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An Ecological Study of Insect Populations on Cabbage in Southern California

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An ecological study of insect populations on cabbage plantings was conducted over a two-year period in a coastal environment of southern California. Eleven orders of insects were represented in the collections. The Hymenoptera ranked first in the number of species represented, and the Collembola ranked first in number of individuals. Approximately 375 species of insects were collected, including about 125 each in the Hymenoptera and Diptera, and 50 in the Coleoptera. The cabbage aphid and the western flower thrips were the most numerous phytophagous species. *Diaeretiella rapae* (M'Intosh), a primary parasite of the cabbage aphid, was the most abundant parasitic species; the coccinellid, *Hippodamia quinquesignata punctata* Lec., and the syrphid, *Allograpta obliqua* (Say), were the two most common predators. The imported cabbageworm, cabbage looper, and diamondback moth were the most numerous lepidopterous larvae. Each year, the imported cabbageworm larval population peaked in August, the cabbage looper in September, and the diamondback moth in February and October. Their combined population averaged 15 larvae per plant in August. Twelve species of parasites were reared from the cabbage looper, nine from the imported cabbageworm, and five from the diamondback moth. *Voria ruralis* (Fallen), *Pteromalus puparum* (L.), and *Diadegma insularis* (Cresson) were the most common parasites on these three pests, respectively. *Trichogramma pretiosum* Riley was the only parasite reared from the lepidopterous eggs. Cabbage plants were severely injured by the cabbage aphid during the winter and spring months and by the imported cabbageworm and cabbage looper during the summer and early fall. Injury by the diamondback moth was minor in comparison.

This study shows that although natural enemies of cruciferous crop pests should be conserved and augmented, current biological control methods alone are not adequate to control these insect pests under certain conditions without the supplemental use of pesticides.

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E. R. Oatman and G. R. Platner

An Ecological Study of Insect Populations on Cabbage in Southern California[1]

INTRODUCTION

CRUCIFEROUS CROPS, such as cabbage, cauliflower, and broccoli, are grown extensively in southern California. The cabbage looper, *Trichoplusia ni* Hübner; imported cabbageworm, *Pieris rapae* (L.); diamondback moth, *Plutella maculipennis* (Curtis), and cabbage aphid, *Brevicoryne brassicae* (L.), are nearly always present on these crops and frequently require pesticide applications.

Biological control of this pest complex would be difficult, because although three of these four species originated in Europe, the cabbage looper is a widespread, polyphagous, and often highly destructive native species. However, integrated control, including the use of microbial materials, is a distinct possibility—especially for lepidopterous larvae (Tanada, 1956; McEwen and Hervey, 1959; Hall and Andres, 1959; Hofmaster and Ditman, 1961; Elmore, 1961). Integrated control also would be facilitated by the biological control of even one of the imported pests. Several studies have been conducted on the ecology and natural control of several of these individual species.

In order to assess the relative abundance and role of the phytophagous insects and their natural enemies on cruciferous crops in southern California, ecological studies were conducted on pesticide-free cabbage, *Brassica oleracea* L., from February, 1963, through April, 1965, in coastal areas of San Diego and Orange counties where cruciferous crops are grown throughout the year. A limited preliminary study emphasized the cabbage looper and the imported cabbageworm (Oatman, 1966); it preceded the more comprehensive study in Orange County reported here, which involves the total insect biota in an ecological community.

METHODS AND MATERIALS

In February 1963, eight rows about 300 feet long of Round Dutch cabbage seed were planted on the University of California's South Coast Field Station near El Toro in Orange County. About two months later, eight more rows were planted adjacent to the first planting; and a third planting was similarly established two months after the second planting (fig. 1). By this time, the first planting was mature and was disced under soon after the plants from the third planting were up and thinned. By using this method, a continuous cruciferous plant environment or ecosystem (about ¼ acre at any one time) was maintained with its accompanying biotic community. Methods of planting,

[1] Submitted for publication January 6, 1969.

Fig. 1. Site of ecological study of insect populations on cabbage in southern California, showing 3 successive cabbage plantings at 2-month intervals (right to left).

cultivation, irrigation, and other cultural practices followed those of local commercial cabbage growers, except that pesticides were never applied.

From April, 1963, through March, 1965, 25 plants were examined at weekly intervals by removing plants at random from each of the six inside rows in a diagonal, criss-cross pattern, extending the length of the field. Each plant sampled was carefully examined in the field for all stages of each insect species present by removing and inspecting each leaf, from the time the plants showed primary leaves, until maturity. By this time, young plants in the next planting were being sampled. In this way, 12 successive plantings were surveyed during the two-year period.

Small pieces of leaves to which lepidopterous eggs, early-instar larvae, and pupae, and syrphid fly larvae and pupae were attached were placed in pint-size ice cream cartons. Eggs were placed in a separate carton. Leaf-mining larvae were similarly collected by removing the mined portions of the leaves. Late-instar lepidopterous larvae were teased from the leaves directly into the carton. All collected material was carried to the laboratory in a cold chest and refrigerated at 40° F until the species could be separated (usually within 24 hours) and held for emergence.

Eggs, with a small piece of leaf attached, were transferred individually into ¼-dram glass shell vials, plugged with absorbent cotton, and held for emergence of larvae or parasites. The larvae and pupae were held in one-pint ice cream cartons covered with the top half of a glass petri dish. The larvae were fed cabbage leaves until the appearance of disease or parasites, or until pupation. The pupae were held for emergence of adults or parasites. The pieces of cabbage leaves containing leaf miners were placed in one-gallon ice cream cartons together with pieces of paper toweling to absorb the excess moisture, and held for emergence of parasites or the adult leaf miner. After all emergence had occurred, the numbers of hatched and unhatched eggs, diseased larvae or pupae, parasites, and adults were recorded. Unknown species were forwarded to taxonomic specialists for species identification.

Fifty suction samples were taken of insects which could not be collected using the above method. Each sample covered an equivalent surface area of 1 square foot. Suction samples were taken weekly from each planting from just past the seedling stage until maturity of the heads—at which time the next planting was being similarly sampled. They were taken between 10 a.m. and noon; no samples were taken at night. The plantings were sampled in this manner throughout the two-year period, using a back-pack suction-sampling machine (Dietrick, 1961). The samples were carried to the laboratory in a cold chest where the arthropods were separated from the trash with the use of modified Berlese funnels (Dietrick *et al.*, 1959).

The insect specimens thus obtained were identified to the lowest taxonomic category possible with the use of a dissecting microscope, and their numbers were recorded. The common predaceous and phytophagous species were identified by sight or by comparison with museum reference material. Others were forwarded to taxonomic specialists for determination.[2]

The presence of naturally occurring pathogens in the aphid and lepidopterous larval populations was verified.[3] However, because of the scope of the problem, a detailed positive identification of every disease-induced mortality with a thorough record of its occurrence, was impractical, and thus was not included in the natural mortality data.

Weather data were recorded daily.

RESULTS AND DISCUSSION

Taxonomic groups and their ecological relationships

Eleven orders of insects were represented in the collection made during the course of the study: Coleoptera, Collembola, Diptera, Hemiptera, Homoptera, Hymenoptera, Lepidoptera, Neuroptera, Orthoptera, Psocoptera, and Thysanoptera. In number of species, Hymenoptera ranked first, followed by Diptera and Coleoptera. The greatest number of individuals were in the order Collembola, followed by Thysanoptera, Homoptera, and Hymenoptera. The Orthoptera was least common, consisting of only 10 grasshopper nymphs collected during the two-year period.

About 125 apparent species each of Hymenoptera and Diptera and about

[2] Hymenopterous parasites were identified by Dr. S. E. Flanders, Department of Biological Control, University of California, Riverside; Dr. P. M. Marsh, Dr. B. D. Burks, Dr. C. F. W. Muesebeck, and Miss L. M. Walkley, Insect Identification and Parasite Introduction Research Branch, U. S. Department of Agriculture; and Dr. Henry Townes, American Entomological Institute, Ann Arbor, Michigan. Dipterous parasites were identified by Dr. H. J. Reinhard, Department of Entomology, Texas A. & M. University, College Station; Dr. P. H. Arnaud, Jr., Department of Entomology, California Academy of Sciences, San Francisco; and Dr. C. W. Sabrosky, Insect Identification and Parasite Introduction Research Branch, U. S. Department of Agriculture. The coccinellids were identified by Dr. K. S. Hagen, Division of Biological Control, University of California, Berkeley; syrphids by Dr. Y. Sedman, Department of Biological Sciences, Western Illinois University, Macomb; miscellaneous lepidopterous pests by Dr. G. T. Okumura, Bureau of Entomology, California State Department of Agriculture, Sacramento; aphids by Dr. R. C. Dickson and thrips by Dr. W. H. Ewart, Department of Entomology, University of California, Riverside; and the agromyzids by Dr. G. Steyskal, Insect Identification and Parasite Introduction Research Branch, U. S. Department of Agriculture.

[3] Dr. I. M. Hall, Insect Pathologist, Department of Biological Control, University of California, Riverside.

50 species of Coleoptera were collected in the suction samples. The largest number of species was present in October and the largest number of individuals was present in February. On February 4, 1964, a total of 17,740 individuals or 355 per suction sample, consisting of 8,368 Collembola; 6,296 aphids; 1,429 thrips; 1,364 Hymenoptera; 226 Diptera; 22 Coleoptera; 18 leafhoppers, 13 Hemiptera; and 4 psocids were collected.

In a New York study, Pimentel (1961*a*) recorded 177 species of insects in 11 orders associated with cabbage. His orders were the same as the ones given above, but were ranked differently in number of species represented, with the Diptera providing the greatest number, followed by Hymenoptera, and Coleoptera. The greatest difference, however, was in the total number of insect species collected. This was probably due primarily to the continuous growing season in southern California with 52 possible weekly collections per year, compared to a four-months' season and 12 collections in New York. In the present study, it was conservatively estimated that about 375 species of insects were collected which was more than twice the number collected by Pimentel. The use of the suction sampling machine to supplement direct counts in the field also might have contributed to this difference. Some of the species collected by this method were probably transients, since the Field Station where the study was conducted adjoins an area of intensive cropping and permanent rangeland.

The Collembola, of which there were five or six apparent species, were the most abundant nonphytophagous insects present. Populations built up to very high numbers with the maturing of each planting, especially during the winter months. Of the phytophagous insects, the thrips were the most numerous in total individuals and, although some eight to ten apparent species were collected, the population was comprised almost entirely of the western flower thrips, *Frankliniella occidentalis* (Pergande). In each planting, their numbers increased as the cabbage matured, reaching a peak at full maturity of the crop. Their feeding damage, however, was negligible, being confined primarily to the oldest, outer leaves.

The Psocoptera and Neuroptera were less common, with only three to four apparent species each and generally low numbers of individuals. Except for about five species of Hemiptera and 10 of Coleoptera, most of the species apparent in these two orders were nonphytophagous. Practically all of the Hymenoptera collected were parasitic species except for a few bees, wasps, and ants, which were occasionally present in low numbers. The dipterous species were nonphytophagous with the principal exception of the serpentine leafminer, *Liriomyza brassicae* (Riley).

All of the species in the Homoptera and Lepidoptera were phytophagous, with several species in each order playing dominant roles in the ecological community of the cabbage plantings at intervals during each year of the study. In addition to the five to 10 species of aphids present, two of which were common, 15 to 20 apparent species of leafhoppers and two psyllids were collected all of which were of minor importance and usually in low numbers. Many of the aphids and leafhoppers were probably transients from surrounding areas, following harvest of a crop or the drying up of native vegetation.

