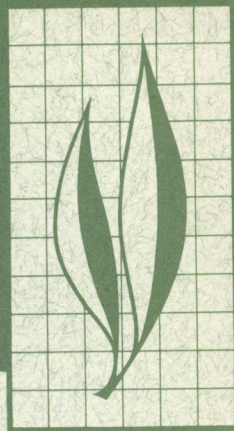


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of Predators on Cotton:
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and Predator Efficiencies**

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**Within-plant Distribution
of the Immatures of
Heliothis zea (Boddie) on Cotton**

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Upon Cotton Fruiting Structures**

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Within-plant Distribution of Predators on Cotton: Comments on Sampling and Predator Efficiencies (Wilson and Gutierrez)

Within-plant distribution of four predators found in California cotton fields is described. Adult stages of all predators were found in greatest frequency in the terminal portions of the plant, and, within that region, adults tended to be more common on fruiting parts than the same species of larvae. In general, the smaller predators, *Geocoris* and *Orius*, were found higher on the plant than the larger predators *Chrysopa* (larvae) and *Nabis*. Their respective areas of activity corresponded to the location of suitably sized (stages) prey. Those predators closest to the plant terminal were more effectively sampled with the standard University of California sweepnet.

Within-plant Distribution of the Immatures of *Heliothis zea* (Boddie) on Cotton (Wilson, Gutierrez, and Leigh)

A detailed study of the within-plant distribution of cotton bollworm (*Heliothis zea* (Boddie)), its eggs and larvae, was conducted in the field, and sampling schemes for them were developed.

The average location of bollworm eggs was approximately one-third of the distance in nodes from the terminal, while older larvae were found lower on the plant than younger larvae. The sampling scheme for bollworm eggs relies on the finding that the mainstem leaves are the preferred oviposition site. Field observations indicate that early first instar larvae can be detected in squares by the presence of frass and the flaring of the bracts. These criteria are used in a suggested sampling scheme for first-through-third instar larvae.

Fruit Predation Submodel: *Heliothis* Larvae Feeding Upon Cotton Fruiting Structures (Wilson and Gutierrez)

Field and laboratory data on the numbers and age distribution of two varieties of cotton fruits, the association of various-age bollworm larvae (*Heliothis zea* (Boddie)) and various age fruit, as well as the attack rates of the larvae on the fruits were used to develop a submodel describing predation of bollworm larvae on cotton fruits. The submodel will be used in the coupling of bollworm- and cotton-plant population models. This model is an important step in the development of dynamic economic threshold levels for bollworm in cotton.

THE AUTHORS:

L.T. Wilson, formerly Graduate Student, Department of Entomology, Davis, is employed at Plant Industry, CSIRO, Narrabri, N.S.W., Australia, 2390.

A.P. Gutierrez is Entomologist, Division of Biological Control Department of Entomological Sciences, Berkeley.

T.F. Leigh is Entomologist, U.S. Cotton Research Station, Shafter, and Lecturer, Department of Entomology, Davis.

Within-plant Distribution of Predators on Cotton: Comments on Sampling and Predator Efficiencies^{1,2}

INTRODUCTION

THE IMPORTANCE OF PREDATORS in controlling pests of cotton (*Gossypium hirsutum* L.) in the Central Valley of California has been reported by van den Bosch and Hagen 1966, Falcon *et al.* 1971, Ehler *et al.* 1973, and Eveleens *et al.* 1973. Use of insecticides for control of pests such as *Lygus hesperus* Knight, often disrupts the cotton agroecosystem by killing both pests and their natural enemies. What often results is rapid resurgence of the target pests, induced outbreaks of otherwise insignificant pests, and economic loss (Ehler, Eveleens, and van den Bosch, 1973; and Eveleens, van den Bosch, and Ehler, 1973).

