constant temperatures*

Species	Date of adult collection from field	Regression equation [1]	r value [2]
G. pallens	July 15, 1968	$Y = -0.115 + 0.00750X$	0.99
	June 2, 1969	$Y = -.075 + .00706X$	.98
G. bullatus	July 15, 1968	$Y = -.125 + .00783X$	.99
	June 2, 1969	$Y = -.081 + .00718X$	.99
G. punctipes [3]		$Y = -.089 + .00751X$	.99

[1] Regression equation $Y = a + bX$, where Y is the reciprocal of the number of days and X is the temperature (° C).

[2] Correlation coefficient.

[3] Data from Champlain and Sholdt (*5*).

sion coefficient was calculated to determine if the variations in the rate of egg development were due to experimental error or whether they were significant variations. Two tests of homogeneity of regression coefficient were calculated based on temperature (° F.). One analysis tested for variation among values for b for *G. bullatus* and *G. pallens*. The other analysis tested the slopes for the rate of development of *G. bullatus* obtained in both years. No significant differences in slopes were found.

The rate of development $\frac{1}{(\text{Time})}$ of *G. pallens* and *G. bullatus* is compared with that of *G. punctipes* in figures 1 and 2. According to the tests for homogeneity of regression, the slopes of the rate of development are not significantly different but the absolute magnitude of the regression lines appear different when comparing tests conducted in 1968 and 1969.

Several possible explanations exist for the differences in the absolute magnitude of these lines. First, the differences in collection dates of field adults varied not only by year but also in time of year (July 15, 1968, and June 2, 1969). On June 2, *Geocoris* adults were primarily overwintering adults, but adults collected on July 15 were mostly first-generation adults. Another contributing factor could have been the time the eggs were removed from the cages. The eggs from adults collected on July 15, 1968, were removed for incubation within 24 hours after deposition, but the adults collected on June 2, 1969, were held in the laboratory for 72 hours before the newly deposited eggs were used in this experiment. Eggs produced during the first 48 hours of this experiment were used for another study. It is possible that, under laboratory conditions, adults may have been exposed to nutritional or crowding stress. This may have affected the physiology of the eggs or caused the adults to lay postmatured or prematured eggs.

In another test, eggs laid by adults used in the interbreeding experiment were incubated in the laboratory at an average temperature of 22.8° C. (range 17.2°–29.4°). The eggs of *G. pallens* took 13.62±2.52 SD days to hatch and eggs of *G. bullatus* took 21.05±6.34 SD days to hatch. Data from the previous experiments (table 5) showed no such extreme differences in incubation periods for the two species when tested at the same time. Although the extension of the interbreeding experiment was not designed to test the effects of temperature on egg developmental time, it is of interest that such a large variation occurred in the hatching time of both species. The large figure for the standard deviation is also of interest. The variation in hatching time among species is probably due to the field collection time of the fifth instar, because these nymphs would have been the overwintering adults. From our field observation and laboratory studies in the fall, *G. bullatus* has an overwintering egg stage, which may account for the wide variation in developmental period and the poor percentage of egg hatch with this species. From these experiments, a possibility exists that the egg stage of each *Geocoris* generation has a different incubation period at the same temperature. Therefore, before any conclusions

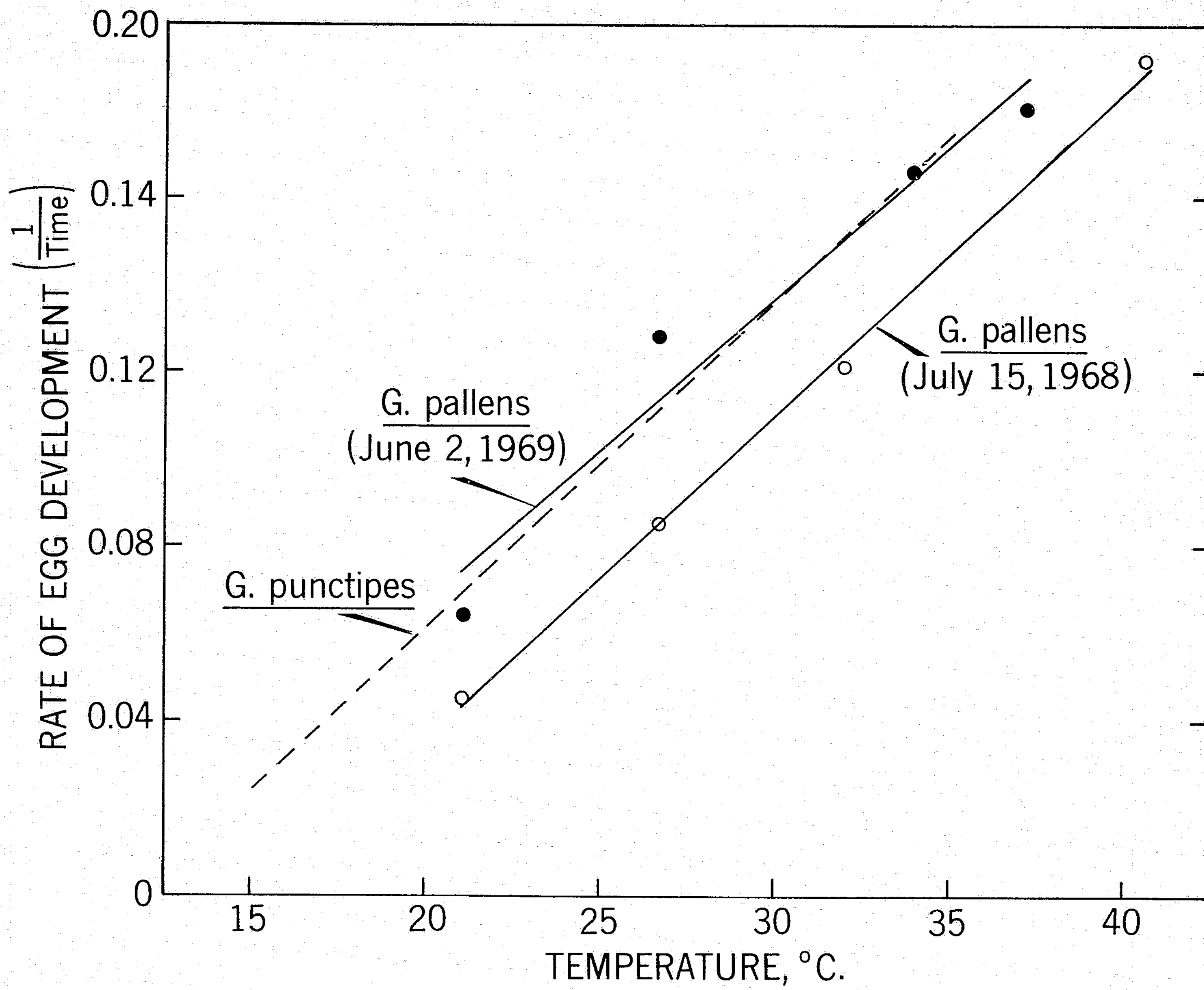

Figure 1—Comparison of rates of egg development of *Geocoris pallens* at two dates of egg collection and of *G. punctipes* as reported by Champlain and Shodt (*5*).

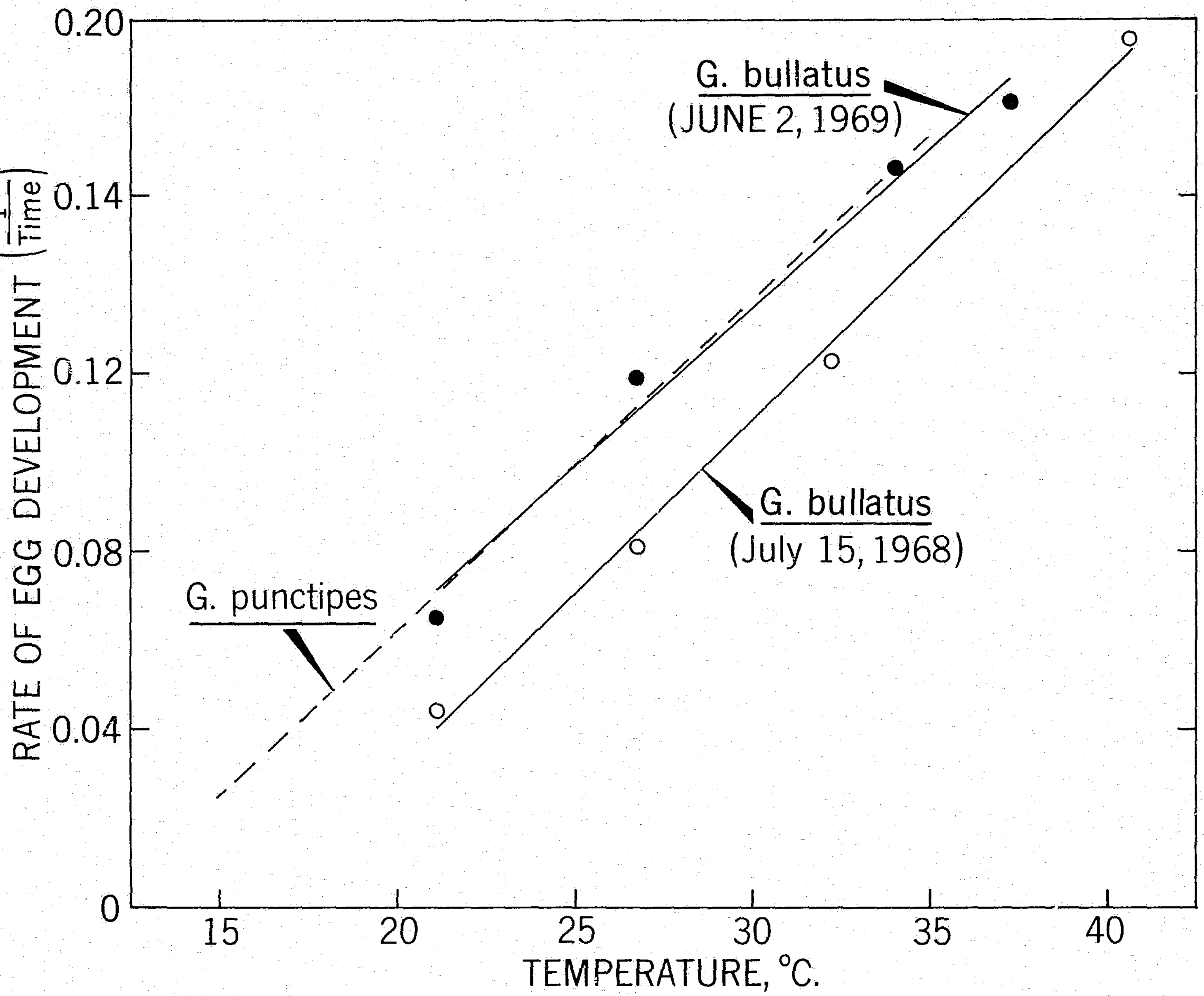

Figure 2.—Comparison of rates of egg development of *Geocoris bullatus* at two dates of egg collection and of *G. punctipes* as reported by Champlain and Sholdt (5)

or comparisons can be drawn from insect biology studies, the time of year or generation that the insect represents should be considered.

Laboratory Evaluation of Different Foods

York (*46*) reported that *Geocoris* required either free moisture or plant moisture as well as insect prey. Sweet (*41*) found that *Geocoris* can survive on sunflower seeds without insect food. However, both of these workers considered only the effects of the different foods on the survival of the adults. Before field studies could be conducted, more information was required on the effects of these foods on all the life stages of *Geocoris*.

Our goals in studying the different diets were to augment the number of *Geocoris* predators in the field by addition of supplemental foods when insect prey was not available and to determine if some of these foods would also act as arrestants for *Geocoris* to keep them in cultivated fields. Before testing different foods in the field, we studied the effects of different diets on the survival and developmental rates of the life stages of both species and on the fecundity of the adults. We also determined the effects of different foods on the fecundity and longevity of field-collected adults. With a better understanding of the food requirements of these species, we could possibly manipulate and augment the number of *Geocoris* predators in the field.

Pea Aphids and Sunflower Seeds

In this test, eggs from adults collected in the field on May 21, 1968, were incubated in a growth chamber at 24° C., 60 percent relative humidity, and 16-hour-day length. The emerging first instars were fed either pea aphids, *Acyrthosiphon pisum* (Harris), shelled sunflower seeds, or a combination of both foods. No other source of moisture was provided. For each treatment, 60 newly emerged nymphs were kept separate from each other in 20-ml. plastic cups that were inverted with the cardboard lid used as the floor of the cage. The top of the cage had an opening fitted with a small cork.

The survival curves of both species fed on different diets are expressed as the daily percentage of live *Geocoris* after eclosion (fig. 3). With both species, nymphs fed only sunflower seeds died within 5 to 6 days after eclosion. Nymphs fed on aphids had a slightly higher survival rate and a few individuals managed to reach the late nymphal instars. All nymphs of both species that were fed only aphids were dead 21 to 24 days after eclosion.

When fed a combination of aphids and sunflower seeds, 55 to 65 percent of the first instar nymphs of both species died in a few days but after the initial decline the remaining nymphal population declined at a slower rate. Out of the original 60 first-instar nymphs of each species, four adults of *G. pallens* were produced, three females and one male, but no eggs were laid. Ten adults of *G. bullatus* were produced and two females out of six produced a total of 15 eggs.

Thus, with no green plant food as a source of moisture, *Geocoris* survival was the greatest with the combination of sunflower seeds and aphids as food. This diet allowed for a small percentage of the population to reach adulthood and lay a few eggs. These foods, when served alone, produced no adults. In the absence of green plant food for moisture, nymphs fed on aphids alone survived a longer period than nymphs fed sun-sunflower seeds alone.

Pea Aphids, Sunflower Seeds, and Beans

In this experiment, all conditions were similar to those of the last experiment except for the addition of green string beans as a source of moisture. The green string beans were cut into 1.5-cm. lengths, and the ends were dipped into paraffin to retard dessication (*5*). Treatment diets consisted of sunflower seeds and beans, pea aphids and beans, and the combination of all three foods. Both species were tested on all diets. There were 53 replicates with *G. pallens* and 30 with *G. bullatus* in as many individual cages. The source of first instars was the eggs of adults collected in the field on July 15, 1968. Every other day, all cages were checked and food was replenished.

With the addition of beans to each diet, the percentage survival of *Geocoris* increased considerably over those fed the same foods without beans (figs. 3 and 4). In the previous experiment, *Geocoris* fed on aphids alone survived longer than those fed on sunflower seeds alone. In this experiment, *Geocoris* fed on sunflower

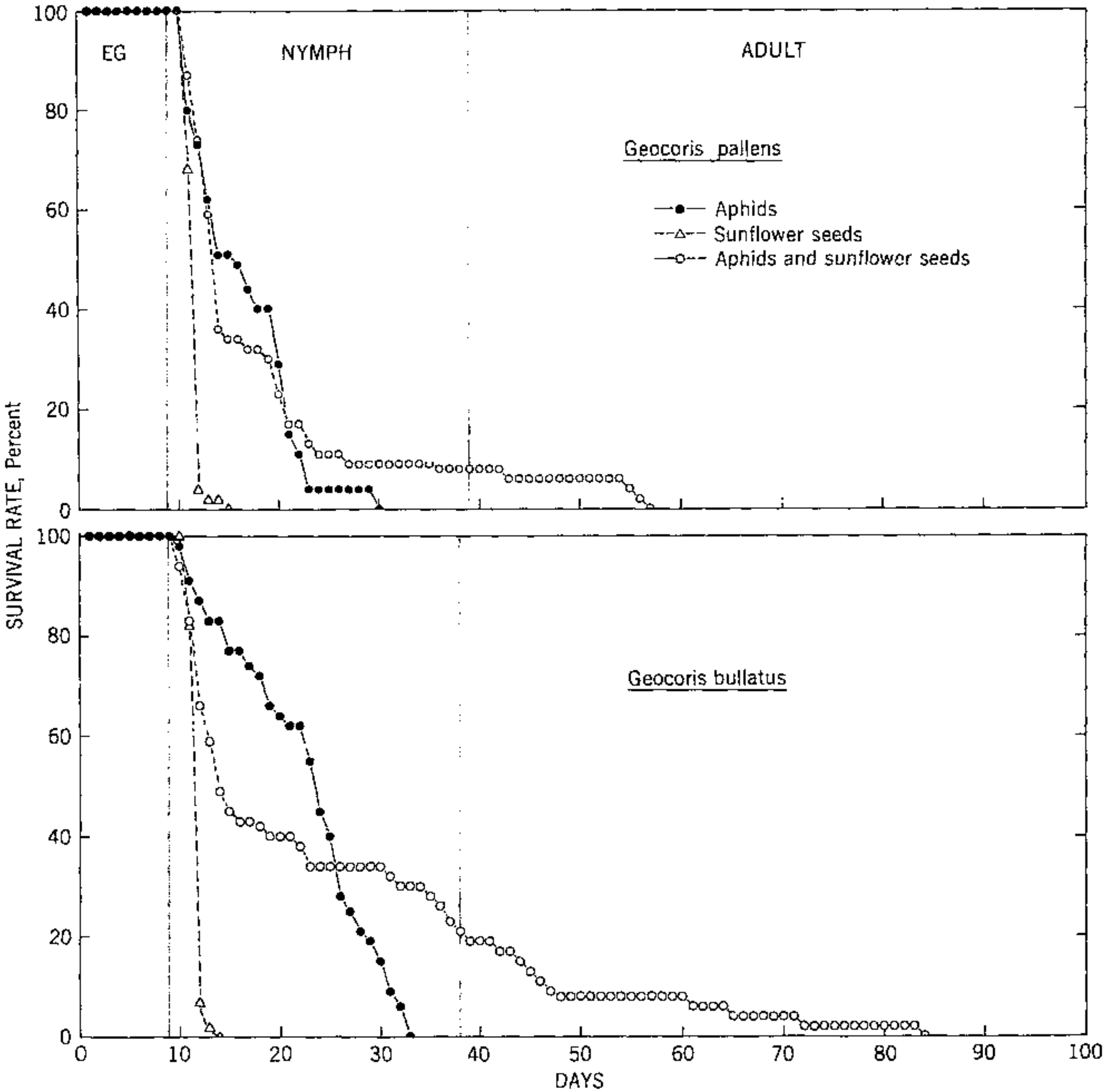

Figure 3.—Survival of *Geocoris pallens* and *G. bullatus* fed sunflower seeds, aphids, or both.