Aphids and their natural enemies

Counts of known species of aphids and aphid parasites collected by suction during the last year of the study (May 5, 1964, through April 27, 1965) revealed that the cabbage aphid, *Brevicoryne brassicae* (L.), was by far the most common species present, followed by the green peach aphid, *Myzus persicae* (Sulzer); and that *Diaeretiella rapae* (M'Intosh) was the dominant aphid parasite (table 1 and figs. 2 and 3). *Diaeretiella rapae* is considered the principal parasite of the cabbage aphid throughout Europe, the U.S.S.R., Canada, the United States, Australia, and New Zealand (Bonnemaison, 1965). Other aphids present but usually in low numbers were *Macrosiphum* sp., the turnip aphid, *Hyadaphis pseudobrassicae* (Davis), and the corn leaf aphid, *Rhopalosiphum maidis* (Fitch). Other aphid parasites collected included *Lysiphlebus testaceipes* (Cress.) and *Aphidius matricariae* Hal., both of which parasitize the green peach aphid. *Diaeretiella rapae,* although primarily a parasite of the cabbage aphid, also parasitized the green peach aphid.

The total number of aphids collected from cabbage during the last year of the study averaged 14.4 per square foot with the cabbage aphid averaging 12.7 and the green peach aphid 1.5 per square foot. *Diaeretiella rapae* averaged 4.5 or about one-third as many as the cabbage aphid. The cabbage aphid population was generally low during July and August and high during the winter and spring months, reaching its peak early in June. The *D. rapae* population reached its peak one week after that of the cabbage aphid, indicating a close host-parasite relation (table 1). At its peak, the cabbage aphid population averaged 113 per square foot, and *D. rapae,* 49 per square foot. After reaching a peak in June, the cabbage aphid population declined to its lowest point in late July, increased to a minor peak in late September, and then declined again to a low point in October and November before starting to steadily increase during the winter and spring months. In general, the *D. rapae* population closely followed that of its host with the parasite to host ratio being 1:2.8 (table 1). The green peach aphid population was generally low during the summer and fall months and high in winter and spring, reaching its peak population in early March at an average of 11 per square foot. The *Macrosiphum* sp. population was generally low throughout the year, averaging only 0.1 per square foot and reaching its peak population in late March. Cabbage probably is not a preferred host plant for this species, but it serves rather as an alternate host primarily during the winter months. *Lysiphlebus* and *Aphidius* species were most abundant during March and April, reflecting their parasite-host relationship with the green peach aphid. The former parasite was nearly three times more abundant than the latter (table 1).

Except for the aphidivorous coccinellids and syrphids, the predaceous insects collected were general predators of smaller lepidopterous larvae, aphids, and other small, soft-bodied insects (table 2). Insect predators (excluding syrphid flies) were generally low throughout the study, averaging only 0.2 individual per square foot during the two-year period. The coccinellids accounted for 43.8 per cent and *Orius* sp. 28.7 per cent of the total number collected. Chrysopids were least represented (table 2).

Three species of coccinellids were collected during 1964—*Hippodamia quinquesignata punctata* Lec., *H. convergens* Guerin-Méneville, and *Coccinella californica* Mann., with the first species accounting for 90 per cent of the population and the other two, 5 per cent each. Although Pimentel (1961*a*) recorded eight species of coccinellids from cabbage in his New York study, he considered only three species to be important predators of aphids on cabbage—one of which was *H. convergens* (Pimentel 1961*b*). The coccinellid larval population was highest in May, suggesting a correlation with the cabbage and green peach aphid populations.

Table 1

NUMBER OF APHIDS AND APHID PARASITES PER 50 SUCTION SAMPLES COLLECTED AT WEEKLY INTERVALS FROM SUCCESSIVE CABBAGE PLANTINGS IN SOUTHERN CALIFORNIA DURING SECOND YEAR OF STUDY

Planting number*	Survey date	Aphids					Aphid parasites			
		Brevicoryne brassicae	*Myzus persicae*	*Macrosiphum* sp.	Other†	Total	*Diaeretiella rapae*	*Lysiphlebus* sp.	*Aphidius* sp.	Total
	1964									
7	May 5	23	8	0	0	31	1	0	0	1
"	12	33	41	1	0	75	18	0	0	18
"	19	261	62	1	0	324	75	0	0	75
"	26	649	57	1	0	707	310	0	0	310
"	June 2	3304	316	13	1	3634	705	9	1	715
"	9	5673	13	0	0	5686	1663	0	0	1663
"	16	174	4	0	0	178	2473	0	0	2473
8		33	19	1	0	53	420	0	0	420
"	23	16	2	3	0	21	98	0	0	98
"	30	23	7	2	0	32	53	0	0	53
"	July 6	43	11	38	0	92	92	0	0	92
"	14	84	5	7	0	96	84	1	0	85
"	22	40	3	2	0	45	72	0	0	72
"	28	9	0	0	0	9	41	0	0	41
"	Aug. 4	23	2	0	0	25	55	0	0	55
"	11	47	0	1	0	48	38	0	0	38
"	18	39	0	0	0	39	134	0	0	134
9		13	2	0	0	15	35	0	0	35
"	25	56	10	3	0	69	58	0	0	58
"	Sept. 1	12	3	0	0	15	64	0	0	64
"	8	49	34	26	0	109	60	0	0	60
"	15	242	5	2	0	249	57	0	0	57

	13	864	0	3	0	867	92	0	0	92
10		29	2	0	1	32	54	0	0	54
"	20	13	9	5	0	27	22	0	5	27
"	27	18	5	0	0	23	51	0	0	51
"	Nov. 2	18	3	0	0	21	25	0	0	25
"	10	28	2	0	0	30	18	0	0	18
"	18	62	2	0	3	67	17	0	0	17
"	24	54	15	2	3	74	27	0	0	27
"	Dec. 1	314	46	0	0	360	46	1	0	47
"	8	728	90	0	6	824	98	1	1	100
11	15	636	66	0	3	705	54	0	1	55
"	23	294	20	1	0	315	20	0	0	20
"	29	1150	13	1	1	1165	63	0	0	63
	1965									
"	Jan. 5	1383	37	0	0	1420	182	0	1	183
"	12	0	0	0	0	0	0	0	0	...‡
"	19	321	38	2	2	363	66	0	0	66
"	26	596	46	1	3	646	160	0	0	160
"	Feb. 2	878	73	1	2	954	358	0	0	358
"	9	1551	68	19	0	1638	564	0	0	564
"	17	1843	439	19	27	2328	289	0	0	289
"	24	1800	410	68	3	2281	240	2	0	242
"	Mar. 3	2246	429	12	7	2694	510	2	0	512
"	9	2400	551	12	7	2970	564	25	11	600
"	16	1037	130	1	13	1181	317	0	0	317
"	23	1073	271	5	53	1402	154	5	0	159
"	30	432	138	3	19	592	282	5	5	292
"	Apr. 6	1340	185	3	21	1549	461	12	0	473
12		62	22	1	1	86	45	6	0	51
11	13	551	128	2	7	688	379	2	3	384
12	20	43	66	2	2	113	108	2	1	111
"	27	153	94	25	6	278	259	16	4	279
Totals		34,986	4,023	300	191	39,500	12,472	89	33	12,594

* Eight rows per planting. First planting on Feb. 4, 1963, with successive plantings approximately every 2 months thereafter.
† Primarily the turnip aphid and corn leaf aphid.
‡ Data inadvertently lost.

Fig. 2. Cabbage aphid colony on cabbage leaf. Arrows indicate several parasitized aphid mummies.

Syrphid flies were the most common aphid predators during the study (fig. 4). Six species were reared from the larvae and pupae collected directly from the cabbage plants. They were: *Allograpta obliqua* (Say), *A. exotica* (Wied.), *Metasyrphus venablesi* (Curran), *Scaeva pyrastri* (L.), *Eupeodes volucris* O.S., and *Sphaerophoria sulphuripes* (Thomson). *Allograpta obliqua* was by far the most abundant species. Pimentel (1961*a*) recorded seven syrphid flies from cabbage in his New York study, including *A. obliqua;* but found that *Sphaerophoria cylindrica* Say was the most abundant species. The syrphid fly larval and pupal population reached its highest peak June 16, 1964, averaging nine per plant (fig. 5). The population generally remained high during the June-to-October period for each year of the study with a second peak in October, averag-

Fig. 3. *Diaeretiella rapae* adult, a primary parasite of the cabbage aphid.

TABLE 2

NUMBER OF INSECT PREDATORS PER 50 SUCTION SAMPLES COLLECTED AT WEEKLY INTERVALS FROM SUCCESSIVE CABBAGE PLANTINGS IN SOUTHERN CALIFORNIA

(May 6, 1963 to April 6, 1965)

Planting number*	Survey date	Coccinellids		Geocoris		Orius		Nabids		Chrysopids		Total
		Adults	Larvae	Adults	Nymphs	Adults	Nymphs	Adults	Nymphs	Adults	Larvae	
	1963											
1	May 6	0	0	1	0	0	0	0	0	0	0	1
"	14	1	17	1	0	2	0	0	0	0	0	21
"	21	2	24	5	0	7	0	0	0	0	0	38
"	28	7	18	0	0	2	0	0	0	0	0	27
"	June 4	12	10	1	0	4	0	0	0	0	0	27
"	11	16	2	0	0	0	0	0	0	0	0	18
2	18	6	1	1	0	11	0	0	0	0	2	21
"	25	11	0	11	0	13	0	0	0	1	2	38
"	July 2	0	0	0	0	0	0	0	0	0	0	..†
"	9	6	0	0	2	0	0	0	0	0	1	9
"	16	3	0	1	0	0	0	0	0	0	0	4
3	23	0	0	0	0	0	0	0	0	0	0	0
"	30	0	0	1	2	0	0	0	0	0	0	3
"	Aug. 6	2	0	0	2	3	0	0	0	0	2	9
"	13	3	0	0	0	1	0	0	0	0	3	7
"	20	3	2	2	2	3	0	0	2	0	0	14
"	27	10	4	3	2	2	0	0	1	0	3	25
"	Sept. 3	4	7	3	8	0	3	0	9	0	0	34
4	10	0	0	2	1	3	0	0	0	0	0	6
"	19	8	0	0	2	4	0	0	1	0	0	15
"	24	14	2	0	2	1	1	1	2	0	0	23
"	Oct. 1	7	0	0	4	0	0	0	2	0	0	13
"	8	4	2	2	8	2	2	0	3	0	1	24
"	15	10	1	1	0	1	0	0	0	0	0	13
"	22	26	0	0	3	1	2	1	8	0	0	41
"	29	11	4	0	0	0	0	0	2	0	0	17
"	Nov. 5	9	4	1	0	2	2	0	3	1	0	22
5	12	1	0	0	0	0	0	0	0	0	0	1
"	19	1	5	0	0	0	0	0	0	0	0	6
"	26	0	0	0	0	0	0	0	0	0	0	0