The concept of "integrated control" as developed in California (Stern *et al.* 1959), stressed the notion that natural enemies, cultural, and other biotic factors should be manipulated in a manner to achieve suppression of pest populations. More disruptive tactics such as pesticide applications would be used only as economic infestations developed. This concept depends heavily on the assumption that the "economic threshold" for a pest species is known (i.e., when the cost of treatment is less than or equal to the benefits), and that methods are available to assess the impact of the natural enemies and other factors on pest populations. In general, methods for assessing the impact of pests on crops and natural enemies on pests are inadequate.

While beneficial arthropods are recognized as an essential element of integrated control, very little is known concerning the various components involved in determining their efficiency at controlling pest species. This paper examines—

- 1) within-plant distributions of various predators in cotton; and
- 2) how this information explains why predators are sampled with varying degrees of efficiency.

Comment is also made concerning the relative importance of within-plant distributions of predators in determining their efficiency as biological control agents.

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METHODS

Predator numbers and their within-plant distributions were visually determined on each sampling date by examining a minimum of six 1-meter rows of cotton. The number and location of each species by age (i.e., egg, larva, and the like) were recorded by mainstem and branch node—and plant part (i.e., fruit, and upper and lower surfaces of leaves). In addition, 16 fifty-count sweep samples were taken, from 7 to 10 a.m. on each sampling date with a standard University of California sweepnet (0.37 m diameter).

Time in these results is expressed both as Julian days and degree days (D°) above the developmental threshold for cotton (12°C , Gutierrez *et al.* 1975). The degree day calculations were made using a computer program developed by Frazer and Gilbert (1976).

The study was conducted at three locations near Bakersfield and Shafter, California, in the San Joaquin Valley during the summer of 1974.

RESULTS AND DISCUSSION

A total of 6,731 insect predators were visually observed in this study: *Orius tristicolor* (White), 1,804; *Geocoris pallens* Ståls and *Geocoris punctipes* (Say), 1,233; *Nabis americanoferus* Carayon, 95; and *Chrysopa carnea* Stephens, 3,599. In addition, crab spiders (thomisids) and wolf spiders (lycosids) were found, but because they were abundant only late in the season, they are not included in these results.

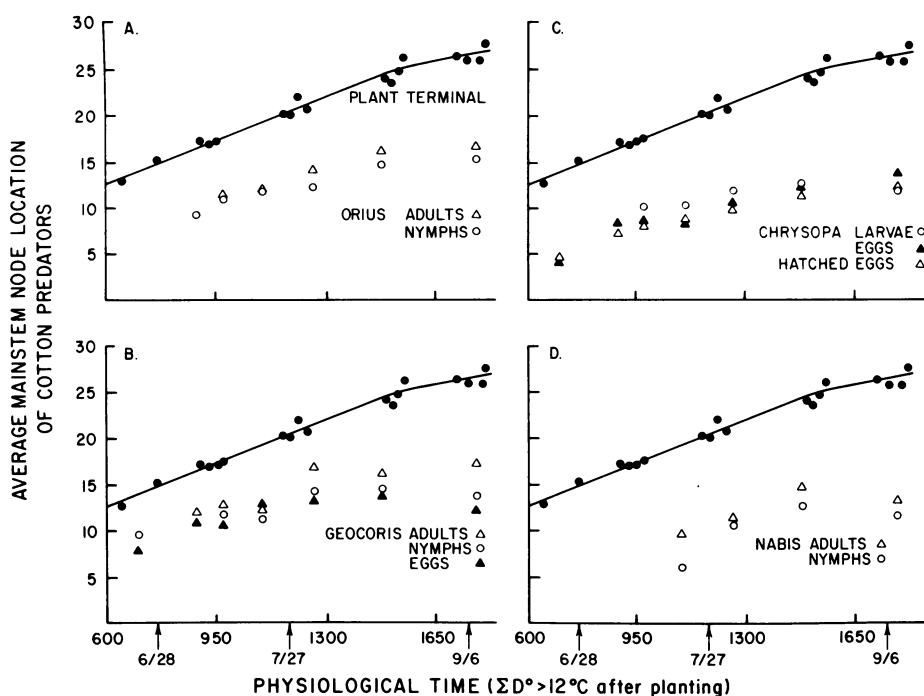


Fig. 1a-d. The average mainstem node location through time for the different predator species (immatures and adults). Shafter, California, 1974.