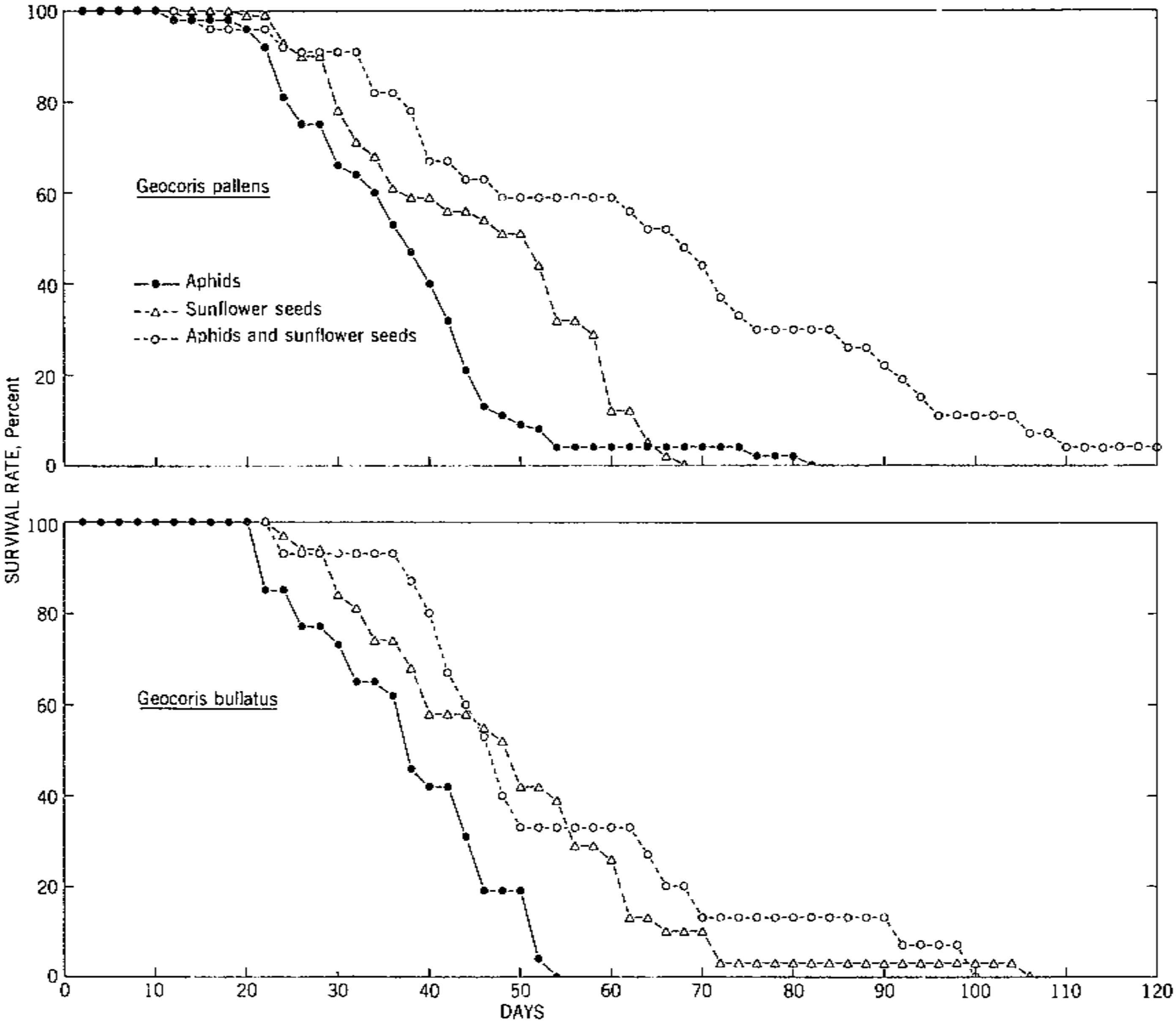

Figure 4.—Survival of *Geocoris pallens* and *G. bullatus* fed sunflower seeds, aphids, or both, with the addition of beans to all treatments.

seeds and beans had a greater proportion of nymphs alive at any one time than those fed on aphids and beans, except for *G. pallens*, when 4 percent outlived by 14 days those fed sunflower seeds and beans (fig. 4). With the combination of all three foods, survival rates of both species were considerably higher than with the other two treatments, except that *G. bullatus* fed sunflower seeds and beans had a temporary higher rate of survival at 43 to 55 days, and a few survived longer than those fed on the combination of all three foods.

The developmental period of the life stages for *G. bullatus* on different foods is graphically illustrated in figure 5. Eggs of *G. bullatus* hatched in about 9 days, and on all diets the first instars took 7 to 9 days to develop. During the second instar, however, the length of the developmental period substantially differed among *G. bullatus* fed on different foods. For example, the second instars fed on sunflower seeds and beans took almost twice as long to develop as those fed the combination of all three foods. These differences in the length of developmental periods between treatments increased during the remaining nymphal stages (fig. 5). By the time the first adult appeared in the treatment with the combination of all three foods, nymphs fed aphids and beans were still in their fourth, or beginning their fifth, instar; moreover, the nymphs fed on sunflower seeds and beans were still in their third instar.

G. bullatus nymphs fed aphids and beans produced no adults and those fed on sunflower seeds and beans produced only one male. The nymphs fed on the combination of all three foods produced males and females that in turn mated and laid eggs.

The developmental period of the life stages for *G. pallens* on different foods is graphically illustrated in figure 6. As was found with *G. bullatus*, no striking difference existed in the developmental period for the first instars. The second instars fed on sunflower seeds and beans continued to have a longer developmental period for the remaining instars than those fed the other diets.

G. pallens fed on the combination of all three foods had over 70 percent of its population reach adulthood and the resulting females laid eggs. *G. pallens* fed on aphids and beans had about 20 percent of the original population reach adulthood, but the resulting females laid no eggs. *G. pallens* fed on sunflower seeds and beans produced only one male, which died within 2 days.

Thus, both species of *Geocoris* fed on the combination of all three foods produced the most adults in the shortest time. This diet was the only one that resulted in egg production. However, both species of *Geocoris* fed on aphids and beans had a shorter developmental time and produced more adults than those fed on sunflower seeds and beans. *Geocoris* fed sunflower seeds and beans had a higher survival rate during the early nymphal stages than those fed on aphids and beans.

Life tables were used to assess the biological effects of the combined diet of aphids, sunflower seeds, and beans on both species of *Geocoris*. *Geocoris* fed other diets were excluded from the life-table analysis, because the few that reached maturity did not lay eggs. The biological effects based on life-table computations take into account the age-specific death rate, survival rate, and age-specific birth rate. The age-specific death and birth rates are the particular death and birth rates that are characteristic of a particular age group. The method and terminology used for these computations are discussed by Birch (*2*), Messenger (*29*), and Watson (*45*).

The first column in tables 7 and 8 is the pivotal-age column (X) based on 2-day intervals from birth. The second column is the number of surviving individuals from the original colony starting from the proportion of individuals at 1.0 and decreasing through time to 0.0. A colony is the number of individuals of the same age group observed from the time they are born to the time they died. The fecundity rate is the mean number of eggs/female alive at the age interval X. The number of female eggs was obtained by dividing the total number of eggs by 2 because of the previously observed 1:1 sex ratio for both species. Progeny production began at 42 days after introduction of *G. pallens* eggs and 50 days after for *G. bullatus*. The peak production for *G. pallens* was 3.4 female eggs/female/2 days, which occurred 56 days after the eggs were laid. The peak for *G. bullatus* was 1.7 female eggs/female/2 days, which

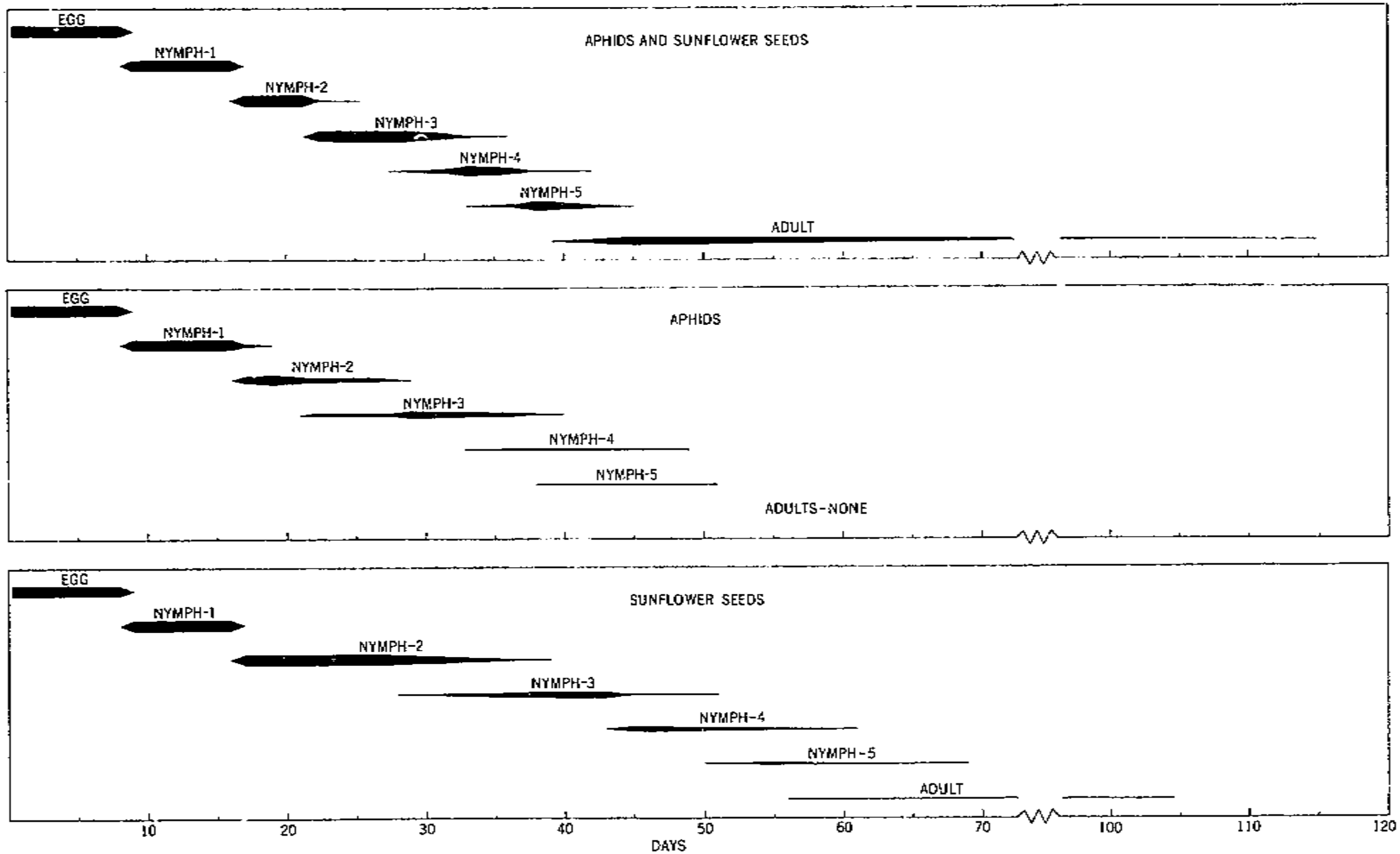

Figure 5.—Comparison of the developmental periods of all life stages of *Geocoris bullatus* on three diets, with the addition of beans to all treatments.

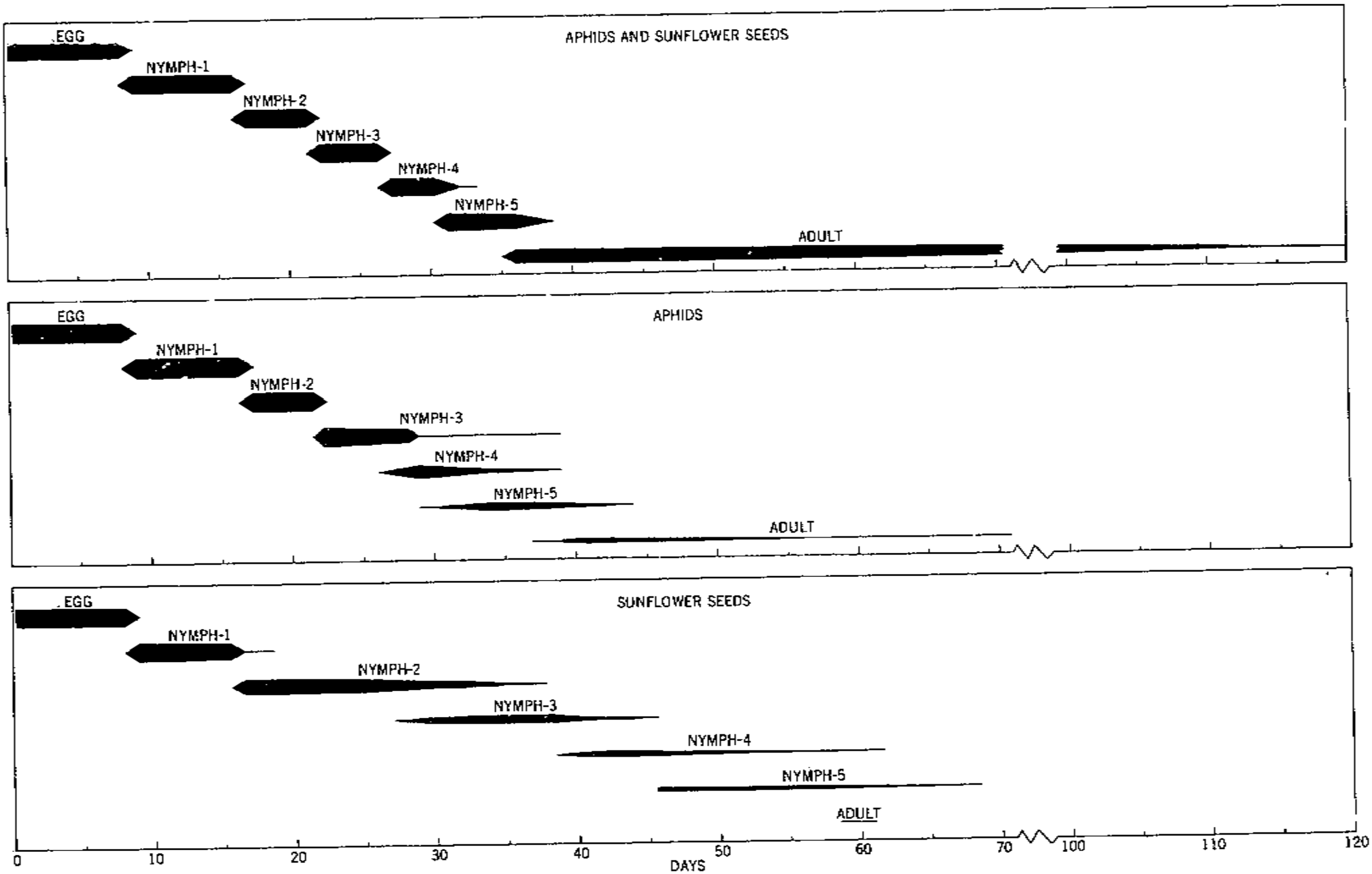

Figure 6.—Comparison of the developmental periods of all life stages of *Geocoris pallens* on three diets, with the addition of beans to all treatments.