Continued on next page

TABLE 2—*Continued*

Planting number*	Survey date	Coccinellids		Geocoris		Orius		Nabids		Chrysopids		Total
		Adults	Larvae	Adults	Nymphs	Adults	Nymphs	Adults	Nymphs	Adults	Larvae	
"	Dec. 3	3	1	0	0	2	0	0	0	0	0	6
"	10	0	1	0	0	0	0	0	0	0	0	1
"	17	1	0	0	0	0	0	0	0	0	0	1
"	23	2	1	1	0	0	0	0	0	0	0	4
	1964											
"	Jan. 8	..‡	0	0	0	0	0	0	0	0	0	0
"	13	0	0	0	0	0	0	0	0	0	0	0
"	22	0	1	0	0	1	0	0	0	0	0	2
"	28	0	2	0	0	0	0	0	0	0	0	2
"	Feb. 4	0	3	0	0	5	0	0	0	0	0	8
"	11	0	1	0	0	13	0	0	0	0	0	14
"	18	0	0	0	0	5	0	0	0	0	0	5
6	25	0	0	0	0	1	0	0	0	0	0	1
"	Mar. 3	0	2	0	0	0	0	0	0	0	0	2
"	10	0	8	0	0	4	0	0	0	0	0	12
"	17	0	0	0	0	1	0	0	0	0	0	1
"	24	0	2	0	0	4	0	0	0	0	0	6
"	31	0	3	0	0	9	0	0	0	0	0	12
"	Apr. 6	0	0	0	0	7	0	0	0	0	0	7
"	14	0	0	0	0	0	0	0	0	0	0	0
"	21	0	0	0	0	1	1	0	0	0	0	2
"	29	0	0	0	0	0	0	0	0	0	0	0
7	May 5	0	0	0	0	2	0	0	0	0	0	2
"	12	0	0	1	0	12	0	1	0	0	0	14
"	19	0	0	0	0	4	0	0	0	0	0	4
"	26	0	0	2	0	2	3	0	0	0	0	7
"	June 2	0	3	0	0	1	1	0	0	0	0	5
"	9	0	3	0	0	0	0	0	0	0	0	3
"	16	0	5	1	0	2	0	0	0	0	0	8
8	23	0	0	0	0	1	0	0	0	0	0	1
"	30	0	0	11	1	3	0	0	0	0	0	15
"	July 6	0	1	5	1	4	0	0	0	0	1	12
"	14	0	0	0	0	3	0	0	0	4	0	7
"	22	0	0	2	1	4	1	0	0	0	0	8
"	28	1	0	1	0	9	0	0	0	3	0	14
"	Aug. 4	0	0	2	2	3	1	1	2	0	0	11
"	11	0	0	1	0	1	0	0	0	0	0	2

"	15	0	0	0	0	0	0	1	0	0	0	1
"	22	0	0	0	0	2	1	1	2	0	0	6
"	29	0	0	0	0	0	0	0	6	0	0	6
"	Oct. 6	1	0	0	0	3	0	1	18	0	0	23
"	13	2	0	0	0	0	0	1	30	0	0	33
10	20	0	0	0	0	40	0	0	0	0	0	40
"	27	0	0	0	0	14	0	1	3	0	0	18
"	Nov. 2	0	0	0	0	2	0	0	0	0	0	2
"	10	0	0	0	0	1	1	0	0	0	0	2
"	18	0	0	0	0	0	1	0	0	0	0	1
"	24	0	0	0	1	1	2	0	0	0	0	4
"	Dec. 1	0	0	2	0	1	0	0	0	1	0	4
"	8	0	0	0	0	0	1	0	0	1	0	2
"	15	0	0	0	0	1	0	0	0	0	0	1
"	23	0	0	0	0	0	0	0	0	1	0	1
"	29	0	0	0	0	0	0	0	0	0	0	0
	1965											
"	Jan. 5	0	0	0	0	1	0	0	0	0	0	1
"	12	0	0	0	0	0	0	0	0	0	0	..†
11	19	0	0	0	0	0	0	0	0	0	0	0
"	26	0	0	0	0	0	0	0	0	0	0	0
"	Feb. 2	0	0	0	0	0	0	0	0	0	0	0
"	9	0	0	0	0	0	0	0	0	0	0	0
"	17	0	0	0	0	0	0	0	0	0	0	0
"	24	0	0	0	0	0	0	0	0	0	0	0
"	Mar. 2	1	0	0	0	1	1	0	0	0	0	3
"	9	0	0	0	0	0	0	0	0	1	0	1
"	16	0	1	0	0	0	0	0	0	0	0	1
"	23	0	0	1	0	0	0	0	0	2	0	3
"	30	0	1	0	0	0	0	0	0	0	1	2
"	Apr. 6	0	0	0	0	1	0	0	0	0	0	1
"	13	0	0	0	0	1	0	0	0	0	0	1
12	20	0	1	2	0	12	0	0	0	0	0	15
"	27	0	0	0	0	1	0	0	1	0	0	2
Sub-totals		189‡	143	72	48	248	26	10	99	15	16	866§
Totals		332		120		274		109		31		

* Eight rows per planting. First planting on Feb. 4, 1963, with successive plantings approximately every 2 months thereafter.
† Data inadvertently lost.
‡ Eighty-six adult coccinellids removed from 1964 collection for species identification.
§ Does not include 86 adult coccinellids from 1964 collection nor 2 assassin bug nymphs and 1 spiny soldier bug nymph which would increase total to 955, including 418 coccinellids.

Fig. 4. Syrphid fly larvae feeding on cabbage aphids on a cabbage leaf.

ing about four per plant. The syrphid fly population peaks in June and October, 1964, coincided with the cabbage aphid population peaks (fig. 5 and table 1), indicating a close predator-prey relation. However, during February, March, and April, when the aphid population was high, the syrphid fly population was low. This was especially evident in 1965 (fig. 5 and table 1). There were noticeable breaks in the continuity of the syrphid fly population trend between successive plantings which were not particularly evident with the aphid population (table 1 and fig. 5). Although aphid alates quickly infested the young plants in the new plantings, the syrphid fly adults apparently preferred to oviposit on the old plants with their established aphid colonies, thus creating a time lag in their relation with the aphid population. The effectiveness of the syrphid fly predators was probably reduced by parasites which parasitized 15.9 per cent of the overall population. Parasitization was highest during the January-to-March period and lowest during the April-to-June period, averaging 24.1 per cent and 12.2 per cent, respectively. During the June-to-August period, parasitization averaged 17.4 per cent and 21.1 per cent during the October-to-December period. The two principal parasites were *Diplazon latatorius* (F.) and *Pachyneuron syrphi* (Ashmead) with the former species being far the most common.

As in other areas of the world, *Diaeretiella rapae* is the principal parasite on the cabbage aphid in southern California and syrphid fly larvae and coccinellids are the most common predators (Bonnemaison, 1965; George, 1957; Hafez, 1961; Herrick and Hungate, 1911; Hughes, 1963; Pimentel, 1961*b*;

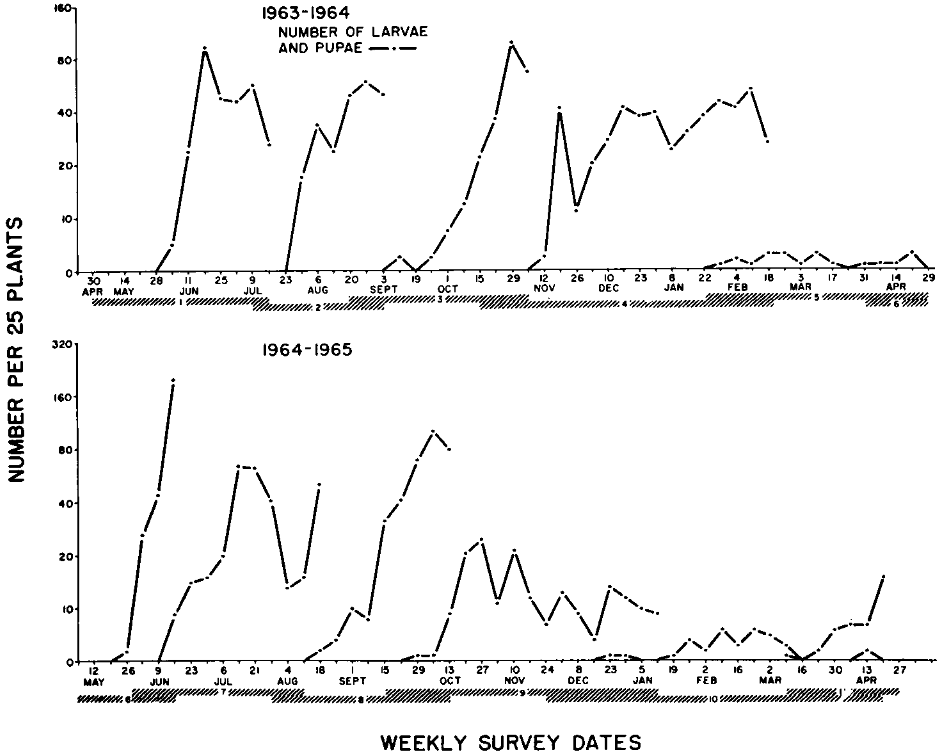

Fig. 5. Population trends of syrphid fly larvae and pupae on cabbage in 1963 to 1965 study. Successive cabbage plantings shown by numbered horizontal bars.

and Prethebridge and Mellor, 1936). In New York, Herrick and Hungate (1911) considered *D. rapae* the most effective natural enemy of the cabbage aphid, followed by the coccinellid, *Hippodamia convergens,* and then syrphid fly larvae. Pimentel (1961*b*), however, could not determine which natural enemy was the most important. In England, Prethebridge and Mellor (1936) considered syrphid fly larvae more effective than parasites in reducing cabbage aphid numbers, and that both were ineffective when the weather was favorable for aphid reproduction. Hafez (1961) concluded that parasitism, although a primary mortality factor, was not the main factor affecting the cabbage aphid in the Netherlands, primarily because of hyperparasitism.

In the present study, no attempt was made to determine which natural enemy was the most effective in reducing the cabbage aphid population. However, *D. rapae* was the most common and abundant species present, especially when its host population was high, and syrphid fly larvae were the most common and abundant predators (figs. 3 and 4). Weather apparently is a major factor influencing the cabbage aphid in southern California since the population was generally highest during the usually cool, wet months (November through April) and lowest during the warm, dry months of May through October (table 1 and fig. 6). Subsequent observations on continued successive cabbage plantings through 1968 have substantiated this. Cabbage plantings in southern California are severely damaged by high populations of the