Within-plant distribution

Vertical distribution—Figures 1 a-d show the average mainstem node location through time for each of the different predators (immatures and adults). In general, adults were found higher on the plant than the immature stages. This was in contrast to the activity of their larval prey, beet armyworm (*Spodoptera exigua* (Hubner), cabbage looper (*Trichoplusia ni* (Hubner)) and the cotton bollworm (*Heliothis zea* (Boddie)), which were found lower on the plant as they matured (unpublished data).

Table 1 presents a summary of linear regression equation constants for the average location of the predator species (i.e., on mainstem nodes) against the average number of mainstem nodes per plant. Also included is a column of b values forced through (1,1). From a biological point of view, the regressions need not be linear, but they should pass through the (1,1) intercept, because early in the season when the plants germinate they are one node tall, and any predator on newly germinated plants must be at this node.

Table 1.
REGRESSION OF AVERAGE MAINSTEM NODE LOCATIONS AGAINST AVERAGE
MAINSTEM NODE HEIGHTS FOR FOUR PREDATOR SPECIES

Predator	a	b	r ²	n	b forced (1,1)
<i>Orius</i>					
Adults	-0.493	.653	.972***	5	.614
Nymphs	0.407	.563	.973***	6	.562
<i>Geocoris</i>					
Adults	2.786	.540	.830*	6	.653
Nymphs	4.512	.375	.749*	6	.566
Eggs	3.724	.391	.601*	7	.546
<i>Chrysopa</i>					
Larvae	5.723	.245	.719	5	.478
Eggs	-6.201	.780	.935***	7	.439
Egg cases	3.870	.639	.969***	7	.406
<i>Nabis</i>					
Adults	-1.432	.588	.718	4	.505
Nymphs	-7.700	.774	.736	4	.418

* Significant at 5% level.
** Significant at 1% level.
***Significant at 0.5% level.

The fact that the adults were located consistently higher in the plant than their immature stages (indicated by larger slope values) profoundly affected the sampling efficiency of the conventional method (i.e., sweepnet, see sampling comparison section). The adults of all species also tended to be located closer to the center of the plant (smaller average branch node location) than the immatures. This result may have been an artifact, since higher branches where adults were found have fewer lateral nodes.

Structure preference—In those species where the adult stage was observable, a greater number of adults relative to immatures were found on fruit (Table 2). Sufficient data were obtained for *Orius* nymphs to conclude that, during the peak period of square retention (mid July), the highest proportion of the population occurred on fruit (see Figs. 2a and 3b). Consistent site preference trends were not observed for most of the predators, perhaps in part due to small sample size. The combined proportion of adults and immatures (except *Orius* nymphs and all eggs) were compared to the

squaring cycle of the plant (Figure 2b). The results were very similar to those presented for *Orius* nymphs and imply similar site preferences. In general, *Chrysopa* and *Geocoris* eggs were easily found and were often located on the bottom surface of leaves. The top surface of leaves was not preferred by any of these predators.

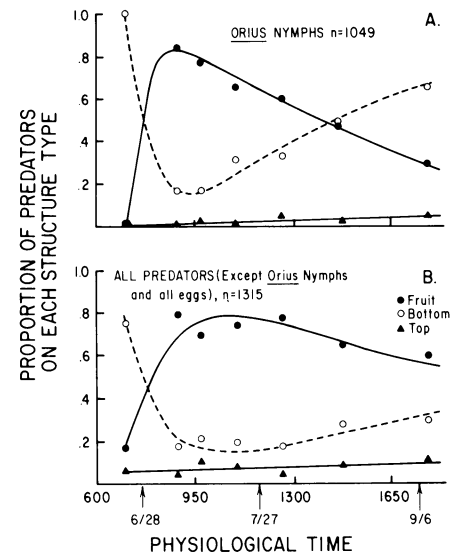


Fig. 2. A plot of (a) the proportion of *Orius* nymphs which are found on the different plant structures through the season, and (b) the combined proportion of adults and immatures (except *Orius* nymphs and all eggs) on the different plant structures through the season. Shafter, California, 1974.