TABLE 7.—*Life-table calculations for* Geocoris bullatus *fed on aphids, sunflower seeds, and beans*

Pivotal age X (days)	Survival rate l_x	Fecundity rate m_x
0–41	0.80	-----
42	.40	-----
50	.33	0.90
52	.33	.70
54	.33	.70
56	.33	.70
58	.33	.80
60	.33	.60
62	.33	.40
64	.27	.75
66	.20	.83
68	.20	.83
70	.13	.75
72	.13	1.00
74	.13	1.50
76	.13	1.75
78	.13	1.00
80	.13	.75
82	.13	1.25
84	.13	.50
86	.13	.25
88	.13	.50
90	.13	.50
92	.07	1.00
94	.07	1.00
96	.07	.50
98	.07	.50
100	0	0
Total	5.89	19.96

TABLE 8.—*Life-table calculations, including 2 provisional* r_m's *for* Geocoris pallens *fed on aphids, sunflower seeds, and beans*

Pivotal age (days) X	Survival rate l_x	Fecundity rate m_x	$l_x m_x$	Provisional r_m's 0.05 $e^{7-r_m x} l_x m_x$	Provisional r_m's 0.06 $e^{7-r_m x} l_x m_x$
0–35	0.82	0	0	-----	-----
36–40	.67	0	0	----	-----
42	.67	.11	.07	9.40	6.18
44	.63	1.88	1.18	143.38	92.35
46	.63	2.26	1.42	156.13	98.56
48	.59	2.69	1.59	158.17	97.88
50	.59	2.47	1.46	131.43	79.72
52	.59	2.47	1.46	118.92	70.69
54	.59	3.25	1.92	141.50	82.46
56	.59	3.44	2.03	135.38	77.32
58	.59	2.25	1.33	80.25	44.93
60	.59	2.66	1.57	85.72	47.04
62	.56	.77	.43	21.24	11.43
64	.52	3.18	1.65	73.76	38.89
66	.52	1.54	.80	32.36	16.72
68	.48	1.62	.78	28.55	14.46
70	.44	2.38	1.05	34.78	17.27
72	.37	2.40	.89	26.66	12.99
74	.33	2.22	.73	19.79	9.45
76	.30	2.50	.75	18.40	8.60
78	.30	3.13	.94	20.87	9.57
80	.30	2.13	.69	13.86	6.23
82	.30	2.06	.62	11.27	4.96
84	.30	1.75	.53	8.72	3.76
86	.26	1.64	.43	6.40	2.71
88	.26	1.71	.44	5.92	2.46
90	.22	.58	.13	1.58	.64
92	.19	2.60	.49	5.40	2.15
94	.15	2.13	.32	3.19	1.25
96	.11	2.33	.26	2.35	.90
98	.11	1.50	.17	1.39	.52
100	.11	1.50	.17	1.26	.46
102	.11	.67	.07	.47	.16
104	.11	.33	.04	.24	.09
106	.07	1.75	.12	.66	.23
108	.07	.75	.05	.25	.08
110	.04	2.50	.10	.45	.15
112	.04	2.50	.10	.41	.13
114	.04	.50	.20	.07	.02
116	.04	0	0	----	-----
118	.04	0	0	----	----
120	.04	0	0	----	-----
122	.00	0	0	----	-----
Total		72.33	26.80	1500.58	863.41

occurred 76 days after the eggs were laid. Reproduction ceased after 114 days for *G. pallens* and 100 days for *G. bullatus*.

Table 8 also gives the $l_x m_x$ values. Also the provisional r_m (the intrinsic rate of natural increase) values of 0.05 and 0.06 are given. The method developed by Birch (*2*) from his formula $\Sigma e^{7-r_m x} l_x m_x = 1096.6$ is used to obtain these provisional values. These trial values of r_m were needed for the computation of the accurate r_m, one giving a slightly lower value than 1096.6 and the other slightly higher. These provisional r_m's are needed for the computation of the accurate

r_m value that lies at the point of intersection at 1096.6 on the $e^{7-r_m x}l_x m_x$, column (*45*).

Table 9 gives the growth statistics of both species fed on sunflower seeds, pea aphids, and beans. The calculation of r_m was computed from the provisional r_m's given in table 8. λ is the finite rate of increase and the antilog of r_m, which means the number of times the population will multiply itself per unit of time. *GRR* refers to the gross rate of reproduction, or the mean total number of eggs produced by females during their entire life, which is the sum value of the m_x column. R_o is the net rate of reproduction (total multiplication in one generation) and is the sum of the product of $l_x m_x$ computed at each age interval. T is the mean generation time calculated from the formula $T = \log_e R_o / r_m$. Thus, *G. pallens* had a higher (r_m) intrinsic rate of natural increase because of the combination of a higher survival and fecundity rates and a shorter generation time compared with *G. bullatus* fed on the same food.

It should be emphasized again that statistics obtained from the life-table computations are primarily to demonstrate how life tables can be used to compare the effects of different diets on the biology of the insects. In this study, life tables were used to study the effects of the *Geocoris* diet of pea aphids, sunflower seeds, and beans against those of a diet of pea aphids and beans or sunflower seeds and beans. Growth statistics given in table 9 should not be construed, like the more commonly accepted r_m, as a biological characteristic that describes a population increasing in an environment unlimited in food and space with a stable age distribution. These data indicate *G. pallens* has a greater population growth potential than *G. bullatus*; however, this comparison is restricted to the conditions of the experiment. It may be that under different diets or physical conditions, *G. bullatus* would have equal or greater intrinsic rate of increase than *G. pallens*.

TABLE 9.—*Population growth statistics of* Geocoris pallens *and* G. bullatus *fed on aphids, sunflower seeds, and beans*

Item [1]		*G. pallens*	*G. bullatus*
r_m	—(female/female/day)	0.056	0.019
λ	—(female/female/day)	1.058	1.019
GRR	—(female/female)	72.33	19.96
R_o	—(female/female)	26.80	3.51
T	—(days)	58.7	66.2

[1] r_m, intrinsic rate of increase; λ, finite rate of increase; *GRR*, gross reproductive rate; R_o, net reproductive rate; *T*, generation time.

Sugarbeet Leaves, Beet Leafhoppers, and Green Peach Aphids

Geocoris did not lay eggs when reared on pea aphids and beans or sunflower seeds and beans. However, an earlier experiment conducted in larger cages with sugarbeet leaves as a source of moisture showed that *Geocoris* were able to complete their life cycle on insect food. Eggs were obtained from adult *Geocoris* of mixed species collected in the field August 1, 1967. One egg and sugarbeet leaves were placed in each cylindrical test cage (6 inches in diameter and 2½ inches deep). After eclosion, the nymphs were divided into three groups. All groups were fed sugarbeet leaves and one of the following foods: Group 1, only recently killed or dying beet leafhopper adults, *Circulifer tenellus* (Baker); group 2, sunflower seeds; group 3, green peach aphids. Each treatment was replicated 10 times. All nymphs fed leafhoppers and 9 of 10 nymphs fed aphids reached adulthood. All nymphs fed sunflower seeds but no insect prey died at an early instar before reaching the adult stage.

Egg production of those adults fed aphids was considerably lower than from those fed leafhoppers, even though the survival rate of those adults fed aphids was higher. Two of three females fed aphids laid 16 eggs, but three of six females fed leafhoppers laid 186 eggs. Besides the possibility that green peach aphid was a more suitable food than pea aphids, several other factors probably interacted to improve *Geocoris* survival and fecundity when fed green peach aphids. Sugarbeet leaves served as host plants for the green peach aphid; therefore, the aphids not fed on by *Geocoris* were always alive when the cages were checked. In the other experiment, pea aphids did not survive on beans and those aphids not fed upon were either dead or emaciated when more aphids were added. Larger cages could also have increased survival.

When this experiment was repeated with the same treatments, 60 replications per treatment, all 180 *Geocoris* died in the early nymphal instars. This mortality was attributed to the time of adult collection. These adults were collected on October 19, 1967, in the peach orchard where overwintering *G. bullatus* adults were still active. When brought into the laboratory, the adults readily laid eggs but none of the emerging nymphs got beyond the second instar.

These experiments demonstrate that some *Geocoris* can complete their life cycle and lay eggs when fed on insect prey such as beet leafhoppers or green peach aphids along with sugarbeet leaves. But, caution should be used in interpreting results obtained in the laboratory from field-collected *Geocoris* at different times of the year.

Field-Collected Adults on Different Diets

Our next objective was to evaluate the effects of these same diets on survival and fecundity of field-collected adults. York (*46*) and Sweet (*41*) studied the effects of different diets on the survival of the field-collected *Geocoris* adults but did not include fecundity. As sunflower seeds were to be considered for use as supplemental food in the field, the effects of this food on the fecundity of field-reared adults was investigated.

On July 28, 1969, adults of *G. bullatus* were collected from alfalfa and a pair (male and female) was placed in a separate cylindrical cage (15 cm. in diameter and 6 cm. deep). After 24 hours, each cage was checked for the number of eggs laid and 48 pair were ranked from the highest to the lowest number of eggs laid. All ranked *Geocoris* were then alternately selected for four groups. Group 1 was fed only sugarbeet leaves (control). The other groups were fed sugarbeet leaves and one of the following foods: group 2, sunflower seeds; group 3, green peach aphids; and group 4, sunflower seeds and green peach aphids. Each treatment was replicated 12 times except the treatment with sunflower seeds, which was replicated 11 times. The experiment was conducted on a laboratory bench with overhead fluorescent lights with 16-hour photoperiod and a temperature averaging 23° C. (range 17°–29°).

Survival curves for adults of *G. bullatus* are shown in figure 7. *G. bullatus* fed only on sugarbeet leaves (control) had an average life span of 11 days (range 2–25 days); those fed aphids and sugarbeet leaves averaged 36 days (range 20–83 days); those fed sunflower seeds and sugarbeet leaves, 50 days (range 4–96 days); and those fed a combination of all three foods, 43.2 days (range 18–91 days). Thus, adults fed on sunflower seeds and sugarbeet leaves lived longer than adults fed the combination of all three foods. Furthermore, *Geocoris* fed on aphids did not live so long as those fed sunflower seeds.

In studying the fecundity rate of *G. bullatus*, we made adjustments for the accumulation of food reserves obtained in the field and their egg reserves. As already discussed, we attempted to adjust for variation in adult reproduction by ranking the adults according to the number of eggs laid in the first 24 hours of captivity. Since sugarbeet leaves are considered primarily a source of moisture and contribute little to the total nutrient requirement for *Geocoris* egg production, adults fed only sugarbeet leaves were used as an indicator for the depletion of food and egg reserves. After 4 days of heavy egg deposition, egg production dropped almost to zero on the fifth day for those females fed only sugarbeet leaves. Therefore, the cumulative average number of eggs per female was started on the fifth day after adults were collected from the field (fig. 8).

No direct correlation existed between the different diets when survival rates were compared with fecundity rates as shown in figures 7 and 8. The cumulative average of the number of eggs per female was the greatest for adults fed on all three foods and averaged 75 eggs per female, but this treatment ranked second in survival. Adults fed on aphids and sugarbeet leaves laid the second greatest number of eggs with an average of 49 eggs per female but ranked third in survival. Adults fed on sunflower seeds and sugarbeet leaves ranked third in the cumulative number of eggs laid with an average of 34.3 eggs per female but ranked first in survival. Adults fed sugarbeet leaves alone laid only 0.33 egg per female.

Conclusions and Discussion

In these laboratory studies on the effects of different foods on the life stages of *Geocoris*,

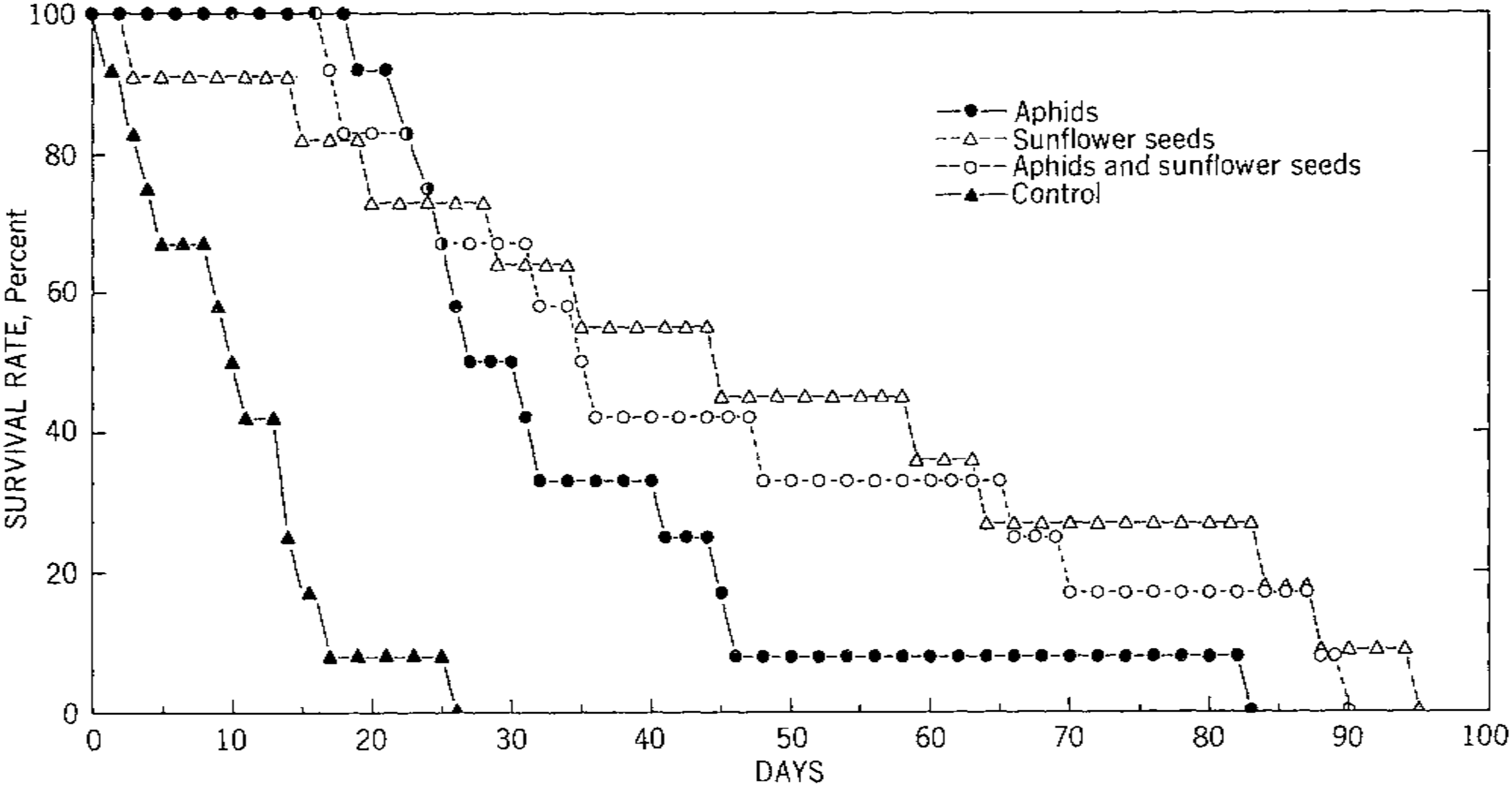

Figure 7.—Survival of field-collected adults of *Geocoris bullatus* fed on four diets, with sugarbeet leaves in all treatments.