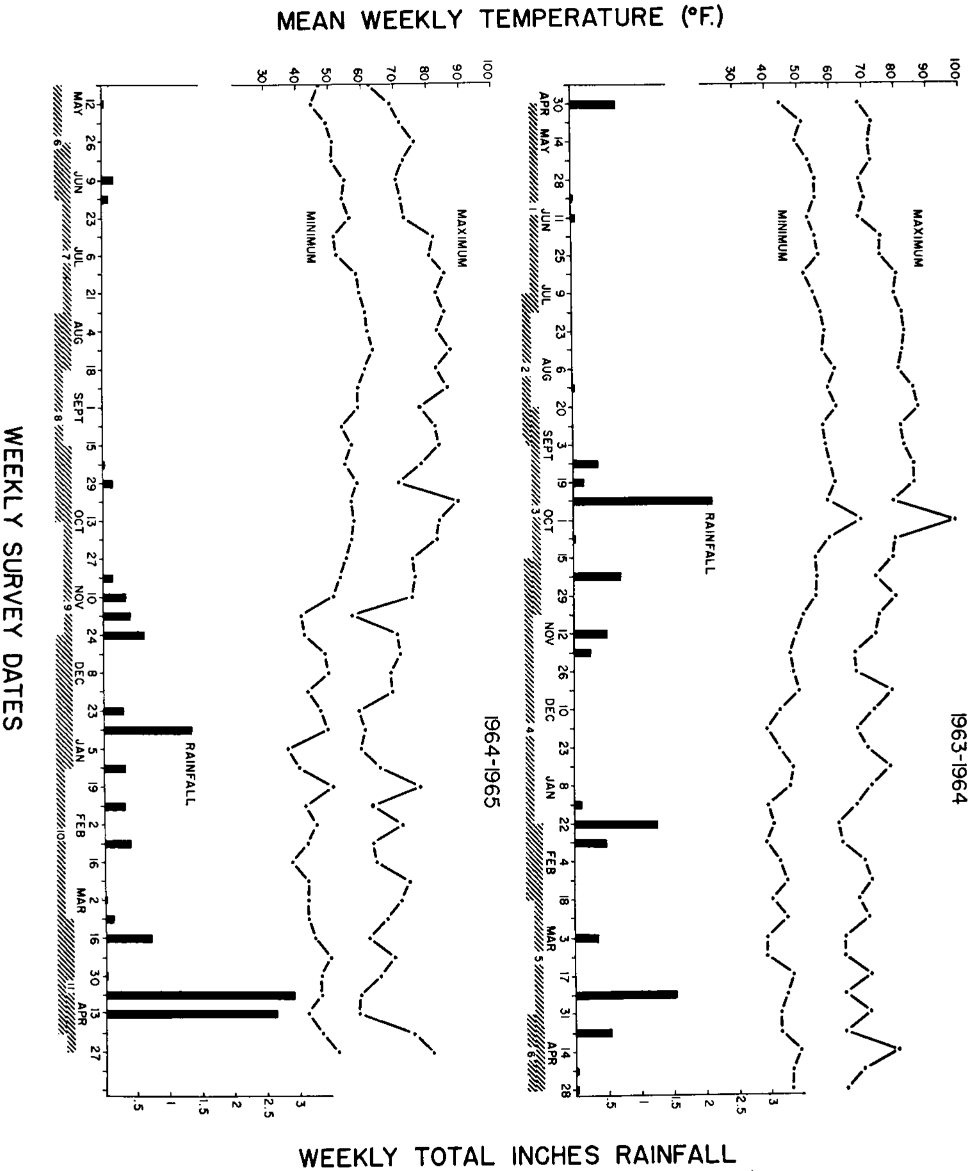

Fig. 6. Mean weekly maximum and minimum temperatures and total weekly inches of rainfall during the 1963–1965 study. Successive cabbage plantings shown by numbered horizontal bars.

cabbage aphid during the winter and spring months in spite of the presence of a full complement of natural enemies (fig. 7).

The role of the cabbage aphid and its natural enemies in the ecological community of cabbage plantings is emphasized by the dominance of *Diaeretiella rapae* in the total number of hymenopterous parasites collected in the suction samples (table 3). During the last year of the study, aphid parasites accounted for 52.2 per cent of the total with 99.0 per cent of them being *D.*

Fig. 7. Cabbage plant infested with cabbage aphids, showing typical aphid injury to half-grown plant during winter growing season.

rapae. The number of hymenopterous parasites collected averaged 8.8 per square foot; aphid parasites were 4.6 per square foot. In general, aphid parasites were more abundant than all other hymenopterous parasites together from December through mid-June (table 3).

The green peach aphid was commonly infected with *Entomophthora aphidis* Hoffman in the spring during the course of the study, but the fungus was not found infecting the cabbage aphid until the spring of 1968. In any case, the incidence of infection was low. In Australia, Hughes (1963) found that *E. aphidis* was a major mortality factor affecting the cabbage aphid in the fall when temperatures were low and rainfall was high.

Lepidopterous larvae and associated parasites and diseases

In addition to the cabbage aphid, lepidopterous larvae were the principal phytophagous insects associated with the cabbage community. Twelve species were collected directly from the plants as larvae: the imported cabbageworm, *Pieris rapae* (L.); cabbage looper, *Trichoplusia ni* (Hübner); diamondback moth, *Plutella maculipennis* (Curtis); beet armyworm, *Spodoptera exigua* (Hübner); cabbage webworm, *Hellula rogatalis* (Hulst); saltmarsh caterpillar, *Estigmene acrea* (Drury); southern cabbageworm, *Pieris protodice* Boisduval and LeConte; bollworm, corn earworm, tomato fruitworm, *Heliothis zea*

TABLE 3

NUMBER OF HYMENOPTEROUS PARASITES COLLECTED PER 50 SUCTION SAMPLES AT WEEKLY INTERVALS FROM SUCCESSIVE CABBAGE PLANTINGS IN SOUTHERN CALIFORNIA DURING LAST YEAR OF STUDY

Planting number*	Survey date	Parasites		
		Aphid†	Other	Total
	1964			
7	May 5...	1	0	1
"	12...	18	172	190
"	19...	75	91	166
"	26...	310	127	437
"	June 2...	715	79	794
"	9...	1663	42	1705
"	16...	2473	85	2558
8		420	52	472
"	23...	98	140	238
"	30...	53	255	308
"	July 6...	92	185	277
"	14...	85	213	298
"	22...	72	266	338
"	28...	41	230	271
"	Aug. 4...	55	217	272
"	11...	38	305	343
"	18...	134	268	402
9		35	208	243
"	25...	58	208	266
"	Sept. 1...	64	459	523
"	8...	60	392	452
"	15...	57	643	700
"	22...	84	1105	1189
"	29...	121	950	1071
"	Oct. 6...	136	882	1018
"	13...	92	760	852
10		54	175	229
"	20...	27	330	357
"	27...	51	364	415
(Continued in next columns)				
(Continued from left columns)				
10	Nov. 2...	25	136	161
"	10...	18	119	137
"	18...	17	56	73
"	24...	27	171	198
"	Dec. 1...	47	91	138
"	18...	100	77	177
11	15...	55	74	129
"	23...	20	11	31
"	29...	63	18	81
	1965			
"	Jan. 5...	183	53	236
"	12...	0	0	..‡
"	19...	66	13	79
"	26...	160	20	180
"	Feb. 2...	358	29	387
"	9...	564	63	627
"	17...	289	66	355
"	24...	242	48	290
"	Mar. 2...	512	75	587
"	9...	600	197	797
"	16...	317	151	468
"	23...	159	133	292
"	30...	292	84	376
"	Apr. 6...	473	157	630
12		51	31	82
11	13...	384	216	600
12	20...	111	106	217
"	27...	279	111	390
Totals...		12,594	11,509	24,103

* Eight rows per planting. First planting on Feb. 4, 1963, with successive plantings approximately every 2 months thereafter.

† Consisting of *Diaeretiella rapae*, *Lysiphlebus* sp., and *Aphidius* sp.

‡ Data inadvertently lost.

(Boddie); celery leaf tier, *Oeobia* (= *Udea*) *rubigalis* (Guenée); variegated cutworm, *Peridromus saucia* Hübner; granulate cutworm, *Feltia subterranea* Fabr.; and *Loxostege* sp. The first three species were by far the most abundant (and the most active throughout the year). A total of 5,341 larvae and pupae of the imported cabbageworm, 4,096 cabbage looper, and 2,989 diamondback moth were collected during the two-year study.

Reid and Cuthbert (1957) listed 13 lepidopterous species as pests of cabbage and other cole crops in the southeastern part of the United States; the cabbage looper was by far the most destructive pest, followed by imported cabbageworm, and the diamondback moth. Reid and Bare (1952) and Smith and Brubaker (1938) considered these three species to be the most important lepidopterous pests on cole crops in South Carolina and Louisiana, respectively. Either the cabbage looper or imported cabbageworm was considered the most destructive, according to whether it was the spring or fall crop, but in all cases the diamondback moth was considered the least injurious pest. By contrast, Pimentel (1961*c*) in New York, and Harcourt (1963) in Canada found that the imported cabbageworm, diamondback moth, and cabbage looper, in that order, were the most serious pests on cabbage, although ranking varied between the first two named pests, according to early or late crops. Harcourt listed five additional lepidopterous species on cabbage which he considered minor pests for a total of eight species affecting cabbage in Canada.

The egg, larval, and pupal populations of the cabbage looper, imported cabbageworm, and diamondback moth are shown in figures 8, 9, and 10. Eggs of the diamondback moth are not included because of the high variation in numbers—due primarily to their small size and inconspicuous location sites, especially on older plants. A total of 2,089 imported cabbageworm and 1,231 cabbage looper eggs was collected. The egg population of the imported cabbageworm reached a peak of 3.6 eggs per plant on July 30, 1963, and 6.6 per plant on August 18, 1964, whereas the egg population of the cabbage looper reached a peak of 4.6 per plant on September 9, 1963, and 2.6 per plant on October 20, 1964 (fig. 8). The egg population of both species was generally lowest during the January–April quarter of each year. None of the imported cabbageworm eggs were parasitized, whereas an average of 7.8 per cent of the cabbage looper eggs were parasitized by *Trichogramma pretiosum* Riley (fig. 11). The species was also reared from diamondback moth eggs collected from young cabbage plants during March, September, and October. On September 29, 1964, 12.5 per cent of the 32 diamondback moth eggs collected were parasitized. An average of 3.9 per cent of the eggs collected during the last year of the study were parasitized with only one adult *T. pretiosum* emerging from each egg. Parasitization of cabbage looper eggs was highest (averaging 13.3 per cent) during the October–December quarter and lowest (zero) during April–June. In 1963, egg parasitization reached a peak of 35.3 per cent on October 29, and a peak of 26.3 per cent on October 6, in 1964 (fig. 12). Later studies showed that parasitization of the cabbage looper eggs reached a peak of 39 per cent on September 14, 1965, and that none of the imported cabbageworm eggs was parasitized prior to the introduction and release of *T. evanescens* Westwood from Europe in 1966 (Oatman *et al.*, 1968).

The cabbage looper and imported cabbageworm larval populations were generally highest from July through December and lowest during the first half of the year. The diamondback moth larval population varied considerably, but in general was highest during the June-to-August, October-to-January, and March-to-April periods (fig. 9). The cabbage looper population reached peaks on October 1, 1963, and September 15, 1964, averaging 9.5 and 4.1 larvae per plant, respectively. The imported cabbageworm larval population peaks averaged 8.9 per plant and 11.5 per plant on August 6, 1963, and August 25, 1964, respectively. The diamondback moth larval population reached peaks, averaging 1.6 per plant on October 22, 1963; 1.7 per plant on February 11, 1964; 3.6 per plant on October 13, 1964; and 2.8 larvae per plant on March 30, 1965 (fig. 9). The peak larval population for the three species combined averaged 12.2 per plant on August 13, 1963, and 13.1 per plant on August 25, 1964.