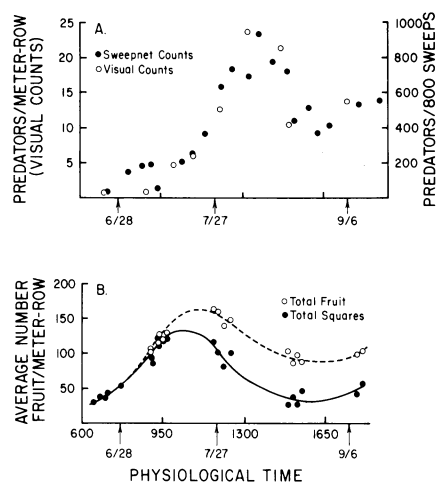


Fig. 3. A plot of (a) the seasonal trend for total predators observed using the WPVS and sweepnet methods, and (b) the number of fruits (total squares and total fruits) per meter-row through the season. Shafter, California, 1974.

Table 2.
PROPORTION OF PREDATORS UPON STRUCTURES (AVERAGE FOR SEASON)

Predator	Fruits	Leaves	Branches	n
<i>Orius</i>				
Adults	.764	.228	.008	755
Nymphs	.550	.440	.010	1049
<i>Geocoris</i>				
Adults	.716	.243	.041	148
Nymphs	.626	.345	.029	238
Eggs	.279	.706	.015	847
<i>Chrysopa</i>				
Larvae	.532	.457	.011	94
Eggs	.115	.878	.007	564
Hatched eggs	.059	.937	.004	2941
<i>Nabis</i>				
Adults	.625	.375	0	40
Nymphs	.273	.727	0	55

Comparisons of sampling methods

Comparison of sweepnet and whole plant visual samples (WPVS)—Figure 3a depicts the seasonal trend for the total predators, according to the WPVS and sweepnet methods. The results indicate that peak numbers occurred during early August with a smaller peak appearing in September. A comparison with Figure 3b shows that predator numbers decline after the maximum fruit-carrying capacity of the plant has been reached, and the plants cease to produce new growth. Late in the season (September), when the first or bottom crop had matured, the plants began a second regrowth. The data suggest that predator numbers also began to increase at this time.

The linear regression of total predators per meter-row, sweepnet (S) versus WPVS counts can be described in Equations 1 or 2.

$S = 0.3884 + 0.0977 \text{ WPVS}, r^2 = 0.911, n = 9, \text{ normal regression}$ [1]

$S = 0.1217 \text{ WPVS}, \text{ forced regression}$ [2]

Because the WPVS method and the sweepnet sample different numbers of plants, the two methods were made comparable by conversion to meter-row counts. This involved multiplying the sweepnet counts times a correction factor (C), where

$C = 1/(50 \text{ sweeps} \times 0.3683 \text{ meters/sweep}) = 0.0543/\text{meter}$

This C value is a modification of a correction estimate presented by Byerly *et al.* (1978) who converted sweepnet and De-vac® counts to single plant estimates for comparison with a Whole Plant Bag Sample Method (WPBS).

The slope in Equation 2 indicates that the sweepnet is only 12 percent as efficient as the WPVS for estimating total predator numbers. This value is comparable to 10 percent extracted from Figure 2 of a paper by Smith *et al.* (1976) for the same comparison.