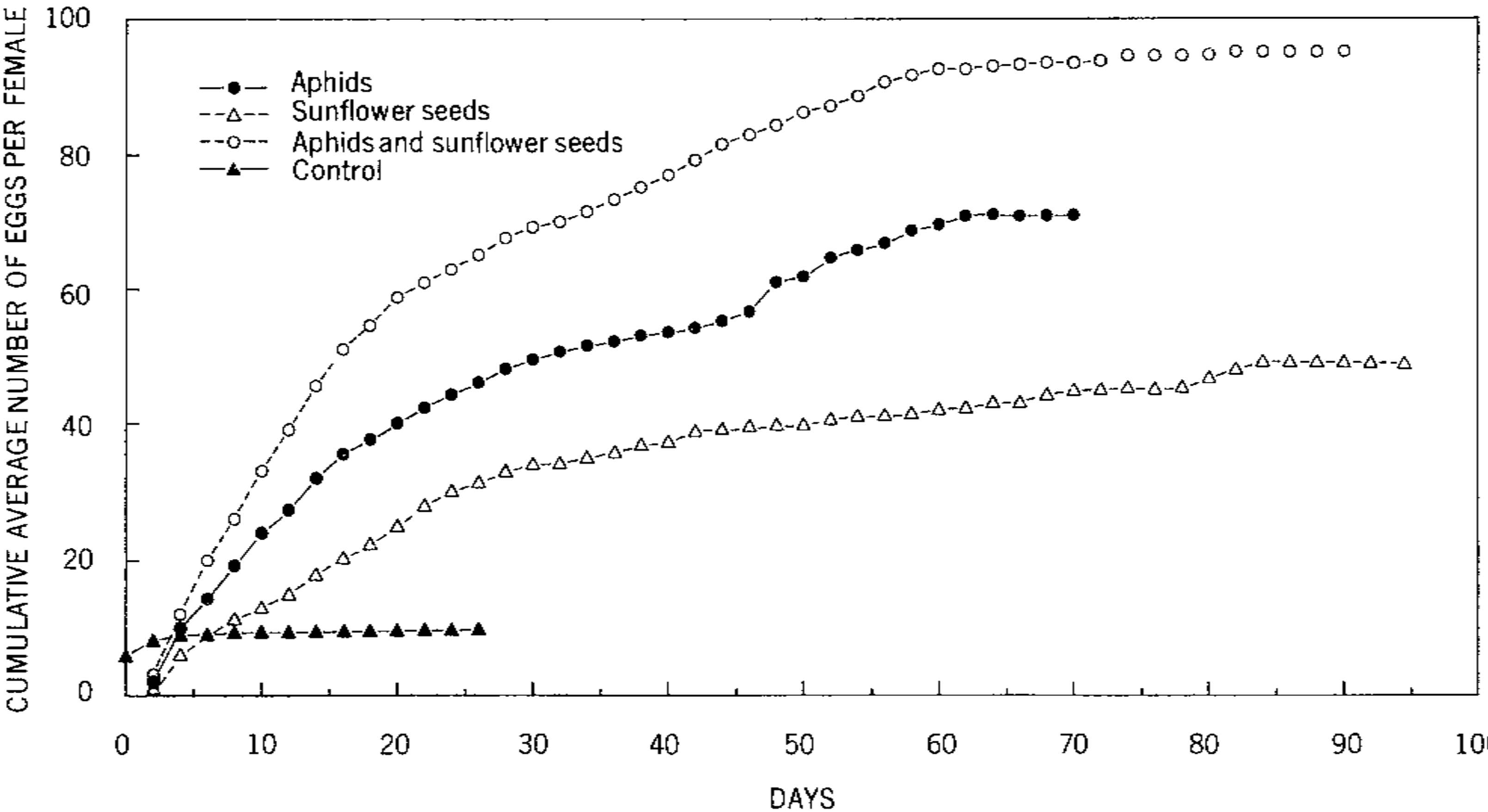

Figure 8.—Cumulative number of eggs laid by field-collected adults of *Geocoris bullatus* fed on four diets, with sugar beet leaves in all treatments.

both species fed the combination of all three foods had the shortest developmental time, the highest egg production, and the greatest percent survival. With the combination of insect prey and green plants, *Geocoris* nymphal developmental periods were extended but were still shorter than those for nymphs fed on sunflower seeds and green plants. Percentage survival through the earlier nymphal stages was generally lower for those fed on pea aphids and beans than for those fed sunflower seeds and beans. *Geocoris* fed on pea aphids and beans or sunflower seeds and beans did not lay eggs. In another experiment, eggs were laid when green-plant food and either leafhoppers or green peach aphids were fed. All field-collected adults, fed on the same diets, laid eggs, but at different rates.

Therefore, addition of sunflower seeds as a source of supplemental food in cultivated fields should augment the *Geocoris* population. When certain species of prey are scarce, the young nymphs may have difficulty capturing other prey species and sunflower seeds can serve as an alternate food. Sunflower seeds alone would help maintain nymphal development but at a slower rate. Yet, if these nymphs are able to feed on a few insects, the combination of both foods will speed their development over insect prey alone. For adults of *Geocoris*, sunflower seeds would be as good as aphids in extending the length of survival. Fewer eggs would be laid, but egg production would still continue. Thus, a combination diet of insect prey with the addition of sunflower seeds in the field would probably hasten development and increase survival and reproduction.

FIELD EVALUATION OF SUNFLOWER SEEDS

Many examples of growing other plants in or near the cultivated crops for nectar and pollen as supplemental foods for natural enemies of insect pests are cited by van den Bosch and Telford (*44*). Although many laboratory and greenhouse studies have been published, only a few field studies with supplemental foods other than growing the actual plants in or near the field have been reported. Ewert and Chiang (*12*) reported that sucrose spray concentrated the coccinellid beetles, and the beetles fed on the sugar. A followup study by Schiefelbein and Chiang (*33*) found that a cornfield sprayed with sucrose had fewer corn leaf aphids, *Rhopalosiphum maidis* (Fitch), than the unsprayed plots. They attributed the suppression of aphid buildup in the sprayed field to the early abundance of coccinellid and chryosopid populations; but during peak aphid abundance, aphids were more effective in concentrating coccinellids than sucrose sprays.

In our study, we attempted to evaluate sunflower seeds as a supplemental food for *Geocoris* in the field. Our objectives were to determine if sunflower seeds are actually desirable to *Geocoris* when placed in the field and what effects sunflower seeds have in concentrating, or arresting, the *Geocoris* population.

Arrests

Although we observed both species of *Geocoris* feeding on sunflower seeds in the laboratory, no information was available on whether *Geocoris* would feed on sunflower seeds in the field or would concentrate around the seeds. Pitfall traps were used to evaluate sunflower seeds as a possible source of supplemental food and as an arrestant for *Geocoris*. The term "arrestant" is defined by Dethier, Browne, and Smith (*10*) as a chemical that causes insects to aggregate in contact with it, the mechanism of aggregation being kinetic or having a kinetic component.

The pitfall trap consisted of a pint jar housed in a cylindrical cardboard tube buried in the ground. The jar was partly filled with 60 percent alcohol with a layer of mineral oil on top to retard evaporation.[3] A metal lid had the center cut out to the same size as the opening of the jar, and the lid covered the opening of the cardboard tube at ground level. A 6-inch-square wooden slat was placed over the pitfall trap.

Two rows of pitfall traps were placed in or near a field of alfalfa. One row of six traps was

[3] Personal communication from T. Leigh, University of California, Davis.

placed 3 feet from and parallel to the outer edge of the field. The second row of six traps was placed 15 feet within the field. The traps were 7 feet apart. Three of the six traps in each row were randomly selected for the addition of chopped sunflower seeds around a 2-inch radius of each trap. Traps were checked every 2 to 5 days, and the number of *Geocoris* under the wooden cover was counted as well as the number in the jars. Similar counts were also made for traps with no sunflower seeds.

Only adult *Geocoris* caught in pitfall traps were identified as to species. Those *Geocoris* outside the jar but under the wooden covers were counted but not collected. Over a period of 60 days from mid-July to mid-September 1969, 101 *G. bullatus* and 97 *G. pallens* were captured inside the traps baited with sunflower seeds compared with 15 and 18, respectively, caught in the control traps containing no sunflower seeds. These figures show that both species were in the area and that both species were arrested by sunflower seeds (table 10). Both sexes were arrested by sunflower seeds; the sex ratio was 1:1 for *G. bullatus* and 1:2 for *G. pallens*. In the nonbaited pitfall traps, considerably more females were trapped than males, almost a 4:1 ratio, but the total number caught was too small to draw any conclusions.

Almost five times as many *Geocoris* (1,396:-285) were found outside the traps as inside (table 11). From observations and actual counts, it appears that *Geocoris* are not readily caught in traps even though large numbers may be concentrated a few inches away from the opening. Therefore, the number of *Geocoris* inside pitfall traps would be a poor method of estimating numbers.

Greenslade (*16*) reported that pitfall traps, besides being an ineffective method for a quantitative assessment of carabid fauna, should not be used to compare the number of one species in different habitats because the number of a single species may vary in traps, depending on the ground cover and on the resistance they present to horizontal movement. In this study, it was estimated from D-Vac samples (a mechanical suction machine (*11*)) and actual searching in the alfalfa and weeds along the edge of the road that the number of *Geocoris* was at least five times greater in the low-lying weeds adjacent to the field than 12 feet within the alfalfa field. However, of the *Geocoris* caught in and around the nonbaited traps, 89 were caught in the alfalfa and 123, adjacent to the field—almost a 3:4 ratio. These data substantiate the conclusion of Greenslade that pitfall traps are not a suitable method for comparing numbers in different habitate.

These traps were useful for our primary purpose of comparing traps baited with sunflower seeds to nonbaited traps to determine if sunflower seeds would arrest *Geocoris*. From July 11 to September 9, the *Geocoris* in and around

TABLE 10.—*Number of* Geocoris pallens *and* G. bullatus *caught by baited and unbaited pitfall traps at 2 locations*

Location of trap	Baited traps				Unbaited traps			
	G. bullatus		*G. pallens*		*G. bullatus*		*G. pallens*	
	Female	Male	Female	Male	Female	Male	Female	Male
Outside edge of alfalfa	36	41	26	53	8	1	9	3
In alfalfa	12	12	8	10	3	3	6	0

TABLE 11.—*Total number of* Geocoris *in and around baited and unbaited pitfall traps at 2 locations*

Location of trap	Baited traps		Unbaited traps	
	In traps	Around traps	In traps	Around traps
Outside edge of alfalfa	181	742	16	107
In alfalfa	54	481	23	66

the traps with sunflower seeds totaled 1,458 compared with 212 from nonbaited traps (fig. 9). These data, showing a 7:1 ratio, definitely indicate that sunflower seeds serve to arrest *Geocoris*. They were also observed feeding on the sunflower seeds around the traps.

Oviposition

In this study, our objectives were to spread sunflower seeds in a cultivated field to determine if activities of *Geocoris* would be different between baited and unbaited plots.

A randomized complete block design was used for this study with two treatments per block and four replications. In one treatment, chopped sunflower seeds were spread at a rate of one-fourth pound per plot (18 ft. long and 10 ft. wide). The sunflower seeds were hand spread on top of sugarbeet plants and not between the plants or rows. The other treatment, with no sunflower seeds, served as a control. Each treatment plot was separated by a buffer zone the same size as the plot. Twenty leaf samples were taken from each plot about twice a week. After each leaf sampling, the plots with sunflower seeds were re-baited with one-fourth pound sunflower seeds per plot. High humidity, especially during irrigation, caused the sunflower seeds to mold; therefore, repeated applications of sunflower seeds were necessary.

An obvious difference existed in the number of *Geocoris* eggs laid on sugarbeet leaves between plots baited with sunflower seeds and unbaited plots (table 12). For the seasonal average, 41 *Geocoris* eggs were laid per plot baited with sunflower seeds and 19 eggs for the control.

In the control plots, only a few eggs were found from mid-June to mid-August and no eggs were found in September (fig. 10). Egg deposition trends of *Geocoris* in the controls were similar to those in plots baited with sunflower seeds, except for a high peak in egg deposition between July 25 and August 11, 1969, in the controls. More eggs were found in plots baited with sunflower seeds except on August 11, when more eggs were found on control plots.

TABLE 12.—*Total number of* Geocoris *eggs laid on sugarbeets between June 20 and September 12*

[Based on 360 leaves/plot]

Plot	Number of *Geocoris* eggs: Addition of sunflower seeds	Number of *Geocoris* eggs: No sunflower seeds
1	38	13
2	34	24
3	57	21
4	35	17
Total	164	75

Leaf counts did not show any consistent differences between treated and untreated plots in the number of species that were potential prey for *Geocoris*. Eggs and mines of *Psilopa leucostoma* Meigen were common in both treatments. Green peach aphids, thrips, and beet leafhoppers were not abundant enough during the test period to allow for any valid comparisons. Late in the season a mite buildup occurred, but no population differences between the two treatments were apparent.

Conclusions and Discussion

In the experiment with pitfall traps, it was demonstrated that more *Geocoris* aggregated around traps baited with sunflower seeds than around unbaited traps. The concentration of both species of *Geocoris* is probably due to the arrestant property of sunflower seeds rather than the attraction of some volatile chemical in the seed that may attract *Geocoris* from a distance. Once these insects find the sunflower seed, they proceed to feed on it and tend to stay near the source; thus, in time, *Geocoris* will tend to concentrate near the source of sunflower seeds.

In the field experiment, when sunflower seeds were scattered on sugar beets, no evidence was obtained indicating that the addition of sunflower seeds aided *Geocoris* in the reduction of the prey populations. However, the addition of sunflower seeds as supplemental food doubled the number of *Geocoris* eggs laid on sugarbeet plants, as compared with the control.

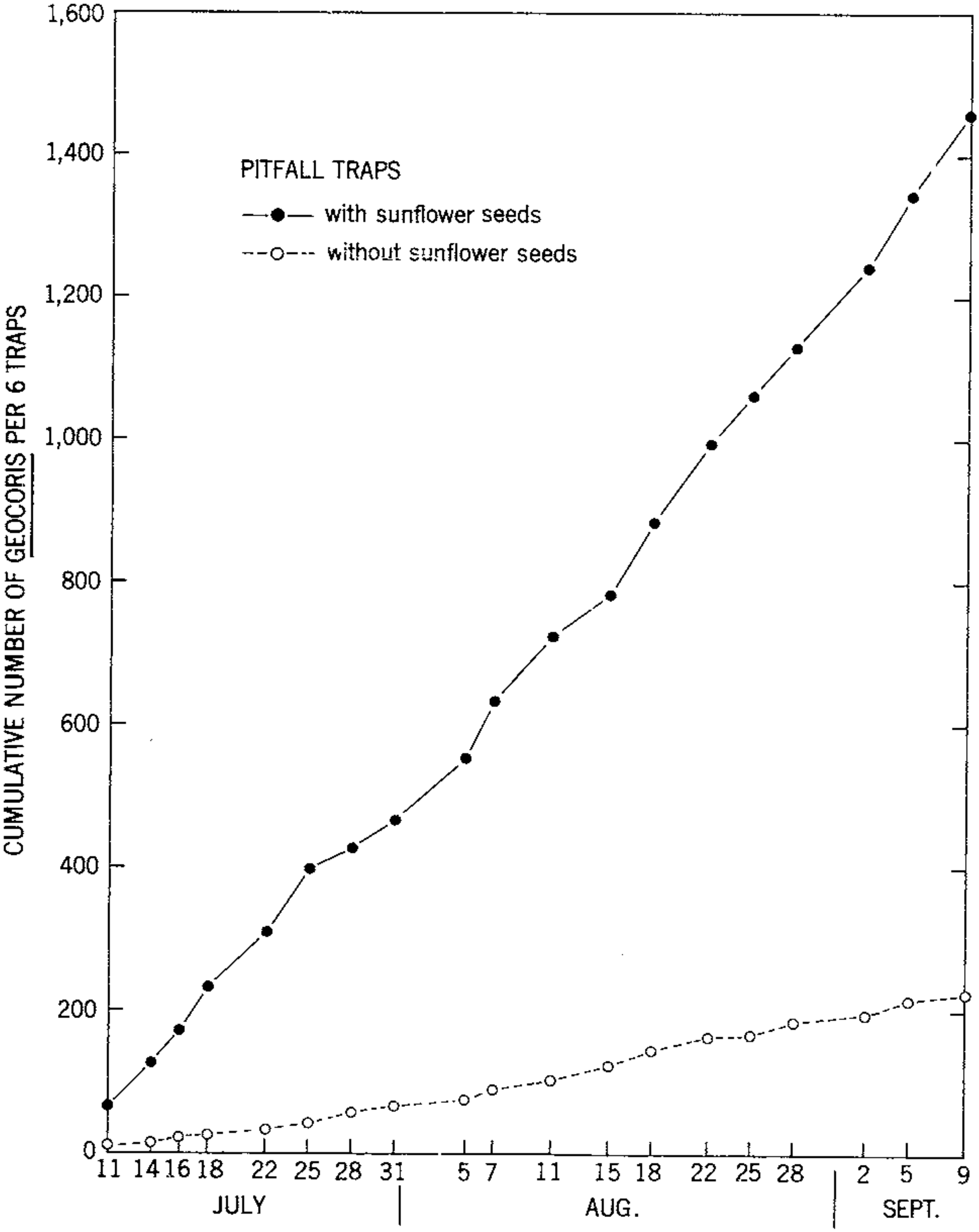

Figure 9.—The cumulative number of *Geocoris* captured in or around pitfall traps baited with sunflower seeds and unbaited.