The pupal population peaks for these three species generally followed closely the larval peaks, especially those of the imported cabbageworm and diamondback moth (fig. 10). The number of

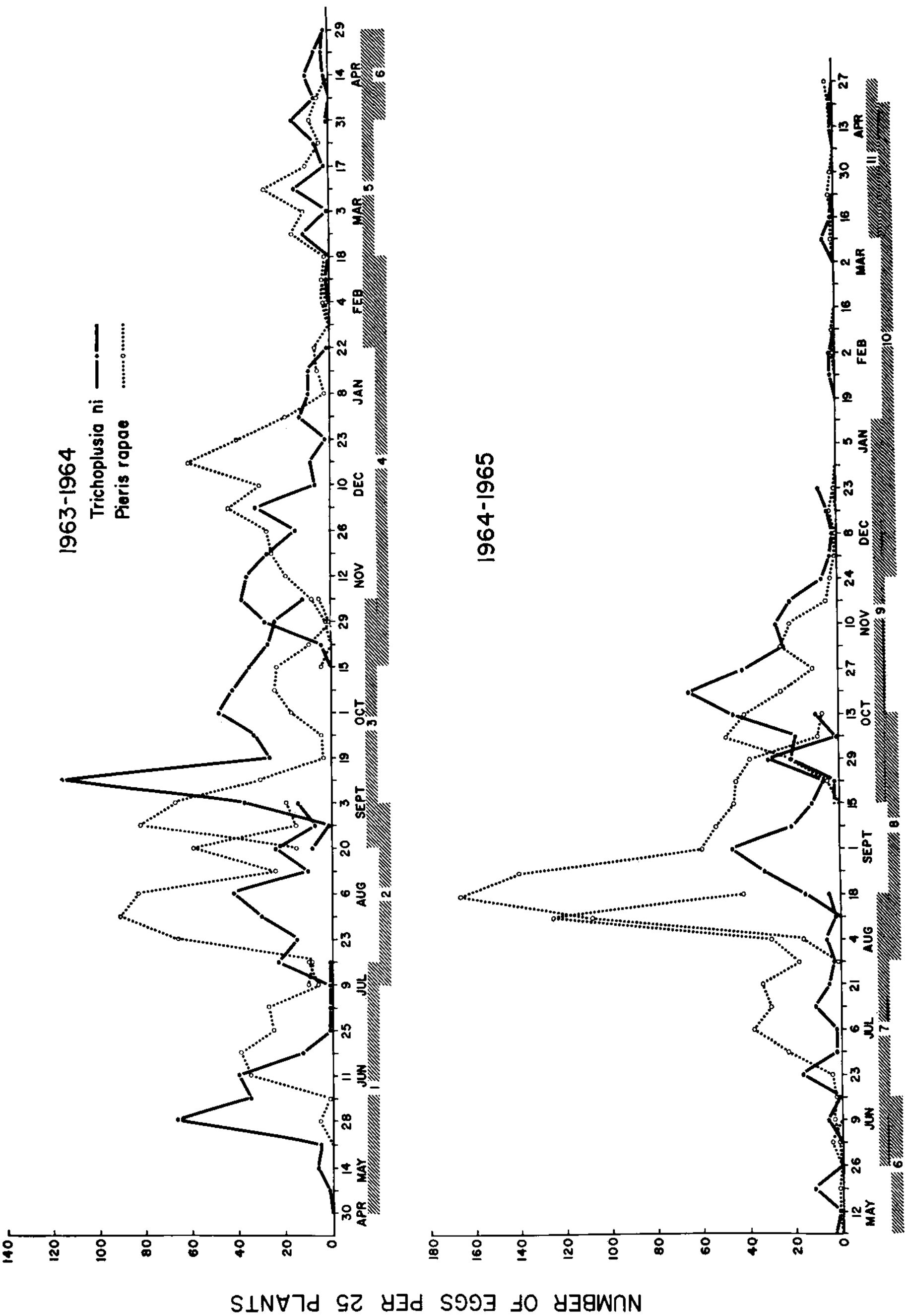

Fig. 8. Population trends of cabbage looper and imported cabbageworm eggs on cabbage during 1963–1965 study. Successive cabbage plantings shown by numbered horizontal bars.

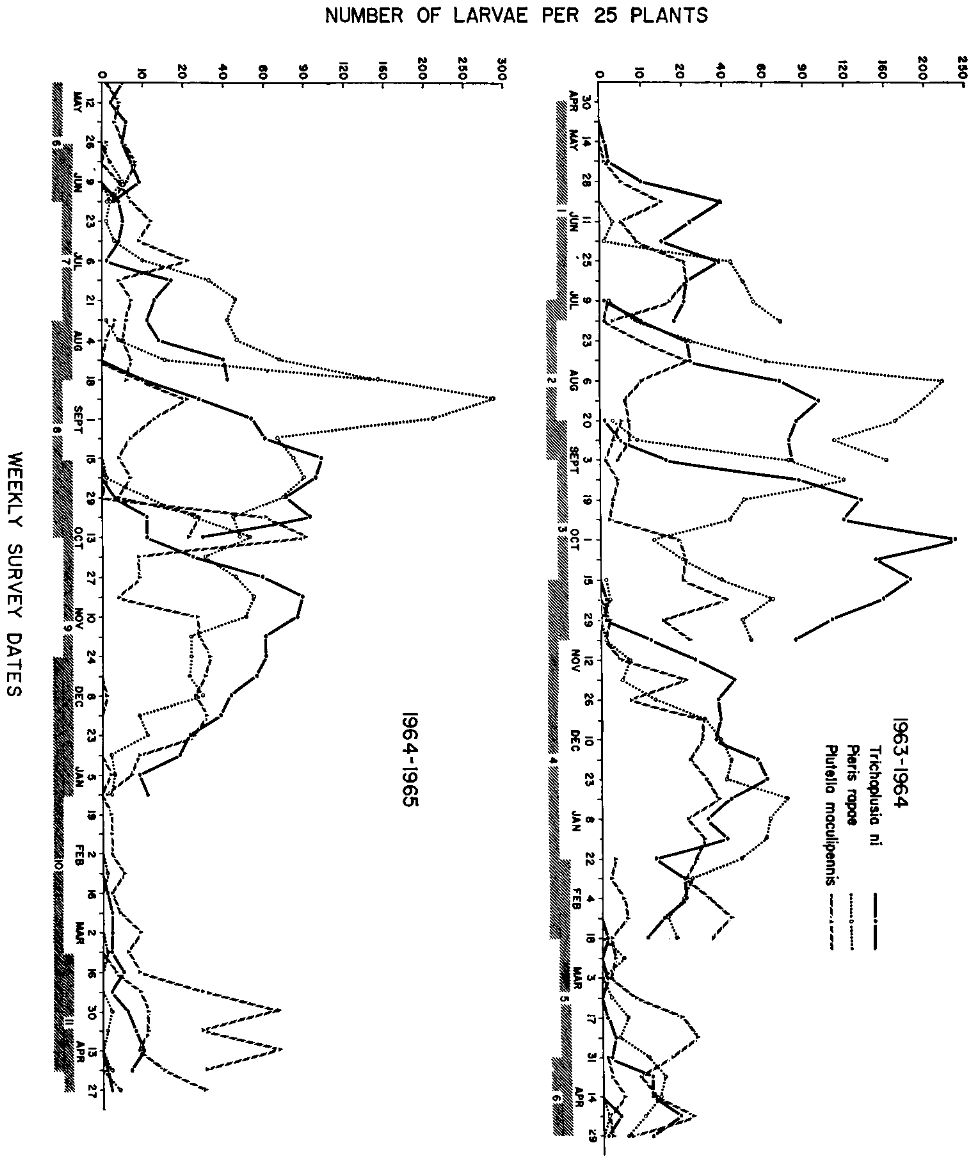

Fig. 9. Population trends of cabbage looper, imported cabbageworm, and diamondback moth larva during 1963–1965 study. Successive cabbage plantings shown by numbered horizontal bars.

cabbage looper pupae collected, however, was considerably lower than that expected relative to the larval population, especially following the peak larval population in late September (figs. 9 and 10). This was probably due primarily to the high larval mortality caused for the most part by a nuclear polyhedrous virus, which was especially prevalent from late September through the fall months (figs. 13 and 14).

Parasitism was an important mortality factor affecting the lepidopterous pest populations on cabbage, especially for the cabbage looper, imported cabbageworm, and diamondback moth

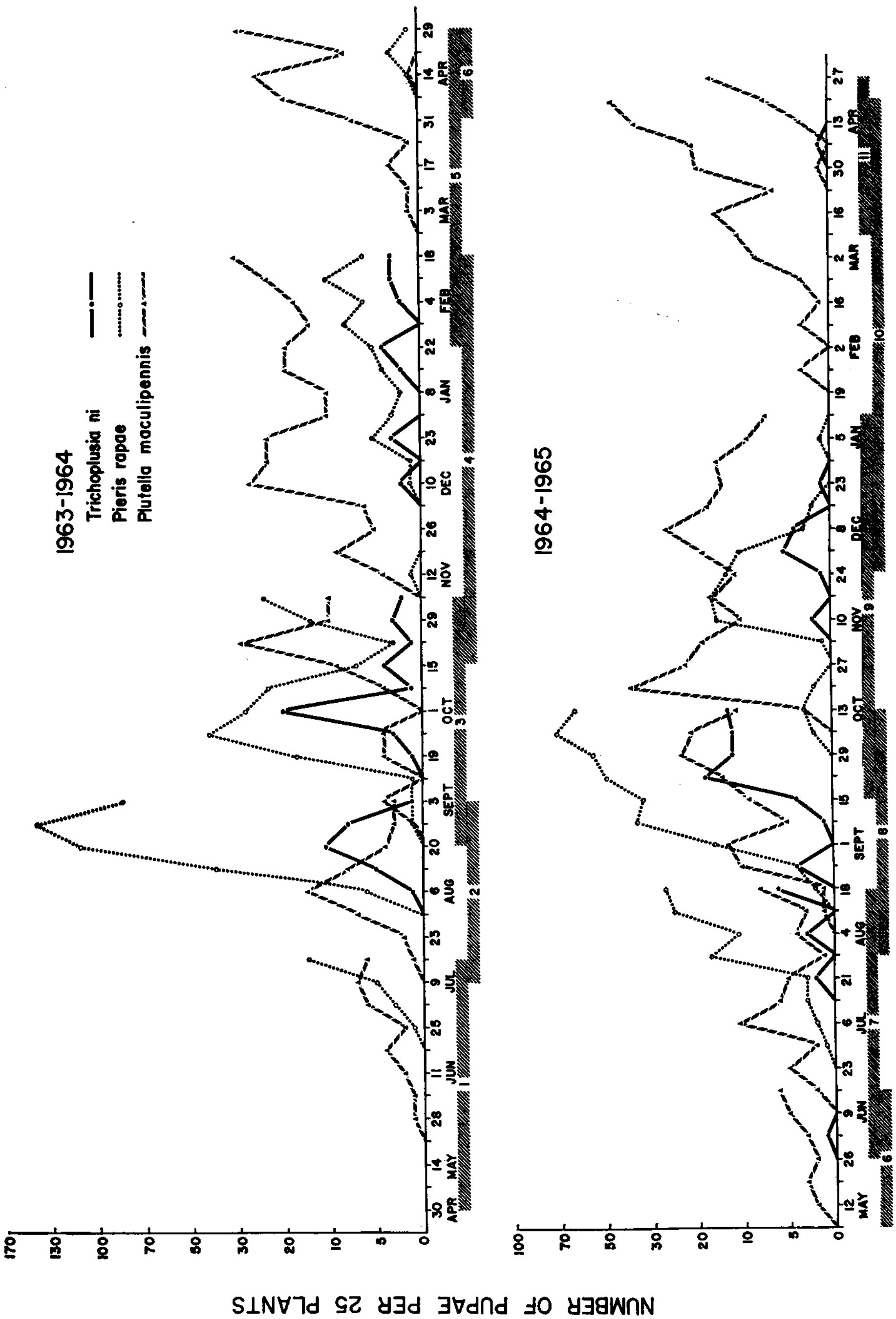

Fig. 10. Population trends of cabbage looper, imported cabbageworm, and diamondback moth pupae during 1963–1965 study. Successive cabbage plantings shown by numbered horizontal bars.