Table 3.
REGRESSION OF SWEEPNET COUNTS AGAINST WHOLE PLANT VISUAL COUNTS (WPVS)

Predator	a	b	r ²	n	b forced (0,0)
<i>Orius</i>					
Adults	.105	.111	.706***	7	.139
Nymphs	.035	.031	.620*	7	.035
<i>Geocoris</i>					
Adults	.307	.029	.017	7	.265
Nymphs	.035	.251	.790***	7	.228
<i>Chrysopa</i>					
Adults	.050	1.135	.429	7	1.602
Larvae	.008	.019	.130	7	.033
<i>Nabis</i>					
Adults	.005	.154	.856***	7	.165
Nymphs	-.020	.208	.442	7	.161

* Significant at 5% level.
** Significant at 1% level.
***Significant at .5% level.

A summary of regression statistics for individual species is shown in Table 3. Again, both the sweepnet and WPVS estimates were corrected to a meter-row basis. Significant regressions were found for *Orius* adults and nymphs, *Geocoris* nymphs and *Nabis* adults. The sweepnet appeared to be more efficient in detecting only *Chrysopa* adults

(b forced >1). This apparent discrepancy is explained by the fact that *Chrysopa* adults often took flight before one could get close enough to count them. The other adult predators rarely left the plant when disturbed, but they did tend to hide and thus hinder the efficiency of the WPVS method. The efficiency of the sweepnet method compared to the WPVS method varied considerably; the lowest value being 3 percent for *Chrysopa* larvae and the highest being 26.5 percent for *Geocoris* adults. This variation can, for the most part, be explained by the within-plant distribution of the different predators and their associated catchability.

Effects of vertical distribution and plant phenology on sweepnet efficiency—The b forced (1,1) values, Table 1, gave the best indication of the vertical distribution of the cotton predators. Comparison of these values with the sampling efficiency values in Table 3 (b forced (0,0)) clearly shows that those predators whose within-plant distributions were nearest to the plant terminal were more efficiently sampled by terminal sampling methods such as the sweepnet. Sampling efficiency may be affected by species-specific traits. The obvious discrepancy of *Nabis* samples (higher sampling efficiency than expected) may be due to the fact that this species unlike the others readily dislodges when the plant is shaken (as when hit with a sweepnet).

It should also be noted that the efficiency of the sweepnet changed through time. Figure 4 presents the seasonal ratios of sweepnet/WPVS both converted to meter-row counts for *Orius*. A peak in sampling efficiency of the sweepnet occurred during the peak in square production (see figure 3b). Mean square successive difference tests (Zar, 1974) were made on the 1974 *Orius* and *Geocoris* sampling efficiency estimates obtained in this study, sweepnet/WPVS comparison, and sampling experiments conducted by Byerly *et al.* (1978), who compared sweepnet with whole plant bag samples (WPBS). In all cases, the assumption that sampling efficiency had a random variability was rejected (Table 4a).

Table 4a.

MEAN SQUARE SUCCESSIVE DIFFERENCE TEST TO DETERMINE IF SAMPLING EFFICIENCY HAS A RANDOM VARIABILITY.* (1974)

Location	<i>Orius</i>		<i>Geocoris</i>	
Shafter:	Adults	Nymphs	Adults	Nymphs
n	8	8	8	9
C	.731	.898	.518	.803
Prob.	.0025<P<.005	<.0005	.025<P<.05	.0005<P<.001
Cave				
n	8	8	8	8
C	.707	.927	.594	.622
Prob.	.005<P<.01	<.0005	.01<P<.025	.01<P<.025
Bartel				
n	9	9	9	9
C	.804	.631	.495	.586
Prob.	.0005<P<.001	.01<P<.025	.025<P<.05	.025<P<.05

*All comparisons differ significantly from the above hypothesis at the indicated probability levels. (H_0 : Sampling efficiency of the sweepnet has a random variability.)