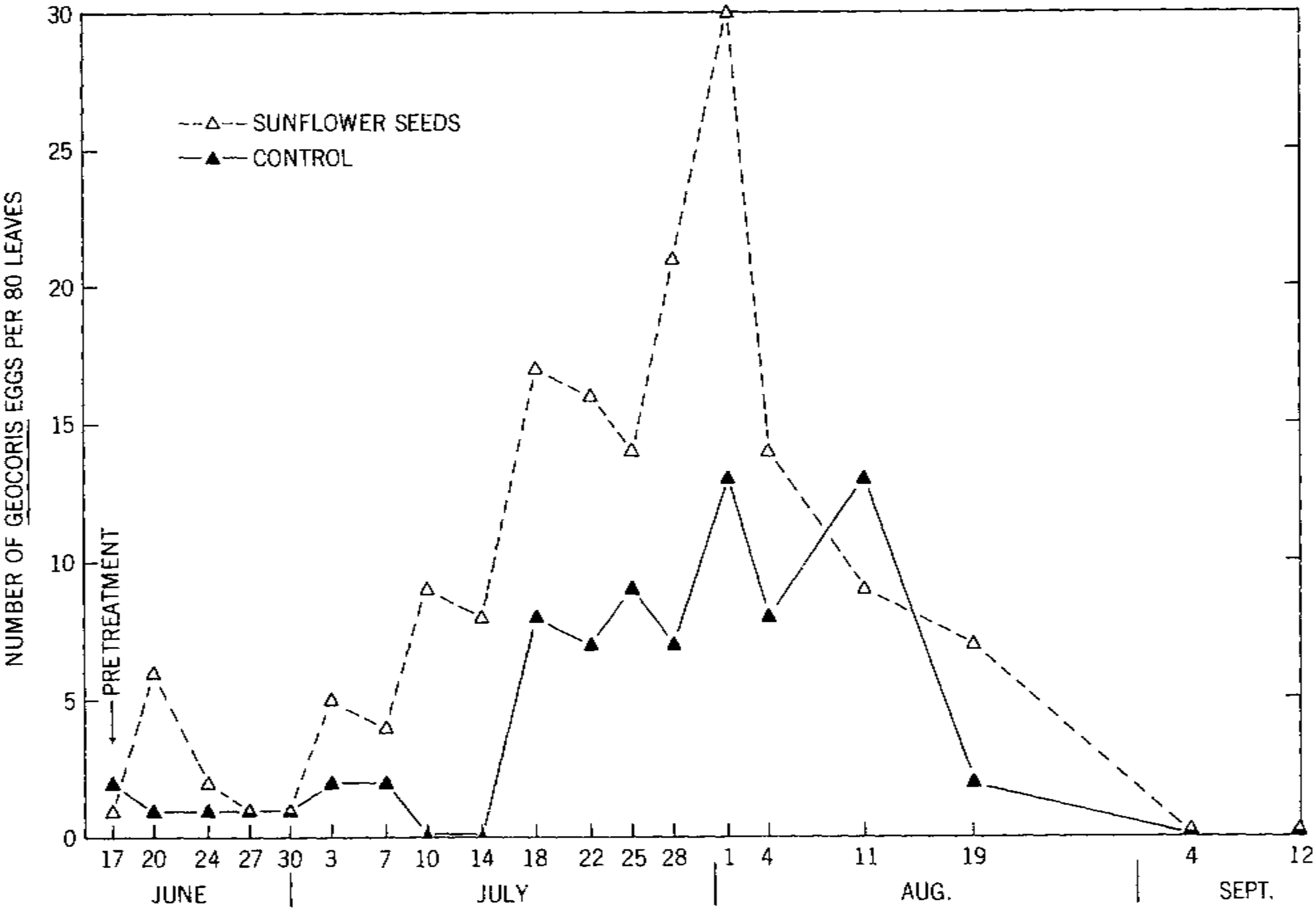

Figure 10.—Numbers of *Geocoris* eggs found on sugarbeet leaves in plots baited with sunflower seeds and unbaited plots.

ALFALFA INTERPLANT STUDY

The maintenance of a refuge for beneficial insects has received considerable attention. Grison and Biliotti (*17*) suggested the use of uncultivated and untreated areas as refuges for beneficial insects. DeBach (*9*) left an untreated area of citrus orchard at any given time as a reservoir for beneficial insects. Schlinger and Dietrick (*34*) harvested alternate strips of alfalfa to conserve natural enemies. Furthermore, Stern and coworkers (*39*) used alfalfa interplants in cotton during 1967 and 1968 for the control of lygus bugs. Our alfalfa interplant study was conducted in 1966 to evaluate alfalfa as a potential reservoir for beneficial insects attacking pests of vegetable and sugarbeet crops.

The major problem in a biological control program in vegetable and sugarbeet crops is to establish natural enemies early in the season. Vegetable and sugarbeet crops are seasonal crops, and a common practice in eastern Washington is to plow the fields after harvest and plant again in spring. In early summer, injurious insects generally become abundant before predator buildup occurs. Alfalfa interplants or border crops theoretically could serve as a permanent reservoir for beneficial insects that could in some way be transferred to vegetable and sugarbeet crops as needed.

Experimental Design

An experiment was designed for the purpose of comparing the abundance of *Geocoris* with other predator and prey species on five crops, as well as to study the feasibility of alfalfa interplants as a reservoir for beneficial insects. Sugarbeet, pea, broccoli, and potato plots were randomly placed in each of eight blocks with a center plot of alfalfa in each block (fig. 11). The Vernal variety of alfalfa was sowed in August 1965 and all other crops were planted in May 1966.

The two methods used to sample the insect populations were the D-Vac mechanical suction sampler (10 D-Vac samples were taken from all plots), and leaf samples (a total of 25 leaves were sampled from the broccoli, potato and sugarbeet plots by taking alternate young, mature, and senescent leaves from plants in the middle three rows of each plot).

Prey Complex

For any study of an omnivorous predator such as *Geocoris*, it is not only necessary to determine the role *Geocoris* plays as part of the predator complex but also its relation to the potential prey complex. The first part of this study dealt with the seasonal trends of the prey species that were the most abundant in the mixed-crop culture and the second half dealt with the predator species.

Lygus

Two of the most abundant pest species were the lygus bugs, *Lygus elisus* Van Duzee and *L. hesperus* Knight. As illustrated in figure 12, lygus bug seasonal trends vary with different crops. Lygus bugs were most abundant on alfalfa through most of the season, and high nymph counts indicated that population buildup occurred on alfalfa. Nymphs and adults were more abundant on sugarbeets than on the vegetables. This indicated a closer host-plant relation or preference of *Lygus* for sugarbeet than for the three vegetable crops.

Of the vegetable crops, broccoli had the lowest number of lygus bugs throughout the growing season. Early in the season, the pea plants had a few lygus bugs, but during the period of pod set there was a substantial increase in lygus bug population. Potato plants had more adults and nymphs for most of the growing season than did the broccoli and peas.

Little information is available on lygus bug injury as it affects yield and quality of sugarbeets and the three vegetable crops. Hills (*19*) reported on *Lygus* damage on sugarbeets grown for seed. However, Stern and coworkers (*39*) reported that when alfalfa interplants were used with cotton, the alfalfa served as an attractant and trap crop for lygus bugs. He reported that less *Lygus* were found in fields with alfalfa interplants than in fields not interplanted.

Pea Aphids

Pea aphid was one of the important prey species occurring in significant numbers in our mixed-crop experiment. Primarily a legume feeder, it was found on peas and alfalfa. Be-

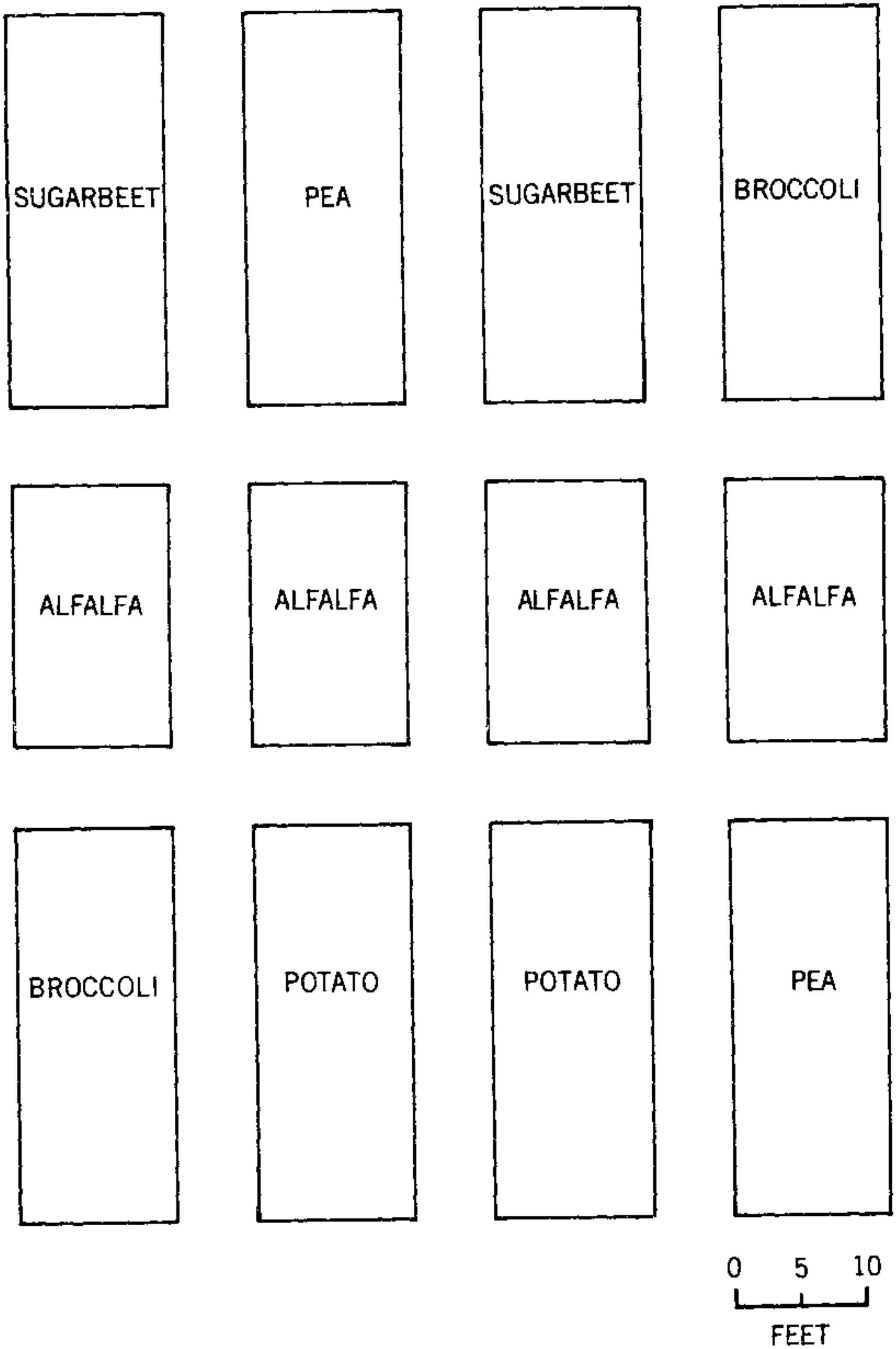

Figure 11.—Illustration of one-quarter of the experimental field of different crops with alfalfa interplants.

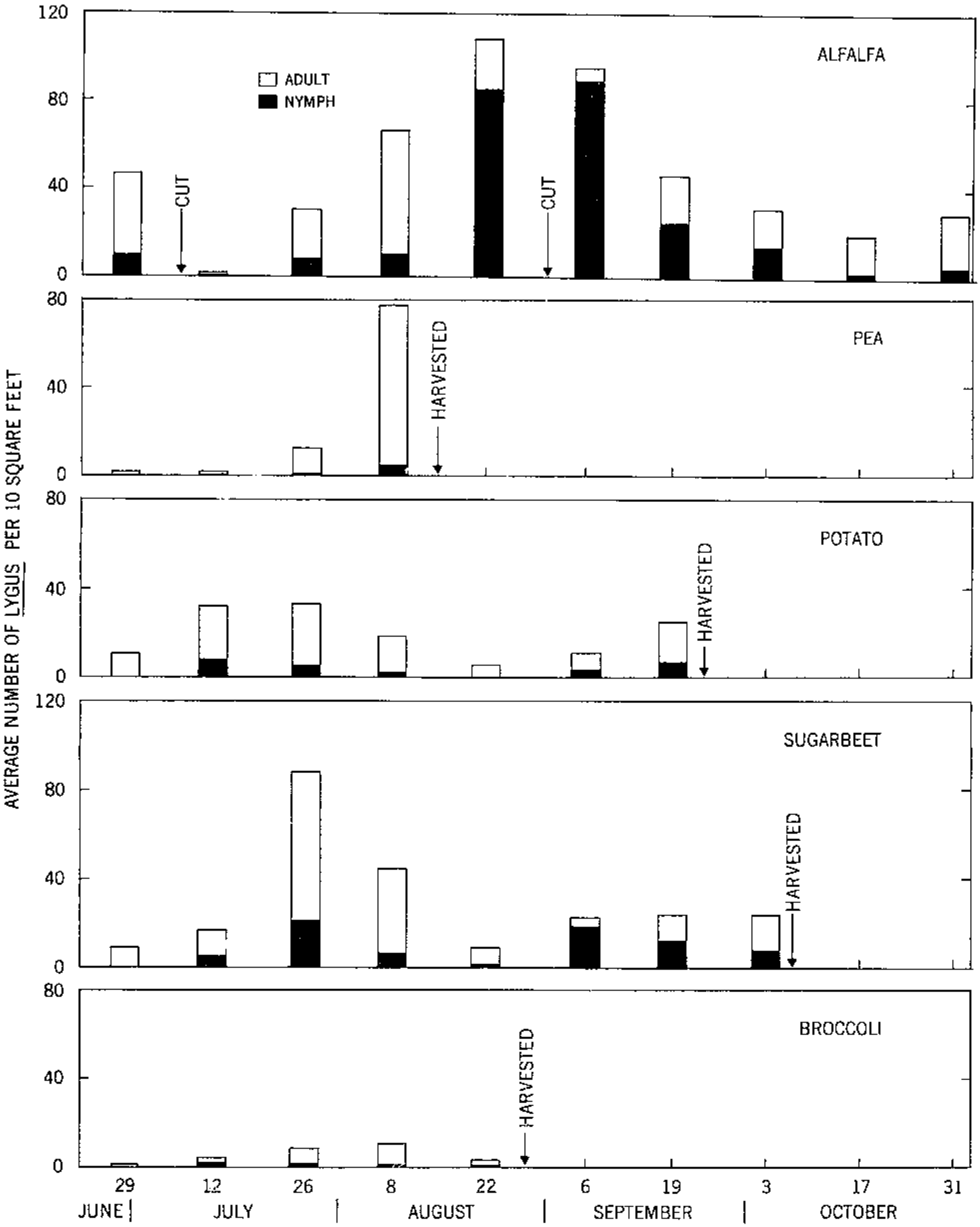

Figure 12.—Seasonal trends of *Lygus* populations on various crops in the alfalfa interplant study, 1966.

cause of the inherent structural differences between the legumes and the other crops grown in the mixed-crop experiment and the behavior differences of the aphid species, the D-Vac mechanical suction sampler was used to measure the pea aphid abundance based on the number of aphids per 1 square foot.

On alfalfa, the pea aphid population was drastically reduced after the first cutting on July 7 and stayed low for the rest of the season. Before the first cutting on alfalfa, the pea aphid population on peas was low but after the alfalfa was cut, the pea aphid population increased and remained high until harvest. Thus, in early spring, before the first cutting of alfalfa and before the peas were grown, the population of pea aphids substantially increased on alfalfa, but after the first cutting the pea aphids moved onto peas (fig. 13).

From these data, it is apparent that alfalfa grown as an interplant with peas will serve as an early-season reservoir for pea aphids. Until suitable aphid-resistant varieties of peas are developed, alfalfa interplants in a peafield would not be feasible. These data agree with those of Cooke (*8*) who considered the spring movement of pea aphids from alfalfa to peas as the major source of aphids on peas.

Green Peach Aphid

This aphid is a major pest of potatoes and sugarbeets in the Yakima Valley because it serves as the major vector of leaf roll virus on potatoes and beet western yellows virus on sugarbeets. In our mixed-crop plots in 1966, populations of the green peach aphid peaked on all host plants about mid-July and started to decline late in July. After the initial buildup, populations of green peach aphid remained low for the rest of the season (fig. 14).