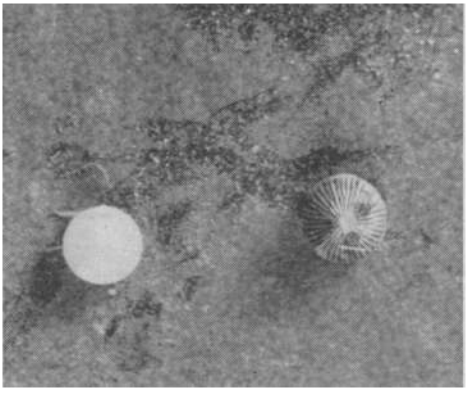

Fig. 11. Cabbage looper eggs on cabbage leaf. Right (dark): parasitized by *Trichogramma pretiosum.*

(figs. 15, 16, and 17). Hymenopterous parasites were represented by 14 species in six families and dipterous parasites by 10 species in two families (table 4). The largest number of species in the order Hymenoptera was in the Braconidae with five; in the Diptera, nine species were in the Tachinidae. *Trichogramma pretiosum* was the only egg parasite reared, and *Brachymeria ovata* (Say), *Pediobius sexdentatus* (Girault) and *Pteromalus puparum* (L.) were the only pupal parasites. All the rest were egg-larval, larval or larval-pupal parasites (table 4). Twelve species of parasites were reared from the larval and pupal stages of the cabbage looper, nine from the imported cabbageworm, five from the diamondback moth, four each from the beet armyworm and the saltmarsh caterpillar, and two from cutworms (table 4). Whereas seven of the 12 species of parasites reared from the cabbage looper were hymenopterons, four of nine from the imported cabbageworm, and all of those reared from the diamondback moth, the five species of parasites reared from the saltmarsh caterpillar were all tachinids (fig. 18). The other hosts had equal numbers of both groups.

An average of 38.9 per cent of the cabbage looper larvae and pupae was parasitized during the two-year study. Parasitism was highest during the October-December quarter at 44.6 per cent with 66.7 per cent occurring in November, and lowest during January-March at 30.4 percent with zero parasitization in March (fig. 15). Parasitization averaged 37.2 per cent in the April-June quarter and 36.8 per cent during July-September. As in the Escondido study (Oatman, 1966), the tachinid, *Voria ruralis* (Fallen), was the dominant parasite of the cabbage looper, especially during the fall and winter months. Tachinid parasites were reared from the cabbage looper throughout the year in varying numbers, but hymenopterous parasites such as *Hyposoter exiguae* (Viereck) and *Copidosoma truncatellum* (Dalman) occurred most commonly during the summer and fall months (figs. 19 through 24). The latter species was especially prevalent September through December along with a nuclear polyhedral virus which was the major mortality factor affecting the population (figs. 13 and 14). The virus was also responsible for most of the 60 per cent larval mortality which occurred in the laboratory, when the field-collected larvae were held for parasitization. Larvae which died in this manner were not included in the totals used for calculating per cent parasitization, since it was not always possible to determine accurately whether they were parasitized. Pupal mortality in the laboratory was only 2.0 per cent. An occasional cabbage looper pupa was parasitized by *Pediobius sexdentatus.* The data indicate that pupal mortality in the field was very low, although predation which was not studied might occasionally be a factor.

Pimentel (1961*c*) found that a polyhedral virus was the major mortality factor affecting the cabbage looper population in New York in 1957 and 1958,

TABLE 4
PARASITES REARED FROM LEPIDOPTEROUS HOSTS COLLECTED FROM CABBAGE IN SOUTHERN CALIFORNIA
1963 to 1965

Parasite	Host					
	Trichoplusia ni	*Pieris rapae*	*Plutella maculipennis*	*Spodoptera exigua*	*Estigmene acrea*	Cutworms*
Hymenoptera:						
Braconidae						
Apanteles glomeratus (L.)		+				
Chelonus texanus Cr.				+		
Meteorus leviventris (Wesm.)						+
Microplitis plutellae Mues.	+	+	+			
Microplitis brassicae Mues.	+					
Chalcidae						
Brachymeria ovata (Say)†		+				
Encyrtidae						
Copidosoma truncatellum (Dalman)	+					
Ichneumonidae						
Diadegma plutellae (Viereck)	+		+			
Diadegma insularis (Cresson)			+			
Diadromus erythrostomus (Cam.)			+			
Hyposoter exiguae (Viereck)	+			+		
Pteromalidae						
Pediobius sexdentatus (Girault)†	+					
Pteromalus puparum (L.)†		+				
Trichogrammatidae						
Trichogramma pretiosum Riley‡	+		+			
Diptera:						
Sarcophagidae						
Helicobia rapax Walker		+				
Tachinidae						
Carcelia reclinata Aldrich & Webber					+	
Eucelatoria armigera (Coquillett)	+	+				
Euphorocera tachinomoides Townsend		+				
Gymmocarcelia ricinorum Townsend					+	
Leschenaultia adusta Loew					+	
Lespesia archippivora (Riley)	+	+		+	+	
Madremyia saundersii (Williston)	+	+				
Siphona sp.	+					
Voria ruralis (Fallen)	+				+	+

* Variegated and granulate cutworms.
† Reared only from host pupae.
‡ Reared only from host eggs.

and that *Copidosoma truncatellum* was present only in 1958. Harcourt (1963) reared four parasites (three hymenopterons and one tachinid) from the cabbage looper in Ontario, Canada, and considered *C. truncatellum* the most important parasite. He also noted that field populations were frequently destroyed by a polyhedral virus disease of the larvae. Clancy (1969) reared five tachinid and five hymenopterous parasites from cabbage looper larvae collected from annual weeds, tree tobacco (*Nicotiana glauca* Graham), and alfalfa in southern California. He noted that *Voria ruralis* was the most common parasite in the fall and winter, and *C. truncatellum* was the most common hymenopteron. He also recorded that 70.9 per cent of the larvae collected from weeds in July were killed by a nuclear polyhedrosis virus, but that virus mortality was highest in larvae from alfalfa. Total parasitism was highest (41.1 per cent) on larvae collected from tree tobacco and was highest in August

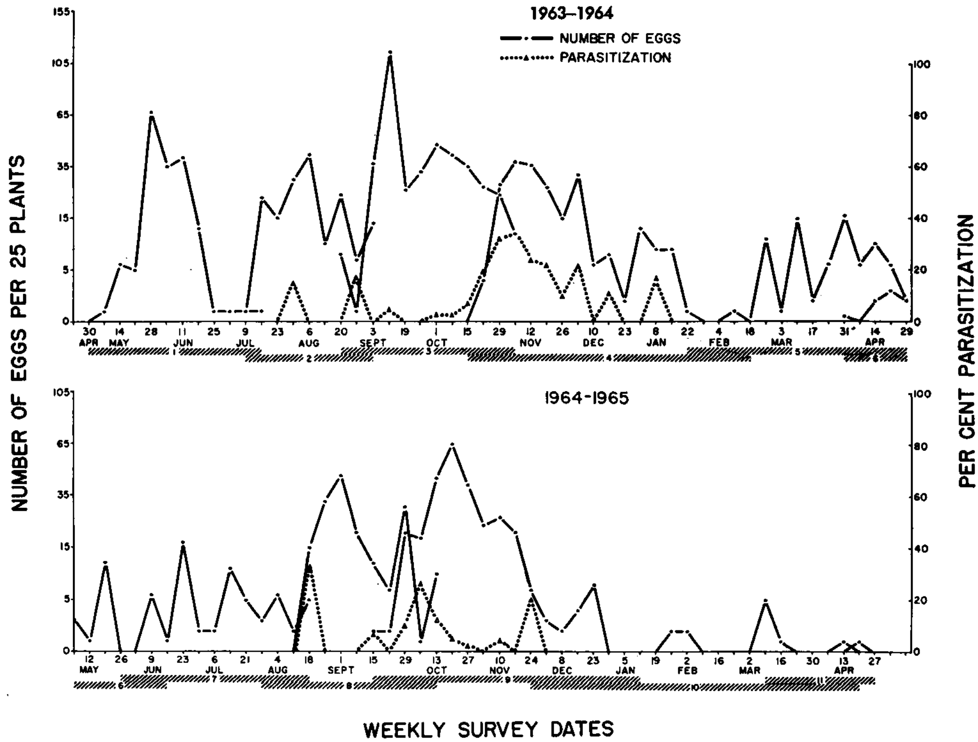

Fig. 12. Population trends and per cent parasitization of cabbage looper eggs on cabbage during 1963–1965 study. Successive cabbage plantings shown by numbered horizontal bars.

and September. McKinney (1944), Butler (1958), and Brubaker (1968) all found that *V. ruralis* was the most common parasite of cabbage looper larvae collected from weeds and cultivated crops in Arizona, being present throughout the year but most abundant during late fall and winter. McKinney reared six parasites (5 hymenopterons and 1 tachinid) from larvae collected on lettuce in addition to *Trichogramma* sp. from the eggs, and reported that the predaceous ground beetle, *Calosoma pereguinator* Guér., readily fed on the larvae.

Fig. 13. Moribund cabbage looper larva infected with nuclear polyhedrosis virus, lying in a fully extended position on a cabbage leaf.

An average of 38.6 per cent of the imported cabbageworm larvae and 76.7 per cent of the pupae were parasitized for an average of 53.9 per cent parasitization of the total larval-pupal population. Parasitization was highest during the July-September quarter at 56.8 per cent, with 62.6 per cent occurring in September—and lowest for the April-June quarter at 31.7 per cent, with 12.5 per cent occurring in June (fig. 16). During the January-March quarter, parasitization averaged 32.9 per cent; during the October-December quarter, the average was 50.7 per cent. Thus parasitization averaged 55.4 per cent during the last half of the year com-

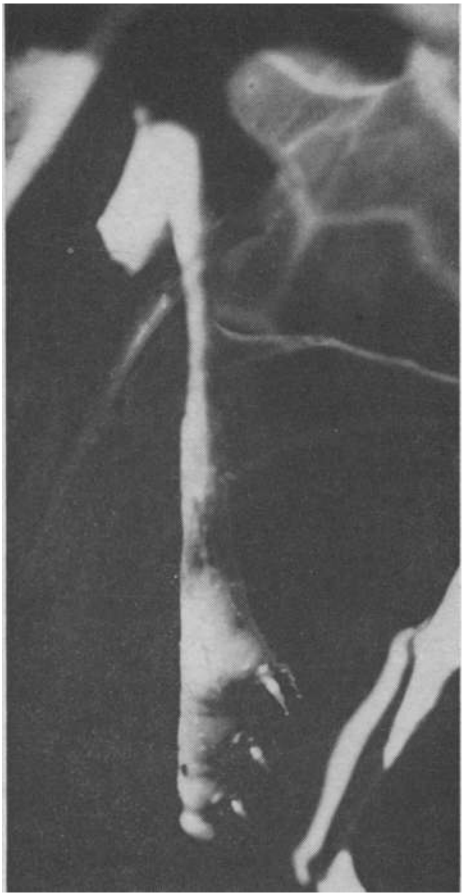

Fig. 14. Cabbage looper larva killed by nuclear polyhedrosis virus, hanging by prolegs from a cabbage leaf.

pared to 32.4 per cent for the first half. Mortality of the laboratory-held, field-collected material averaged 27.9 per cent or only about half that for the cabbage looper, with mortality at 21.5 per cent for the pupae and 32.4 per cent for the larvae. A viral disease was responsible for some of the mortality of both stages. As in the Escondido study (Oatman, 1966), *Pteromalus puparum* was the principal hymenopterous parasite and the primary mortality factor from September through December. *Madremyia saundersii* (Williston) was the most common dipterous parasite (figs. 25, 26, and 27). During this time, dead pupae of the imported cabbageworm (fig. 28) often were found filled with small, rod-shaped bacteria. Whether or not the bacteria were primary or secondary invaders is not known. The number of *P. puparum* reared from 22 host pupae ranged from six to 75, averaging 40.5 per pupa.