Table 4b presents results obtained by comparing sampling efficiency of successive sampling points before and after peak squaring. These results agree rather well with Figures 4 (our data) and 5a-d (data from Byerly *et al.* 1978) implying that for *Orius*

adults and nymphs sampling efficiencies increased until peak squaring was reached, at which time they began to decrease, while sampling efficiencies for *Geocoris* adults and nymphs decreased through the season.

Table 4b.
INCREASING (+) OR DECREASING (–) SAMPLING EFFICIENCY THROUGH
SUCCESSIVE TIME STEPS BEFORE AND AFTER PEAK SQUARING

Squaring period and efficiency rank	<i>Orius</i>		<i>Geocoris</i>	
	Adults	Nymphs	Adults	Nymphs
Pre-peak +	10	9	7	8
	5	1	9	8
Post-peak +	9	6	6	8
	12	12	14	12

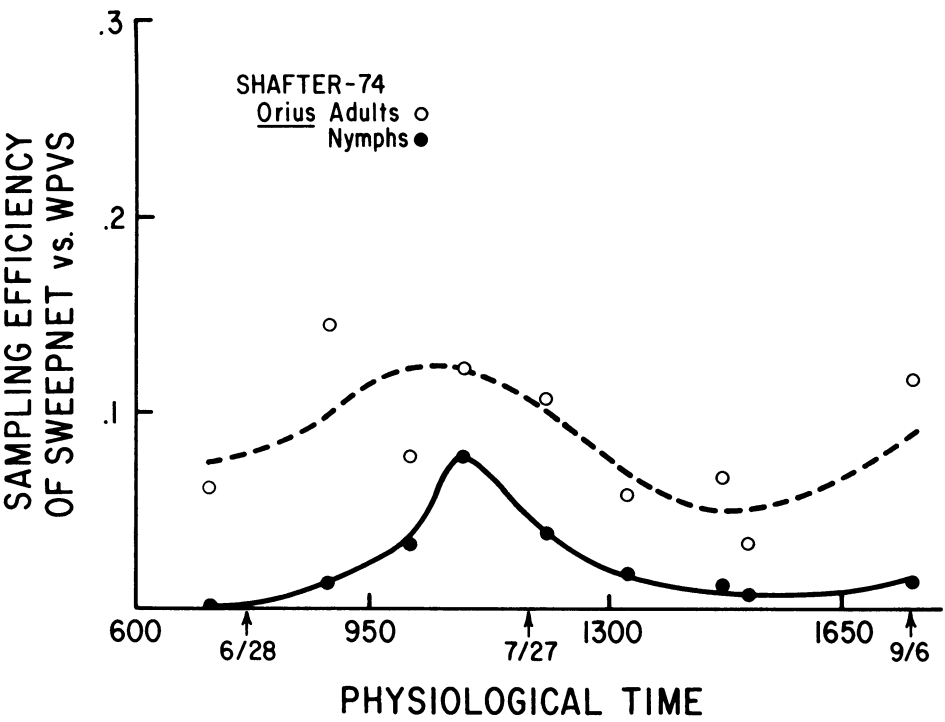
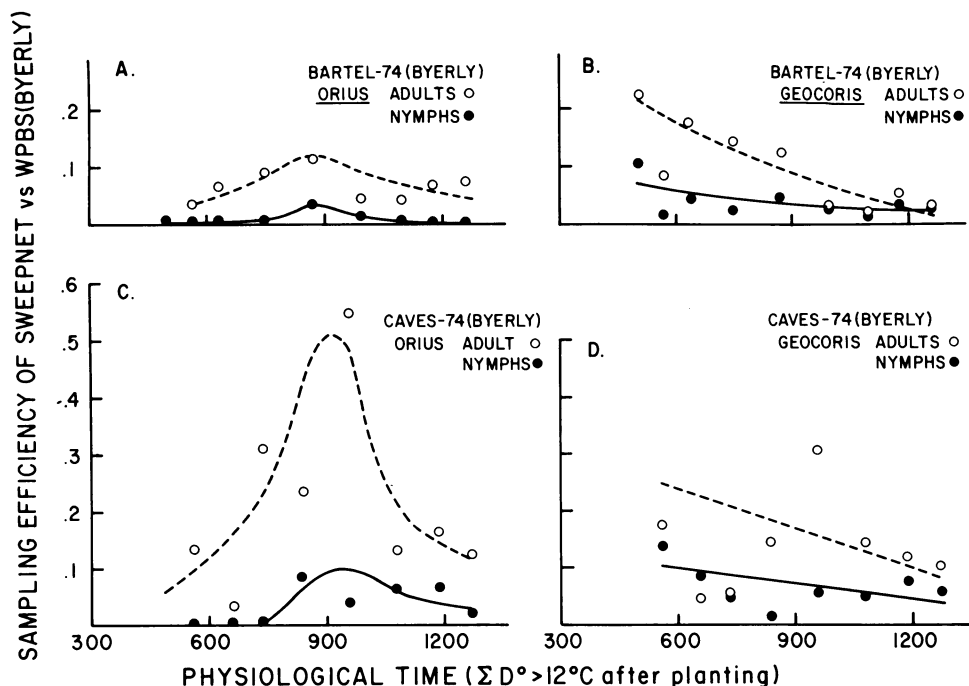