Successful biological control of the green peach aphid on potato and sugarbeet crops is handicapped because the number of aphids tolerated per plant is not based on actual aphid feeding or honeydew damage but on a much lower number based on suppression of plant-disease transmission. With progress in plant breeding, therapeutic control, or other means of virus disease control, the tolerance level of the number of green peach aphids per plant may be considerably raised to improve the prospects of biological control.

Since a stand of alfalfa does not serve as a reservoir for the green peach aphid but does serve as a reservoir for many of its predators, alfalfa interplants or border plants may serve to augment biological control of this aphid on many of these vegetable crops.

Predator Complex

Geocoris

In late June and to the end of July, the population of *Geocoris* increased primarily on alfalfa as indicated by the large number of nymphs collected on alfalfa (fig. 15). Therefore, alfalfa served not only as a reservoir but as a breeding ground for *Geocoris* early in the season before *Geocoris* buildup took place on the other crops.

In August, sugarbeets, potatoes, and peas showed a substantial increase in *Geocoris* nymphs, which coincided with the oviposition trend of *Geocoris* based on leaf counts taken from potatoes and sugarbeets (table 13). The most eggs were found from July 26 to August 8, an average of 46 *Geocoris* eggs per 100 leaves of potatoes and 14.5 eggs per 100 leaves of sugarbeets.

As listed in table 1, lygus bugs and aphids were prey for the *Geocoris* spp. However, in a comparison of the seasonal trends of *Geocoris* with those of the lygus bugs and aphids, no consistent correlation of *Geocoris* numbers to population trends of these prey species was evident on all crops. For example, the period mid-August to mid-September was a low point for *Lygus* on potatoes (fig. 12) but the highest

TABLE 13.—*Average number of* Geocoris *eggs per 100 leaves on 3 crops in the alfalfa interplant field study, 1966*

Date	Average number of *Geocoris* eggs on—		
	Potato	Sugarbeet	Broccoli
June 29	0.5	0	0
July 12	5.5	.5	.5
July 26	8.0	2.5	0
Aug. 8	46.0	14.5	0
Aug. 22	5.0	.5	0
Sept. 6	6.5	0	—
Sept. 19	13.0	.5	—
Oct. 3	—	1.5	—

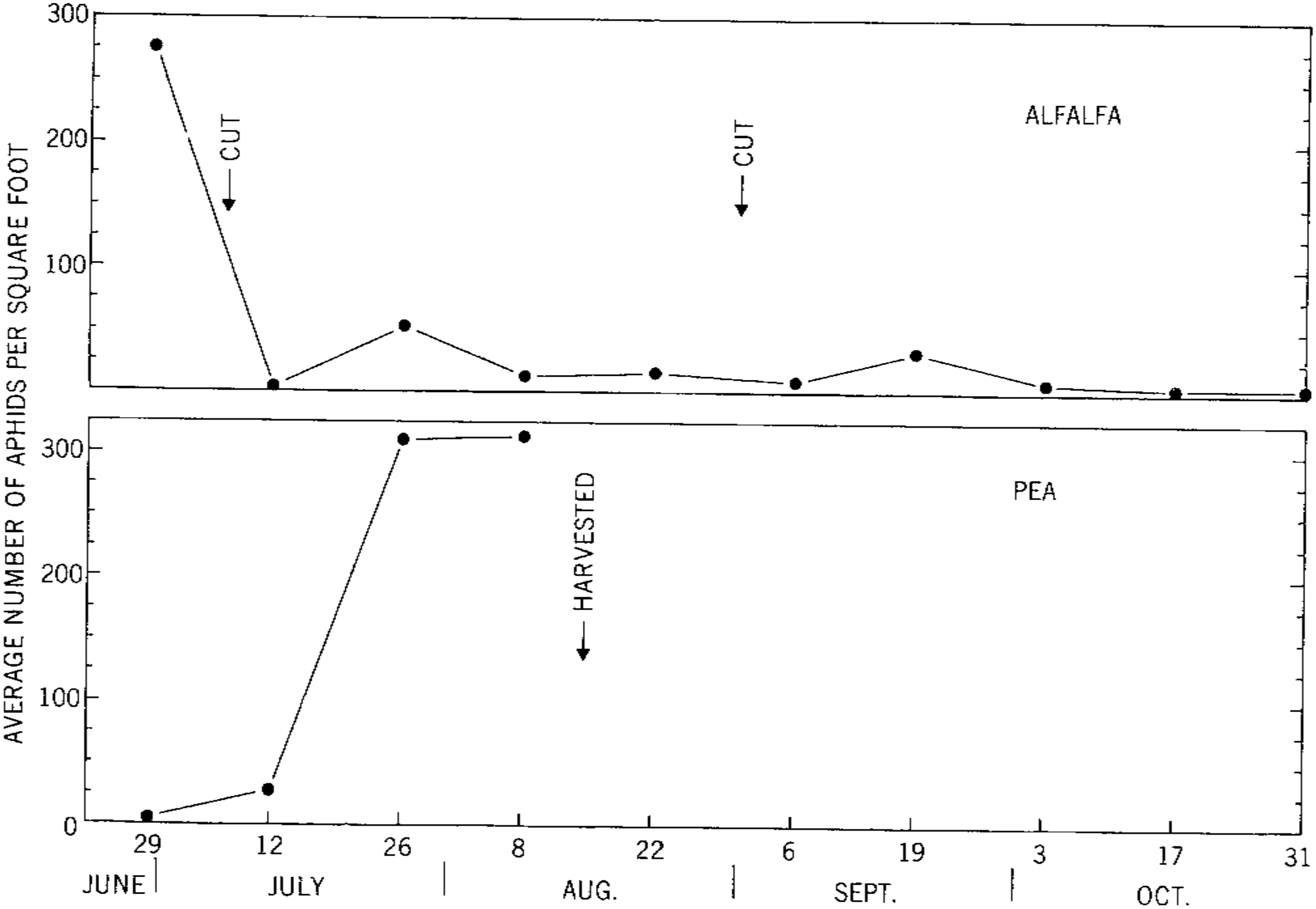

Figure 13.—Seasonal trends of the pea aphid, *Acyrthosiphon pisum*, on alfalfa and pea crops in the alfalfa interplant study, 1966.

abundance for *Geocoris* (fig. 15). Although it is possible that *Geocoris* predation during this period could have substantially lowered the population of *Lygus*, it was surprising that the number of *Geocoris* would continue to be as high as 50 to 60 per 10 square feet through a month when the number of prey remained so low.

Populations of *Lygus* and *Geocoris* on sugarbeets presented a more classical interpretation of the density response of predator-prey synchronization. Populations of *Lygus* peaked on July 26 and continued to decline to August 22 (fig. 12). During the same period, the number of *Geocoris* built up and peaked on August 8

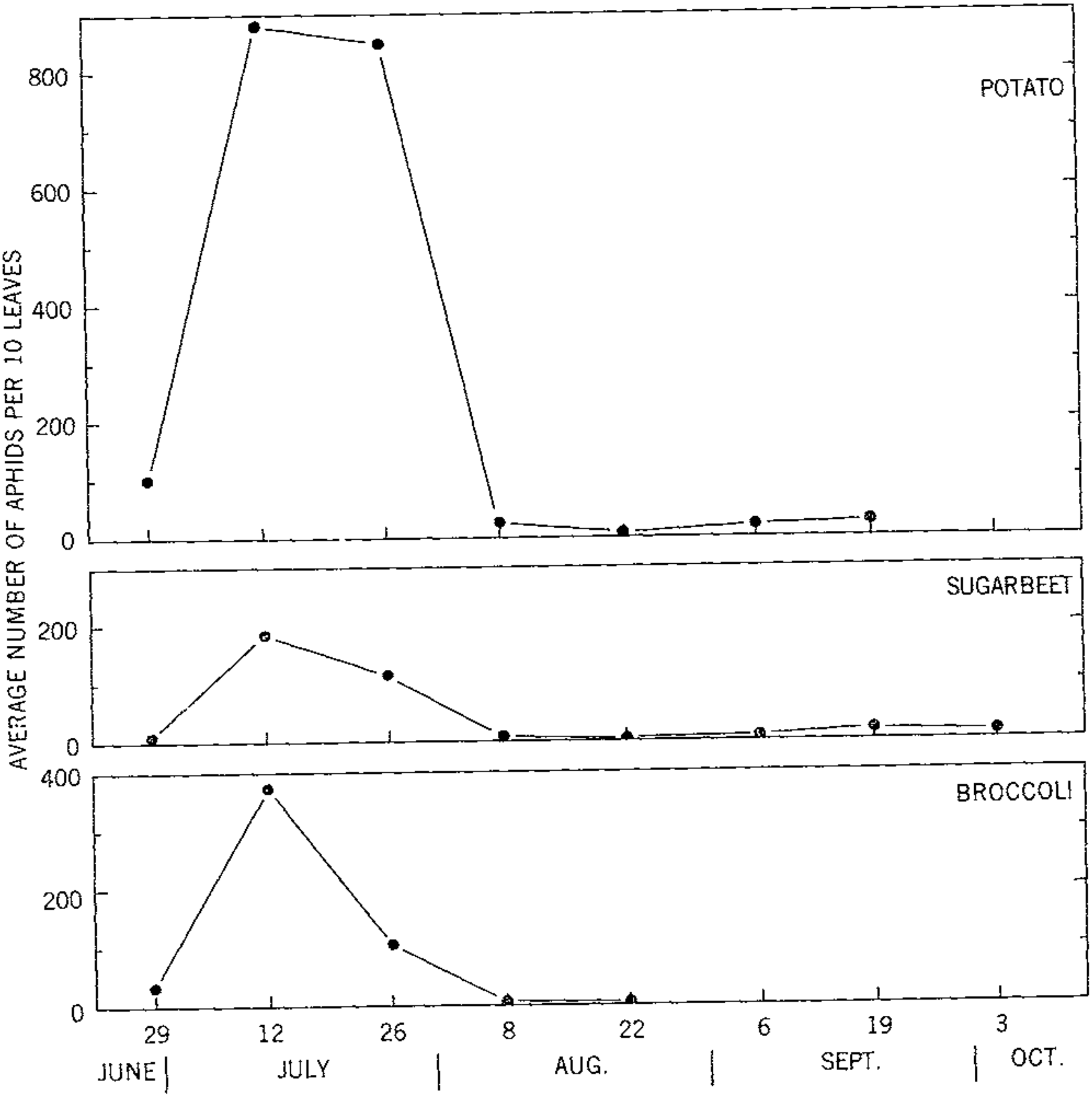

Figure 14.—Seasonal trends of the green peach aphid, *Myzus persicae*, on sugarbeet and vegetable crops in the alfalfa interplant study, 1966.

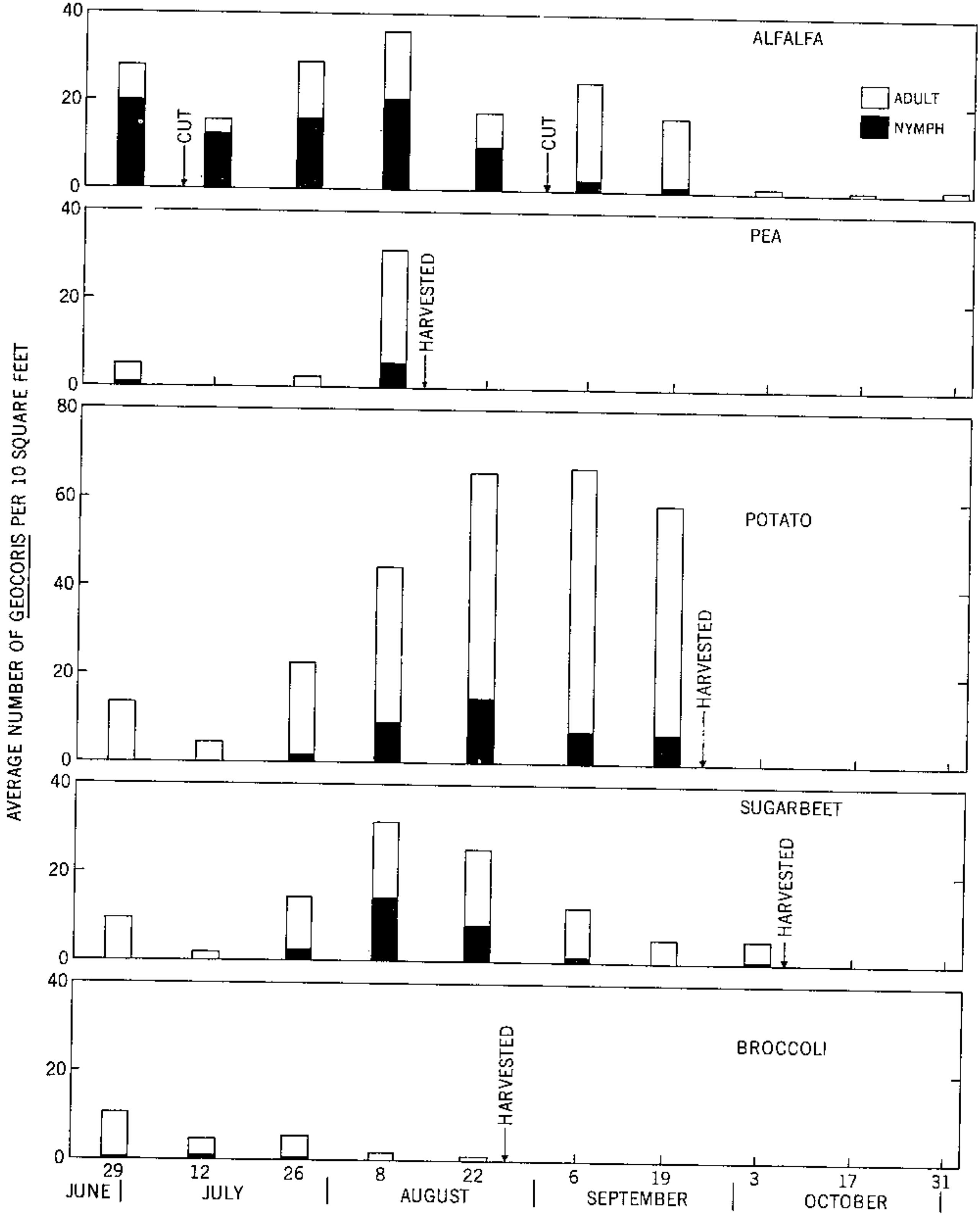

Figure 15.—Seasonal trends of *Geocoris* on various crops in the alfalfa interplant study, 1966.

and then slowly declined but with an increase in the relative number of nymphs (fig. 15). The *Lygus* and *Geocoris* synchronization may account for the decline of the *Lygus* population, because no alfalfa cutting took place during these periods to affect *Lygus* movement from alfalfa to vegetables. As *Geocoris* density decreased the rest of the season, the number of *Lygus* slightly increased.

Geocoris and Other Predators

The abundance of predator species making up the predator complex on various crops is listed in table 14. *Geocoris* spp. were the most abundant predator when based on the total found on all five crops. *Orius tristicolor* (White), *Nabis* spp. (predominantly *N. alternatus* Parshley and *N. americoferus* Carayon) and *Coccinella transversoguttata* Falderman were the three next most abundant predators. The other predator species had an average of less than two individuals per 10 square feet.

On an individual-crop basis, *Geocoris* was the most abundant predator on sugarbeets, potatoes, and broccoli, the second most abundant on peas, and third on alfalfa. *O. tristicolor* was the most abundant on alfalfa, and *C. transversoguttata*, the must abundant on peas.

The potato plots harbored the greatest number of predators with an average of 81 per 10 square feet, followed by alfalfa with 64, sugarbeet with 46, pea with 42, and broccoli with only eight. These figures are the averages for the season and do not reflect the importance of alfalfa as a reservoir source of the predator complex before the other crops begin to grow in late spring or after the crops are harvested in summer and fall.

The seasonal abundance of the four major predators found on these crops during the 1966 season is illustrated in figure 16. *C. transversoguttata* was the only oligophagous predator in significant abundance. This species was found on peas, potatoes, and sugarbeets during the periods of high aphid density, but they were either not present or in low numbers when pea aphids were abundant on alfalfa before the first cutting or when green peach aphids were abundant on broccoli. As shown in figure 16, *transversoguttata* was the most abundant on peas on August 8 during the peak of pea aphid abundance (fig. 13).

Like *Geocoris*, the other omnivorous predator, *Nabis* spp., did not respond consistently with an increase of lygus bugs and aphids in the mixed-culture crops. *O. tristicolor* is primarily known as being predaceous on smaller prey species such as mites and thrips, but no records were kept on these prey species.