The larval parasite, Apanteles glomeratus (L.), which was commonly reared from the imported cabbageworm in the fall at Escondido, was not present at El Toro until field releases were made in October, 1964, using cocoons collected at Escondido. Following its release, the species was recovered from field-collected material through mid-December. However, the species was not recovered at El Toro in 1965, nor since. The reason for its presence in an inland coastal area of San Diego County and its absence from a similar area in Orange County, about 50 miles distant, is not known. Its spread into California apparently occurred naturally as there is no record of its having been released in the state. *Apanteles glomeratus* was imported from Europe and became established in the eastern part of the United States in 1884, and *Pteromalus puparum* had previously been introduced accidentally some time before this date. Both became generally distributed in the United States and Canada (Clausen, 1956). *Apanteles rubecula* Marsh is the most common and effective larval parasite of the imported cabbageworm in Europe (Moss, 1933; Richards, 1940). It had not been reported in North America (Blunck, 1957) prior to its discovery in British Columbia, Canada, in 1963, where it was apparently accidentally introduced (Wilkinson, 1966). In Europe, *A. rubecula* is almost specific to ***Pieris rapae,*** whereas, *A. glomeratus* is most commonly reared from ***P. brassicae*** (L.) (Richards, 1940; Blunck, 1957). *Apanteles rubecula* was released and colonized on the imported cabbageworm on cabbage in Orange County in 1957.

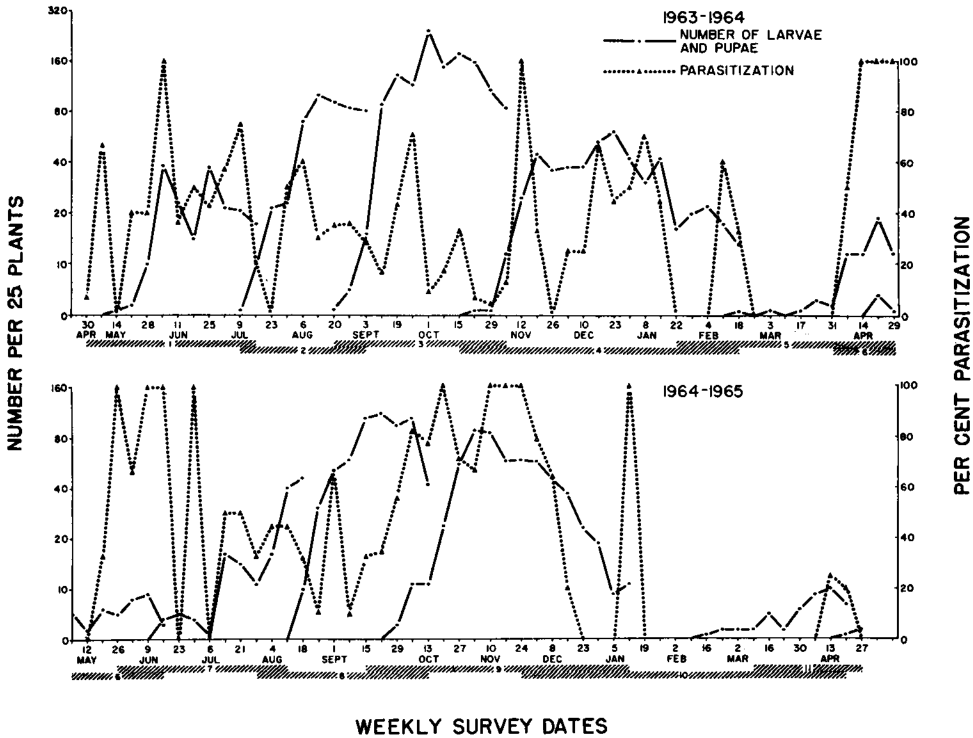

Fig. 15. Population trends and per cent parasitization of cabbage looper larvae and pupae on cabbage during 1963–1965 study. Successive cabbage plantings shown by numbered horizontal bars.

However, the parasite apparently was not established, since it was not recovered in 1968. Efforts to establish the parasite will be continued.

Harcourt (1963) noted that six species of parasites (2 Hymenoptera and 4 Diptera) had been recorded from the imported cabbageworm in eastern Ontario, Canada, including *Apanteles glomeratus* and *Pteromalus puparum,* with the former species being the principal larval parasite. Pimentel (1961*c*) reported that 55 per cent of the imported cabbageworm population was parasitized during 1957 in New York and 48 per cent in 1958, with *A. glomeratus* being the most common parasite. Both workers found that *Phryex vulgaris* (Fall.) was the most common tachinid parasite. Since this tachinid was also commonly reared from the pest in British Columbia, Canada (Wilkinson, 1966), it is apparently the most common tachinid parasite of the imported cabbageworm in the northern part of the United States and in Canada, as well as in England, where it is probably native (Moss, 1933; Richards, 1940). In New Zealand where both *A. glomeratus* and *P. puparum* were introduced and established on the imported cabbageworm, Todd (1959) reported that *P. puparum* was a major mortality factor in the latter part of the growing season, but that there was no evidence that *A. glomeratus* exercised any degree of control. He reported that a virus was the dominant mortality factor in controlling the imported cabbageworm.

Although parasites of the cabbage looper and imported cabbageworm were

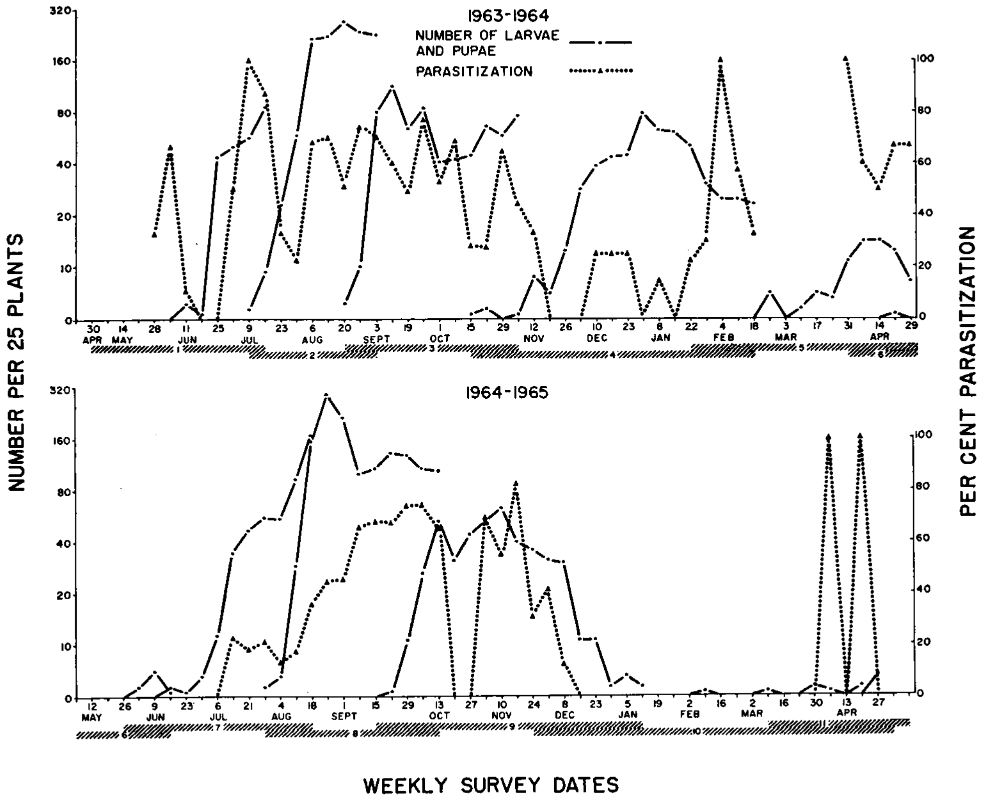

Fig. 16. Population trends and per cent parasitization of imported cabbageworm larvae and pupae on cabbage during 1963–1965 study. Successive plantings shown by numbered horizontal bars.

present throughout the year, parasitization was generally highest during the winter and spring months when the host populations were lowest. As a result, parasitization was usually more erratic during this time, ranging from zero to 100 per cent (figs. 15 and 16).

An average of 35.2 per cent of the diamondback moth larval-pupal population was parasitized during the two-year study. Parasitization was highest during the July-September quarter at 60.3 per cent, with 71.2 per cent occurring in September—and lowest for the January-March quarter at 28.0 per cent, with 12.4 per cent being in January (fig. 17). Parasitization averaged 30.9 per cent during the April-June quarter and 33.6 per cent during the October-December quarter. As a result, parasitization averaged only 29.5 per cent during the cooler first half of the year (January-June) compared to 40.4 per cent for the warmer last half (July-December). Mortality of the laboratory-held, field-collected material averaged only 16.9 per cent compared to 27.9 per cent for the imported cabbageworm and 61.9 per cent for the cabbage looper. Probably disease was a minor factor in the mortality of the diamondback moth material, since no virus symptoms were noted. Pupal mortality averaged 14.8 per cent and larval mortality, 16.9 per cent. Of the three ichneumonid parasites reared from the diamondback moth, *Diadegma* (=*Horogenes*) *insularis* (Cresson) was by far the most

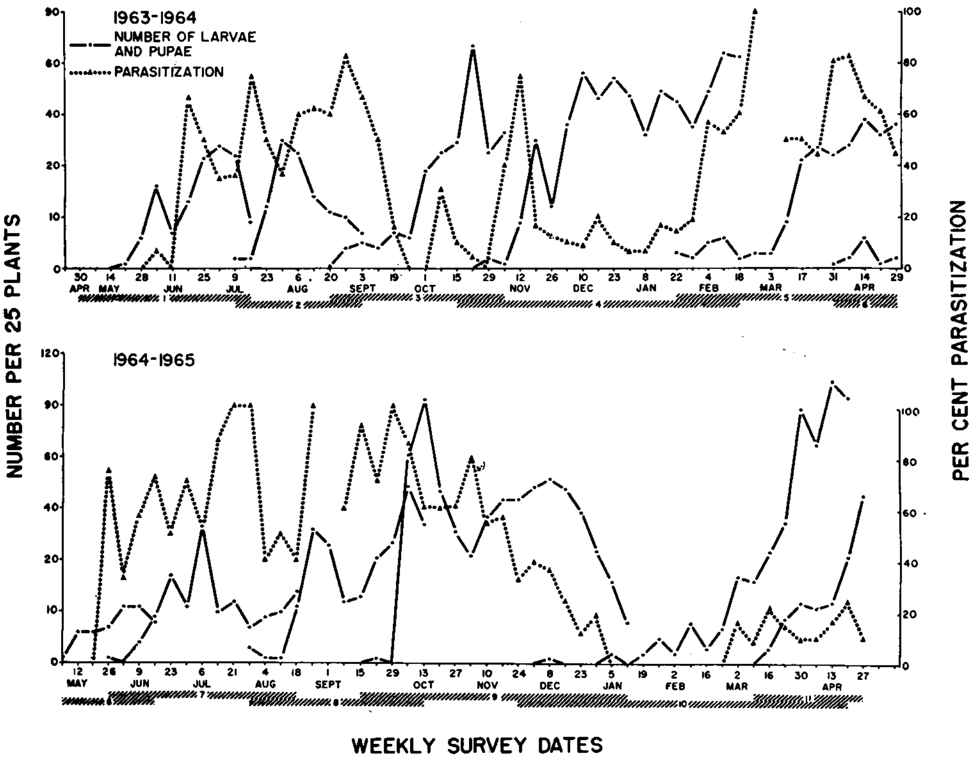

Fig. 17. Population trends and per cent parasitization of diamondback moth larvae and pupae on cabbage during 1963–1965 study. Successive cabbage plantings shown by numbered horizontal bars.

common with *D. plutellae* (Viereck) next. *Diadromus erythrostomus* (Cam.) was the least common ichneumonid parasite. The braconid, *Microplitis plutellae* Mues., although present during most of the year, was not reared in sufficient numbers to be considered an important mortality factor. Parasitization of the diamondback moth usually closely followed the larval-pupal population, increasing and decreasing with the host except for a brief lag in December, 1963, and April, 1965 (fig. 17). This close parasite-host relationship was more effective than that obtained for the cabbage looper and imported cabbageworm and was probably one of the primary factors responsible for the overall lower population of the diamondback moth (figs. 9 and 10). The data also indicate that cooler weather from November through April temporarily favored the diamondback moth over its natural enemies, resulting in a higher host population. Larval feeding damage was minor compared to that caused by the cabbage looper and imported cabbageworm.