Fig. 4. The seasonal ratios of sweepnet/WPVS both converted to meter row counts for *Orius*. Shafter, California, 1974.

Predator efficiencies

The majority of predators in California cotton fields are general feeders and attack a wide range of arthropods. These predators have also been observed to feed on plant tissues (e.g., leaves and fruit), pollen and nectar. Nearly all are cannibalistic and feed on other predator species. The difference between the number of *Chrysopa* eggs (564) and the resulting larvae (94) recorded during this study may in part be explained in this manner. This type of predator mortality may explain the different within plant distributions of adults and their immatures as it serves to reduce the degree of cannibalism.



Figs. 5a-d. The seasonal ratios of sweepnet/WPBS both converted to meter-row counts for *Orius* adults and nymphs and *Geocoris* adults and nymphs. Cave and Bartel, 1974 (data from Byerly *et al.* In Press).

The observed overlap of distributions of suitably sized prey and a predator species increases the predators' success rate. For example, the smallest of the four predators in this study, *Orius* and *Geocoris*, were found close to the plant terminal while the larger more voracious *Chrysopa* and *Nabis* were found further from the terminal (Table 1). Similarly, younger (smaller) stages of their lepidopteran prey, such as *Heliothis zea* (Boddie) and *Spodoptera exigua* Hubner, are found near the terminal, while the older larvae travel downward and away from the terminal.

DISCUSSION

In all cases where adult-immature comparisons were made, the adults consistently occurred higher on the plant and in greater proportion on fruit than did the immatures. Because of this and probably because of their greater size, adults were also sampled more efficiently with the sweepnet than were the corresponding immature stages (Table 3). Byerly *et al.* (1978) reported similar results for adult-immature sampling efficiency.

The sweepnet was useful for estimating relative numbers. However, in a pest management situation, attention must be given to the fact that the sweepnet will sample only a relatively small percentage of the insects on the plant and also that this efficiency is influenced by the phenology of the plant (see also Byerly *et al.* (1978)).

The WPVS method is more useful than the sweepnet method for determining within plant distributions of the various predators and for obtaining behavioral information. Such data are essential for developing accurate and realistic population

models. The WPVS method can be used to estimate population trends, but, due to the increase in sampling time compared to sweepnet, and other commonly used sampling methods, it seems not worthwhile.

Since the majority of predators found within a cotton field will feed upon almost any species of prey within a specific size range, the degree of overlap between the distributions of a predator and a suitably sized prey becomes a major determinant of predation efficiency.

Searching and feeding rates, as well as relative population densities of predator and prey species, are also important, but were not examined here.

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