TABLE 14.—*Average number of predator species on 5 crops in the alfalfa interplant field study, 1966*

Predator	Average number of predators/10 ft. sq. on[1]—					
	Alfalfa	Sugarbeet	Potato	Broccoli	Peas	Average
Geocoris spp	16.8	13.2	39.5	4.8	9.6	16.8
Orius tristicolor	27.0	10.7	17.2	.5	4.6	12.0
Nabis spp	17.9	7.8	11.9	1.1	5.1	8.8
Coccinella transversoguttata	.3	4.5	5.4	1.0	16.3	5.5
Scymnus spp	.5	2.9	3.6	.1	1.9	1.8
Anthocoris melanocerus	.3	2.1	.8	.1	3.2	1.3
Chrysopa spp	.2	3.9	.8	.3	.4	1.1
Deraeocoris brevis	.1	.1	1.1	.1	.3	.3
Hemerobius spp	.1	.4	.4	0	0	.2
Staphylinids	.5	0	.1	.1	.1	.2
Syrphids	.3	0	.1	0	.3	.1
Totals	64.0	45.6	80.9	8.1	41.8	......

[1] Sampling periods: Alfalfa 6/29–10/31; sugarbeet 6/29–10/3; potato 6/29–9/19; broccoli 6/29–8/22; peas 6/29–8/8.

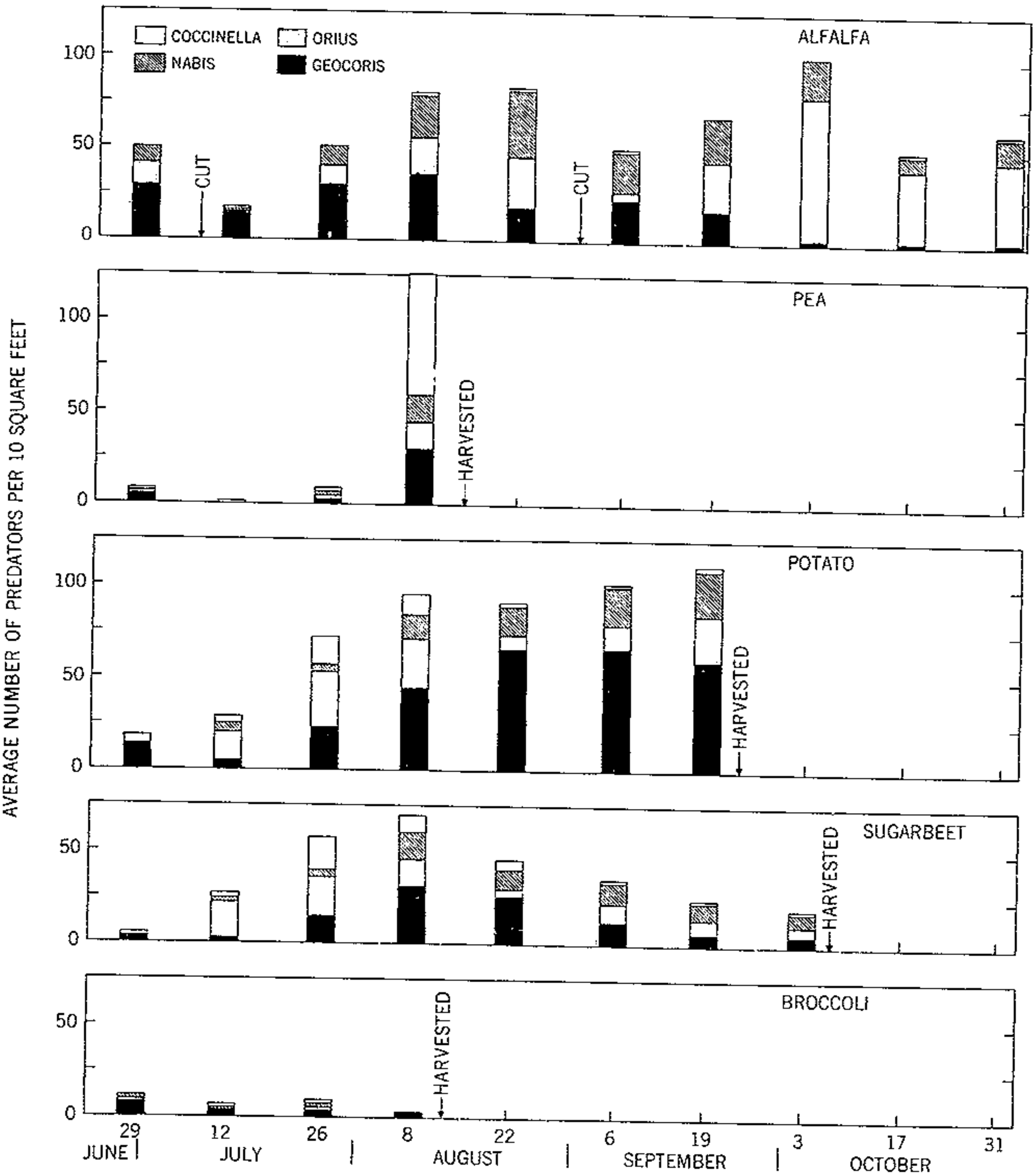

Figure 16.—Seasonal trends of the predator complex on various crops in the alfalfa interplant study, 1966.

Conclusions and Discussion

At times, a single predator species may not appear to be effective because it does not react in a density dependent manner to its prey populations; but as part of the total predator complex, their contribution may make the difference in the success or failure of an integrated control program. This is especially true with the omnivorous predators. As shown in figure 16, a substantial number of predators as a complex responded to the prey complex on sugarbeet, potato, and pea crops.

In evaluating the effectiveness of biological control, all natural enemies, such as insect diseases, parasites, and predators, should be included. For example, it appears that biological control of aphids on broccoli was not promising because of the low density of predators and the high density of aphids (fig. 14 and table 14). No aphid parasite counts were taken on June 29 and July 12 during the accelerated growth phase of the aphid populations, but many parasites of aphids were observed flying around broccoli plants. Therefore, parasites were sampled with a D-Vac machine on July 25, August 8, and August 22. As high as 7 to 9 times more parasites of aphids were found on broccoli than on the other two crops harboring the green peach aphid (table 15). This is a good example where one aspect of natural control, the predator complex, is limited but is replaced by another, the parasites, to suppress the prey populations.

Alfalfa interplants or border planting appear to have a great potential as a reservoir for beneficial insects in the early growing season and as overwintering sites for beneficial insects. The movement of beneficial insects could be manipulated by cutting of the alfalfa or perhaps by the application of selective insecticides before hay cutting to kill the injurious insects.

TABLE 15.— *Numbers of aphid parasites collected on 3 crops in the alfalfa interplant field study, 1966*

Date	Average number of aphids/10 ft. sq. on—		
	Sugarbeets	Potato	Broccoli
July 26	103	96	569
Aug. 8	39	70	636
Aug. 22	<1	1	81

PREDATOR OF *MYZUS PERSICAE* IN A GREENHOUSE STUDY

Numbers of *Geocoris* in the mixed-crop study with alfalfa interplants did not substantially increase during the peak abundance of the green peach aphid on potato, broccoli, and sugarbeet crops. Although *Geocoris* were frequently observed feeding on *Myzus persicae* in the field, it was difficult to evaluate them as predators of this aphid because of the different food preferences of the life stages of the predator and because *Geocoris* were only a part of the predator complex. Since no predator-free plots were included in this field of study, a greenhouse experiment was improvised to evaluate *G. bullatus* as a predator of the green peach aphid.

The experimental design consisted of six metal flats 24 by 24 by 4 inches placed three to a bench on each side of the greenhouse. Each flat had nine sugarbeet plants spaced 15 cm. apart. Five adult virginoparae of *M. persicae* were placed on each plant, or a total of 45 aphids per flat. A 12-inch-high cage with saran cloth walls and a removable plastic lid was placed over each flat. Nine females of *G. bullatus* were placed in each of three cages selected at random. The other three cages served as controls.

In the cages without *G. bullatus*, the population of *M. persicae* had over a 2,000-fold increase in 28 days, but the population of *M. persicae* in the cages with *G. bullatus* had only a ninefold increase for the same period (table 16). Weekly counts were taken in the control cages without *Geocoris* to determine the population growth rate; however, weekly counts were

TABLE 16.—*Comparison of the number of green peach aphids,* Myzus persicae, *in greenhouse cages with and without* Geocoris bullatus

Cage No.	Number of aphids			
	0 days	8 days	14 days	28 days
	Without *Geocoris*			
1	45	534	4,019	[1] 95,000
2	45	768	4,315	[1] 105,000
3	45	775	3,650	[1] 120,000
	With *Geocoris*			
4	45	......	....	129
5	45	......	....	395
6	45	......	....	693

[1] Rough estimate of the number of aphids in each cage based on 3 leaves per cage.

not made in the cages with *Geocoris* because of the possibility of losing the predators.

After 28 days, the unchecked aphid population in the control cage almost killed the sugarbeet plants, but the plants in the cages with *G. bullatus* were still healthy (fig. 17). The picture was taken after the flats were exposed to direct sunlight and wind for many hours. This exposure, plus the shallow root systems in the flats, caused the control leaves to wilt.

When confined with *M. persicae,* these predators were able to suppress the aphid population in a 28-day period (fig. 18). Thus, in the field, *Geocoris* has the potential of suppressing an initial infestation of aphids and delaying the pullulation of the aphid population.

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Figure 17.—Damage on sugarbeets by *Myzus persicae*: The two flats on left were in cages with *Geocoris bullatus*; two flats on right were in cages with no predators.

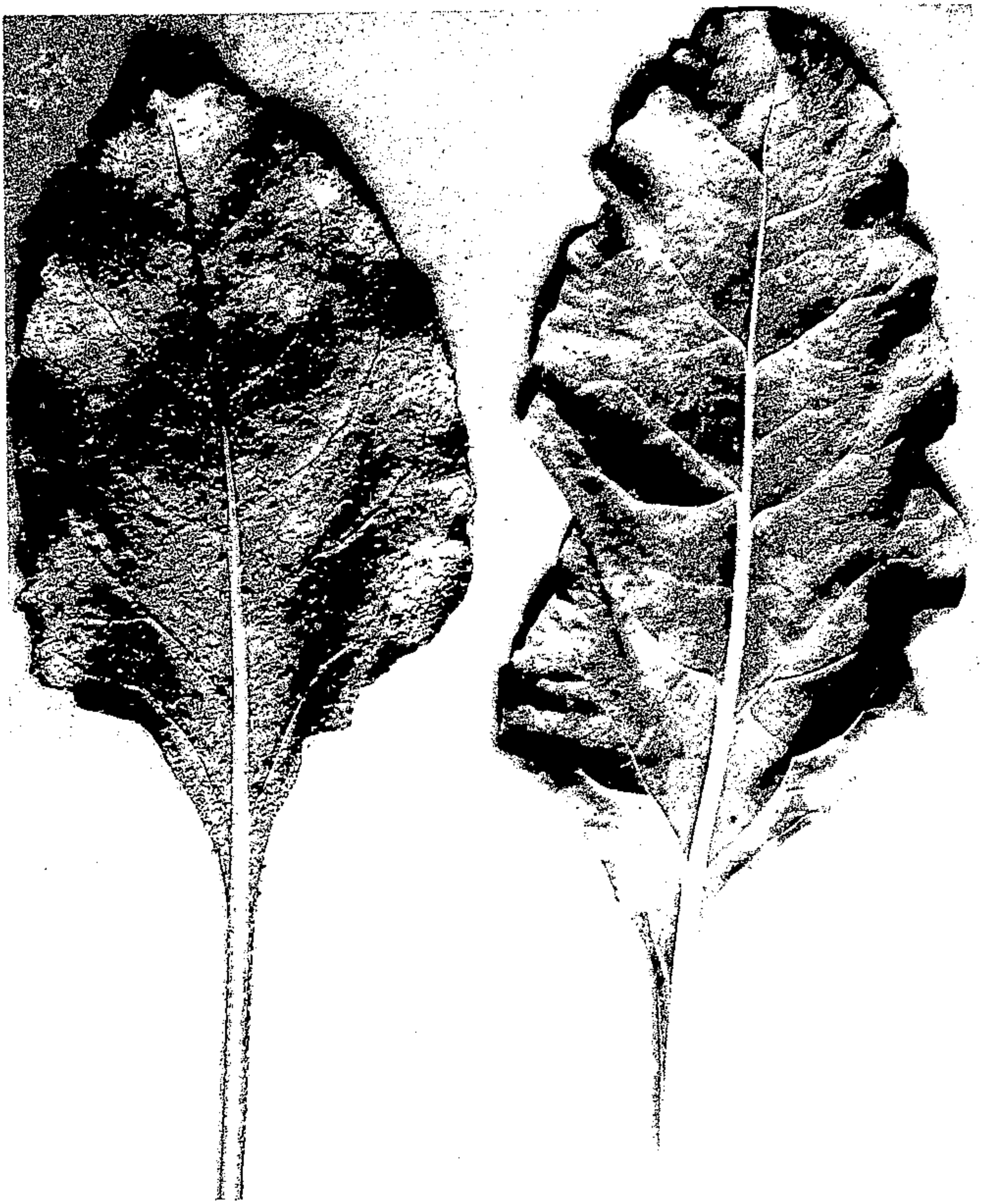

Figure 18.—View of ventral surface of sugarbeet leaves showing differences in number of *Myzus persicae*: *Left*, leaf from control cage; *right*, leaf from cage with *Geocoris bullatus*.

FIELD BIOLOGY AND ECOLOGY

Ovipositional Sites

In areas of low-growing weeds *Geocoris* adults and nymphs were mainly observed on the ground, around or under duff, or near the crowns of plants. On cultivated crops, *Geocoris* were frequently observed on the plants. *Geocoris* eggs have been found attached to decaying plant matter on the ground and also on plants. We did not attempt to compare the percentage of eggs laid on the plants with the number laid in the duff or soil, because of the difficulties involved in locating eggs laid in the latter area.

The ovipositional behavior of *Geocoris* was studied on sugarbeet plants in the field. Leaves were randomly selected and searched for *Geocoris* eggs. The dispersion and placement of the eggs in relation to arthropods on the leaves was recorded for each leaf. The field was sampled until 100 leaves with *Geocoris* eggs were found; 75 percent of these leaves had only one *Geocoris* egg per leaf. The remaining 25 percent of the leaves had two to four eggs either clumped close together or randomly placed on the leaf. Of the 133 *Geocoris* eggs found on the 100 leaves, 74 percent were laid on the lower surfaces and 26 percent on the upper surfaces.

McGregor and McDonough (*28*) and van den Bosch and Hagen (*43*) reported that *Geocoris* frequently deposited their eggs in spider mite colonies. In our study, the sugarbeet field had a heavy mite infestation in one corner of the field. From observations and counts, substantially more *Geocoris* eggs were laid in the section of the field with the heavy mite infestation than in the other parts of the field. About 45 percent of the *Geocoris* eggs laid on mite-infested leaves were in mite colonies. No correlation was apparent between *Geocoris* egg deposition and the abundance of insects such as the green peach aphid or eggs of the leaf miners, *Pegomya betae* (Curtis) and *Psilopa leucostoma* Meigen. Apparently a closer relation exists between *Geocoris* egg deposition and mites than with other arthropod species on sugarbeets.

Flight Activity

The flight activity of *Geocoris* around a ¾-acre field of sugarbeets was studied. Sticky traps were used to study flight activity, a hygrothermograph recorded temperature and relative humidity, and a D-Vac machine was used to sample the population of *Geocoris* in the field.

Each sticky trap was made of clear plastic sheet stretched across and fastened to a 1- by 4-foot window screen frame of aluminum. Each end of the frame was fastened to parallel support poles so that the long side of the frame was horizontal to the ground. The lower side was 5 feet above ground level. Only one side of the plastic sheet was painted with sticky material (Toximul 500®).

One set of sticky traps was placed on each side of the rectangular field, and another set was placed 300 feet downwind from the field. Each set consisted of four sticky traps placed 10 feet apart, and the sticky side of each trap faced a different cardinal direction. Traps were checked daily for insects, and the plastic sheets were changed every 2 or 3 days.

The data obtained from sticky traps, D-Vac machine samples, and hygrothermograph records indicated a correlation between temperature and flight activity of *Geocoris*. Daily high temperatures above 24° C. appeared to increase flight activity of *Geocoris*. Temperatures below 24° usually showed little or no *Geocoris* flight activity. The first *Geocoris* adult was trapped after the initial 24-hour period of trapping on May 9, 1967. At this time the sugarbeet dicotyledon leaves were barely showing. The sugarbeet field was not sampled again until June 5. The number of *Geocoris* caught on the sticky traps appeared to be more strongly correlated to temperature than to the number of *Geocoris* in the sugarbeet field (fig. 19).

Adults of *Geocoris* observed in the laboratory and field would run rather than fly when disturbed; however, on hot and clear summer days in the field, when disturbed from their hiding places under duff or around the crown of plants, *Geocoris* adults would invariably run until contact was made with the hot open surface of the ground and then either turn back to the shady area or take flight for a short distance. These short flights are probably due to the sudden exposure to high temperatures on the unshaded

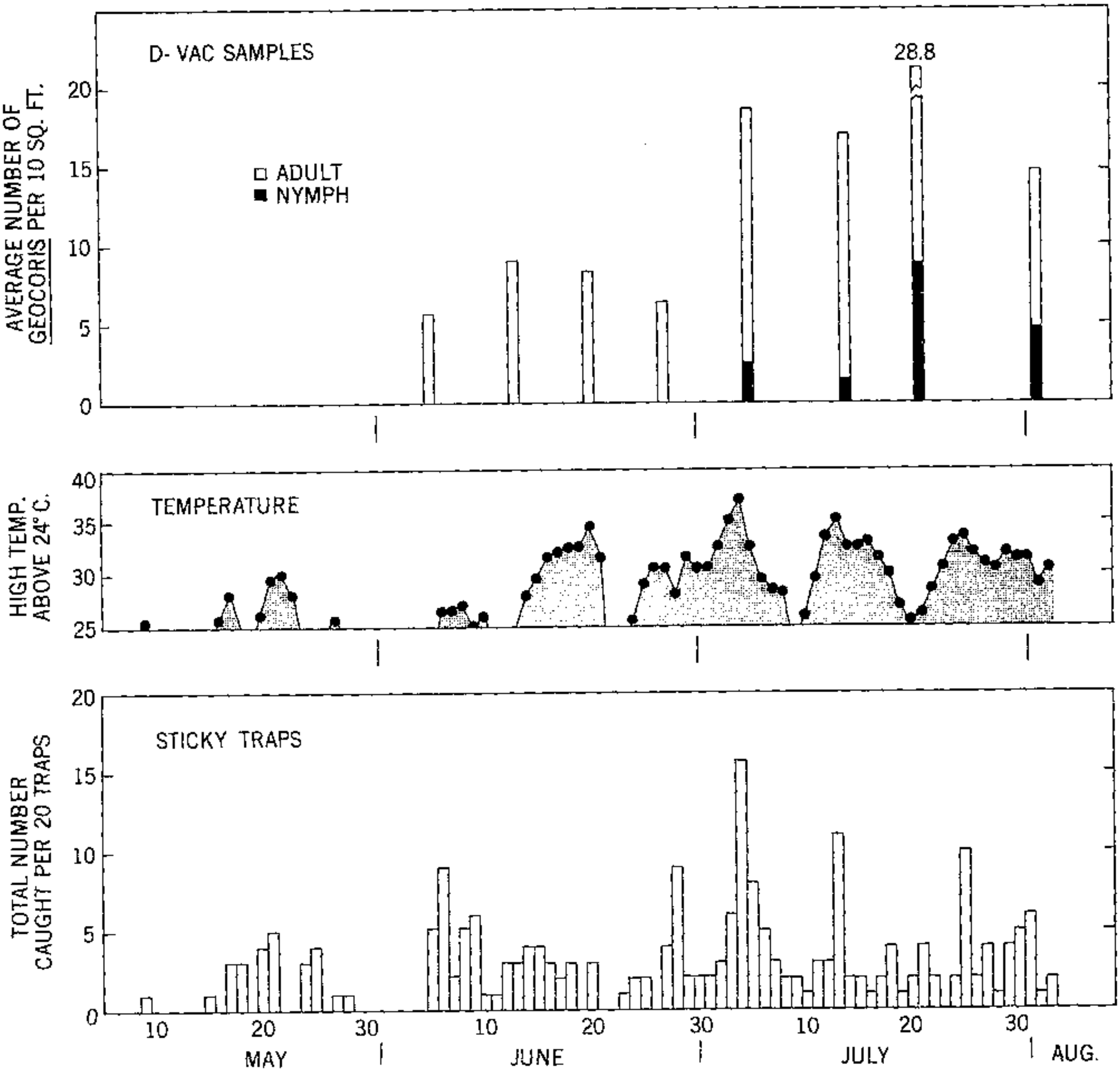

Figure 19.—Flight activity of *Geocoris* in relation to temperature and field counts, as indicated by sticky trap catches.

ground surface rather than to flight as a normal means of escape. On an overcast day they rarely behave in this manner. Thus, during periods of high temperature, increased frequency of flight may be explained by the increase in temperature of the ground surface.

Seasonal Life History

Spring Emergence

A 2-year study was undertaken in a commercial field of alfalfa to study the seasonal trends of *G. pallens* and *G. bullatus*. The particular field studied was selected because of the high water table that required no irrigation and because no insecticides had been applied. Therefore, the effects of two variables, irrigation and insecticides, on *Geocoris* and prey were eliminated.

In 1968 and 1969, 30 square feet of D-Vac samples were taken each week around the same general area of the field. The first year's data were incomplete because sampling was not started until June 5 and adults had already emerged. Interesting results were obtained in the second year, when alfalfa was sampled on March 20, 1969, after the snow had melted and new growth had barely appeared. After 3 weeks without collecting any *Geocoris*, nymphs of *G. bullatus* were found on April 11 and continued to be the only stage and species found until May 15. Unfortunately, at this time all *Geocoris* were stored in alcohol for later identification and when they were eventually checked it was difficult to separate the first and second instars into species because many of the color differences had disappeared. Therefore, the base of the age distribution polygon for *Geocoris* nymphs of the first and second instars was shown as determined in figure 20. However, no difficulty arose in the separation of the *Geocoris* species after the second instar.

First adults were not found until May 15 when two females of *G. bullatus* and one male of *G. pallens* were found in 30 square feet of samples (fig. 20). The peak number of *G. bullatus* adults occurred between May 22 to June 5; whereas, the peak emergence of overwintering *G. pallens* adults extended from June 5 to June 18. Therefore, *G. bullatus* adults were present in substantial numbers before the peak emergence of overwintering adults of *G. pallens*. Also, both sexes of both species were found in the emerging population of overwintering adults.

The most probable controlling factor for spring emergence of *Geocoris* adults is soil temperature; but as no soil-temperature records were kept, air temperature was used to correlate emergence. Overwintering adults were first collected after the warming spell above 24° C. for several days (fig. 20).

Overwintering

Our studies in alfalfa in 1968 and 1969 and other field observations indicate that *G. pallens* adults become scarce at the end of September. Yet, a few *G. pallens* are found on warmer winter days up to December or until snow covers the ground. We found a few overwintering adults of *G. pallens* an inch or so below the soil in cultivated fields in November.

The overwintering behavior of *G. bullatus*, however, is strikingly different in parts of the Yakima Valley. Like *G. pallens*, it, too, becomes scarce in alfalfa and in other cultivated fields in late September. However, at our research station orchard in Yakima, a tremendous buildup of *G. bullatus* occurs in the fall of every year, especially in the peach orchard. We first observed this phenomenon in the fall of 1965 and again in 1966. In 1967 as the *G. bullatus* buildup was progressing in the fall, the orchard was disked. After cultivation, *G. bullatus* disappeared. The effects of cultivation upon the numbers of *G. bullatus* lasted into the fall of 1968 when only a slight buildup occurred. In 1969, another large fall buildup of *G. bullatus* occurred, when as high as 21 to 32 *Geocoris* per square foot were found on the floor of the peach orchard. This phenomenon is associated with orchardgrass cover and return of the green peach aphid to peach trees. It is still under study.

Geocoris eggs are difficult to find on the floor of the orchard, but some eggs were found in the duff in October. Dissections of the fall population of *G. bullatus* females from the orchard exposed a full complement of mature eggs. These females readily laid eggs when brought into the laboratory; but when these eggs were placed in a growth chamber, there was poor hatch and erratic hatching times compared with the sum-

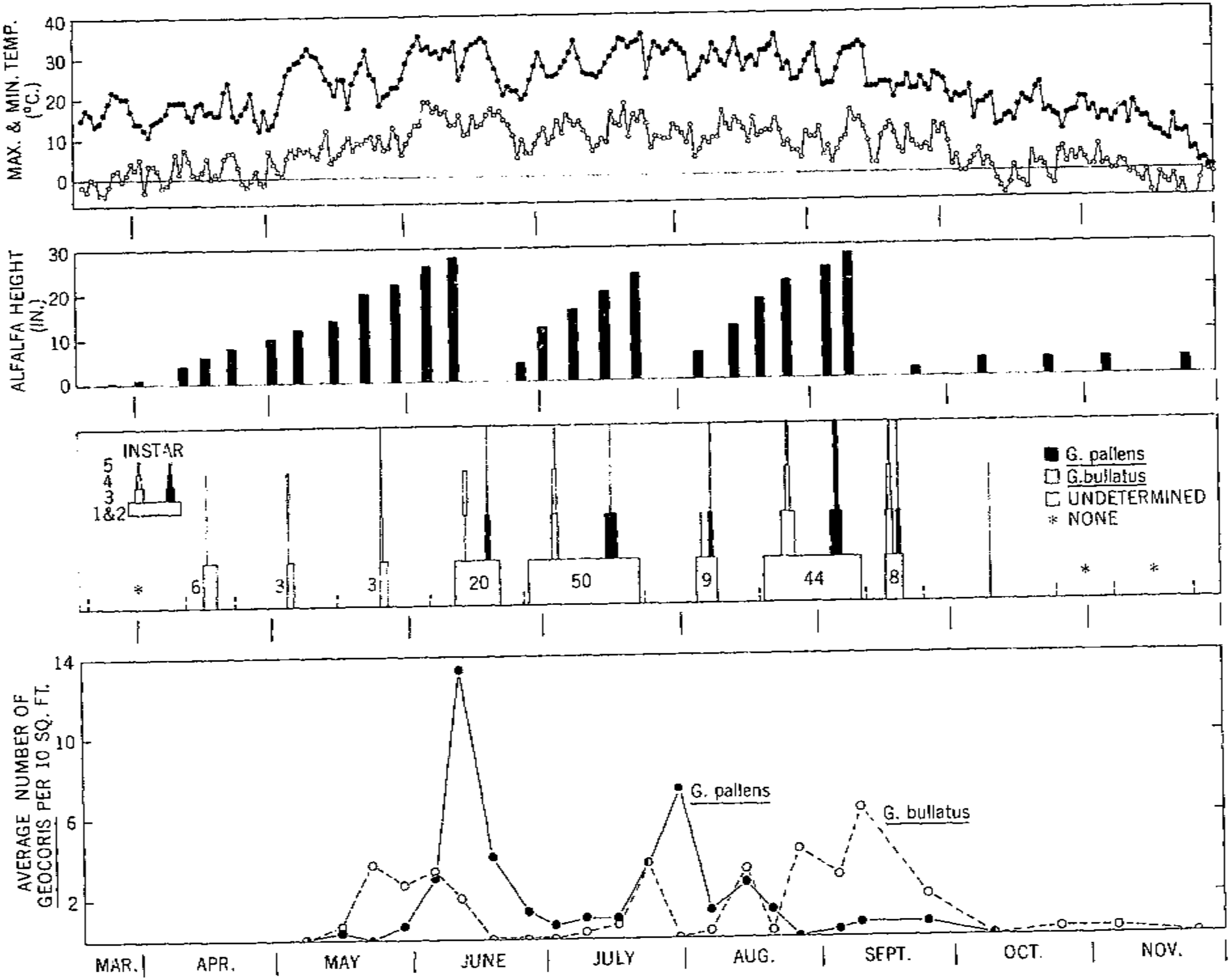

Figure 20.—Seasonal trends of all life stages of *Geocoris pallens* and *G. bullatus* in alfalfa. Maximum and minimum temperature and height of alfalfa are also shown.

mer generation of *Geocoris*. Emerging nymphs all died before or during the second instar when fed on different diets that were suitable for the nymphs reared from summer adults. Thus, a major difference between eggs obtained from summer adults and overwintering adults exists in *G. bullatus*.

As previously mentioned, nymphs of *G. bullatus* appear in April in alfalfa before the appearance of the adults; therefore, several possibilities exist for the manner in which *G. bullatus* overwinters. One possibility is that *G. bullatus* overwinters as eggs laid in the fall or in winter or as both eggs and adults. Smith (*36*) reported that *G. bullatus* overwinters as adults in the field in Idaho. We conducted several tests in an attempt to determine the manner in which *G. bullatus* overwinters. Fifty adults of *G. bullatus* from the fall population were caged under each of the 12 emergence cages in the peach orchard on October 17, 1969. In late winter when the cages were inspected, hundreds of eggs were found between tightly pressed decaying peach leaves, indicating that these eggs were laid in the fall when the peach leaves were still loosely lying on the floor of the cage. In February and March, these eggs were placed in the growth chamber at 21° C. and 60 percent relative humidity and most of the eggs hatched. Since caging of *Geocoris* adults in the fall may have forced unnatural ovipositing, we also inspected the noncaged area of the peach orchard for *Geocoris* eggs hidden in the duff; 10 eggs of *Geocoris* were found in a half hour of searching. Thus, *G. bullatus* lays overwintering eggs in the fall.

Number of Generations on Alfalfa

Although hay cutting interferes with the population growth trends of *Geocoris*, an estimation of the number of generations per year can be obtained from the seasonal trend of different life stages of *Geocoris* species on alfalfa (fig. 20 and table 9). In 1969, overwintering adults of *G. pallens* emerged in great numbers about June 11, followed by a new generation of adults at the end of July. From the nymphal age-distribution polygons between August 20 to September 9 (fig. 20), it appears that another generation was developing at this time although only a few of the resulting overwintering adults were collected in September. Thus, *G. pallens* has at least two complete generations per year, which is a reasonable assumption when compared with the generation time of 58.7 days calculated from the life-table analysis.

However, *G. bullatus* has at least three generations a year because of the early appearance of the nymphs in mid-April, which allows for an extra generation.

SUMMARY

A 5-year project (1965–70) was undertaken to study the biology and ecology of *Geocoris pallens* Stål and *G. bullatus (Say)* in the Yakima Valley of Washington. Since these two omnivorous predator species most frequently occupied the same habitat, rearing and interbreeding experiments were conducted to authenticate their status. All life stages of both species were described so that field specimens could be readily identified. *G. bullatus* is typically larger and darker than *G. pallens*.

In biological studies, the egg stage was exposed to different temperatures. The developmental rates of both species varied more with the time of collection of adults than with species.

Geocoris reared in the laboratory on a combination diet of green plant, insect prey, and sunflower seeds resulted in the shortest development, the highest egg production, and the greatest survival. A diet of green plant and sunflower seeds resulted in a prolonged developmental period for the nymphal stages and the few emerging adults laid no eggs. *Geocoris* fed on insect prey and green plant gave varying results. When fed on pea aphids, the emerging adults laid no eggs; but when fed on green peach aphids or beet leafhoppers, the emerging adults laid eggs. Field-collected adults laid eggs when fed either aphids or sunflower seeds, but a combination of insects, green plant, and sunflower seeds resulted in the best egg production. A diet of sunflower seeds and green plant gave the best longevity, but *Geocoris* fed aphid prey and green plant laid more eggs.

Field tests were conducted to evaluate sunflower seeds as a possible supplemental food for *Geocoris*. Pitfall traps baited with sunflower seeds concentrated seven times more *Geocoris* adults and nymphs than the unbaited traps. Plots with sunflower seeds scattered on plants in a sugarbeet field had over twice as many *Geocoris* eggs as plots without sunflower seeds.

In a mixed-crop field experiment with sugarbeet, potato, pea, and broccoli plots with alfalfa interplants, *Geocoris* was the most abundant predator in the predator complex. On a crop basis, *Geocoris* was most abundant on sugarbeets, potatoes, and broccoli, second on peas, and third on alfalfa. In the early growing season, alfalfa served as a breeding ground and reservoir for *Geocoris*.

In a greenhouse study, when green peach aphids, *Myzus persicae* (Sulzer), were caged at low densities on sugarbeet plants, adults, of *G. bullatus* were able to regulate the aphids at about 250-fold lower population levels than those in the controls.

Flight activity of *Geocoris* was correlated with daily high temperatures above 24° C. On hot and clear summer days, high temperature of the soil surface appears to stimulate *Geocoris* flight.

The seasonal life history of both species of *Geocoris* was studied in a field of alfalfa in 1968 and 1969. In April, before any adults of *Geocoris* were found, nymphs of *G. bullatus* were present. Overwintering adults did not peak in emergence until early to mid-June for *G. pallens*. Most adults of both species disappeared from alfalfa by late September, but *G. bullatus* concentrated in peach orchards with some samples running as high as 21 to 32 *G. bullatus* per square foot. *G. bullatus* overwinter primarily as eggs, and *G. pallens* overwinter as adults. In alfalfa, *G. bullatus* has at least three generations per year and *G. pallens*, at least two generations per year.

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