In New York, Pimentel (1961*c*) found that 40 per cent of the diamondback moth population was parasitized in 1957 and 55 per cent in 1958, with *Diadegma* sp. accounting for 36 per cent and 52 per cent, respectively. Todd (1959) reported that the diamondback moth generally was not a serious pest on cruciferous crops in New Zealand, being effectively controlled by the introduced parasites, *Angitia cerophaga* Grav. and *Diadromus collaris* (Grav.), and that a

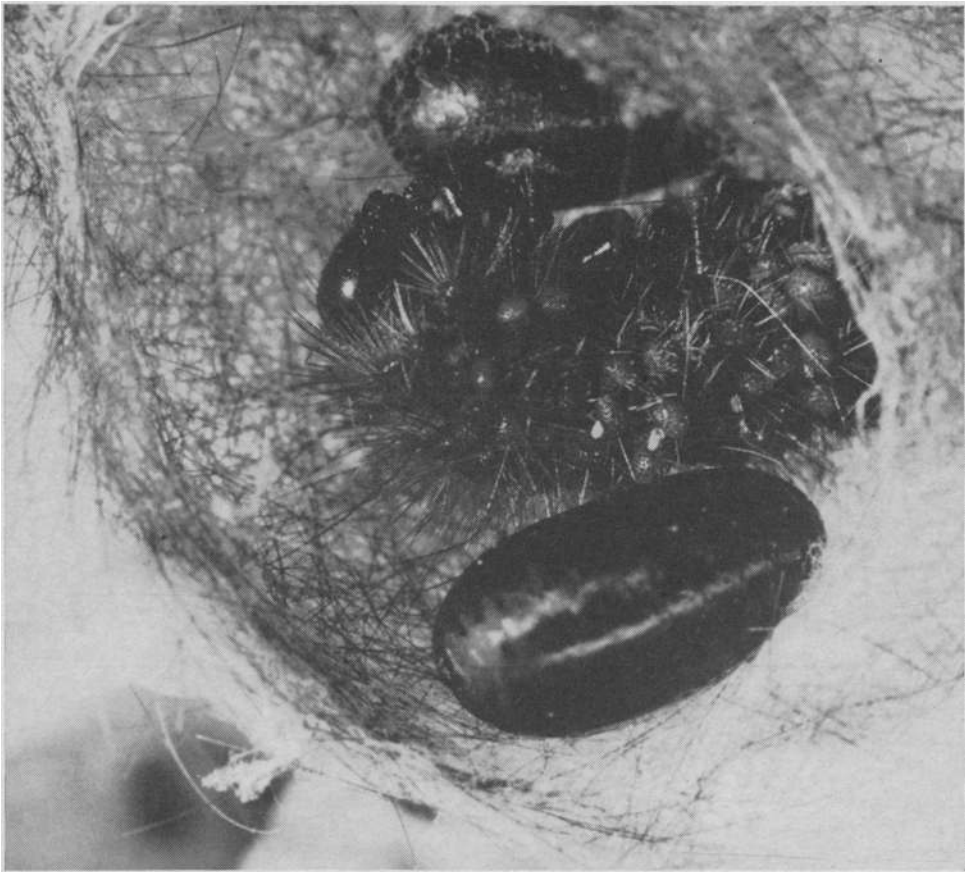

Fig. 18. Puparia of a tachinid parasite and the remnant of a saltmarsh caterpillar larva from which it emerged on a cabbage leaf.

fungus was also effective when population density of the host was high.

Harcourt (1960) reared 10 parasites from the diamondback moth in Ontario, Canada, with *Diadegma insularis* being the principal one. He found that mortality due to disease was negligible, but that mortality of the early larval instars and adults caused by rainfall was a major factor in the population dynamics of the species. Moss (1933) suggested that rain at critical stages in the life cycle of the diamondback moth might be a controlling agent in England. The importance of that mortality is probably reduced in southern California where rainfall is low. In the present study, for example, rainfall averaged only 10 inches per year with most of it occurring between November and April (fig. 6).

Of the miscellaneous lepidopterous larvae collected, the beet armyworm was the most abundant; a total of 207 larvae were collected during the two-year study. Of these 10.9 per cent were parasitized—mostly during the October-December quarter. The hymenopterons, *Chelonus texanus* Cresson and *Hyposoter exiguae,* and the tachinids, *Lespesia archippivora* (Riley) and *Voria ruralis,* were the only parasites reared from the larvae, with the tachinids accounting for about 75 per cent

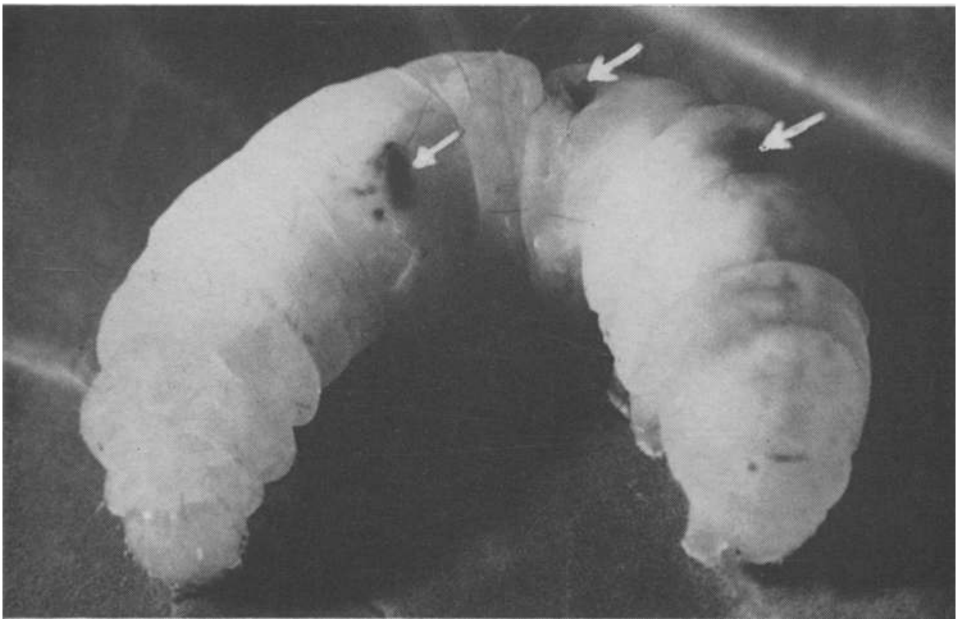

Fig. 19. Cabbage looper larva parasitized by a tachinid parasite, showing darkened areas (arrows) indicative of parasite larval attachment internally.

Fig. 20. Cabbage looper larva parasitized by tachinid parasite, showning puparia of parasite inside tegument of dead host.

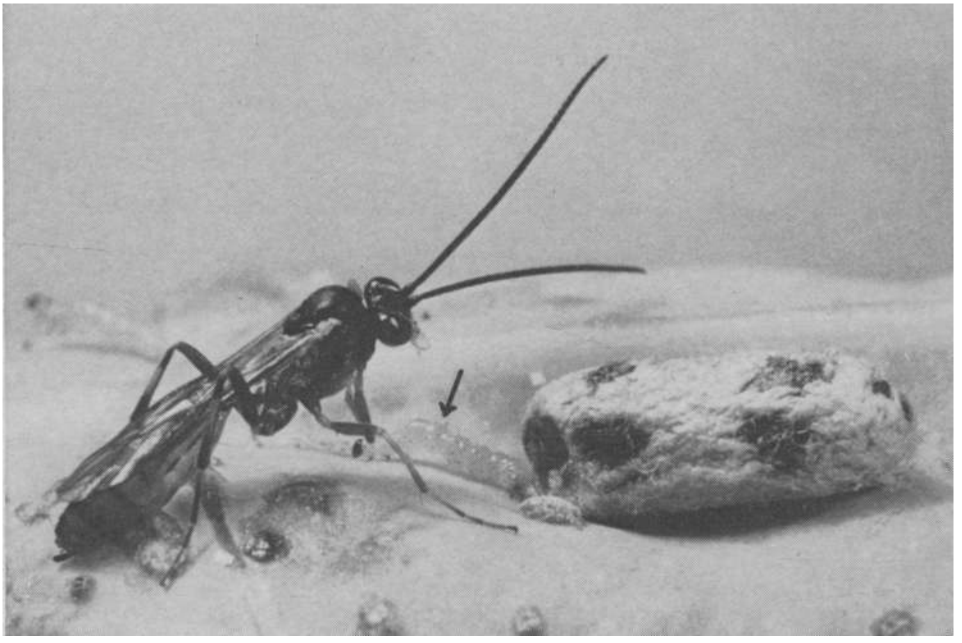

Fig. 21. *Hyposoter exiguae* adult female and cocoon on a cabbage leaf with an early second instar cabbage looper larva (arrow).

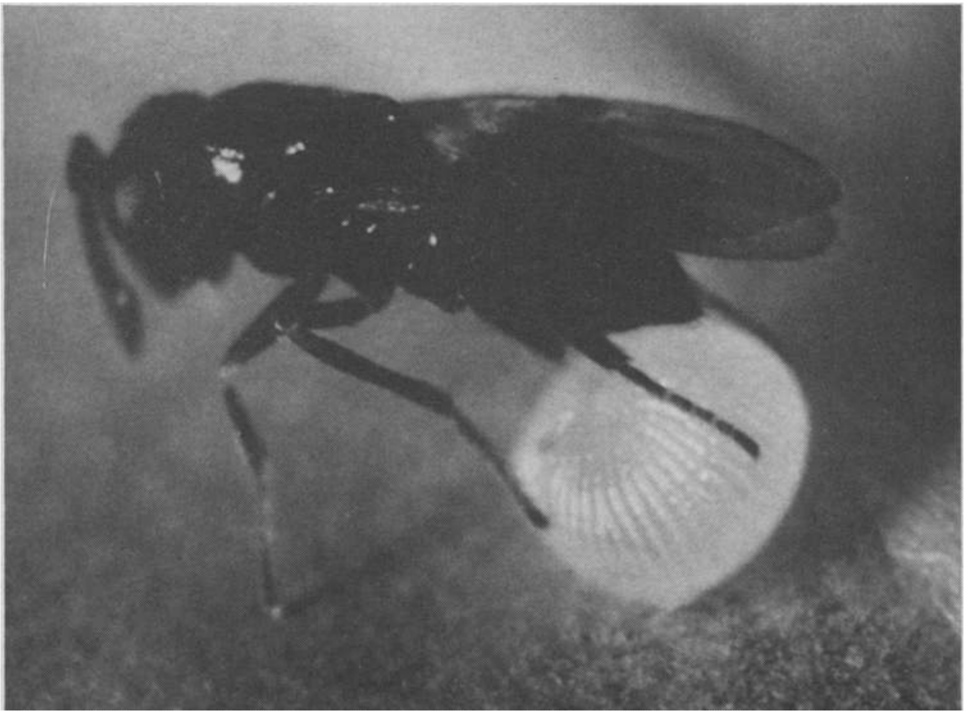

Fig. 22. *Copidosoma truncatellum* adult ovipositing in a cabbage looper egg on a cabbage leaf.

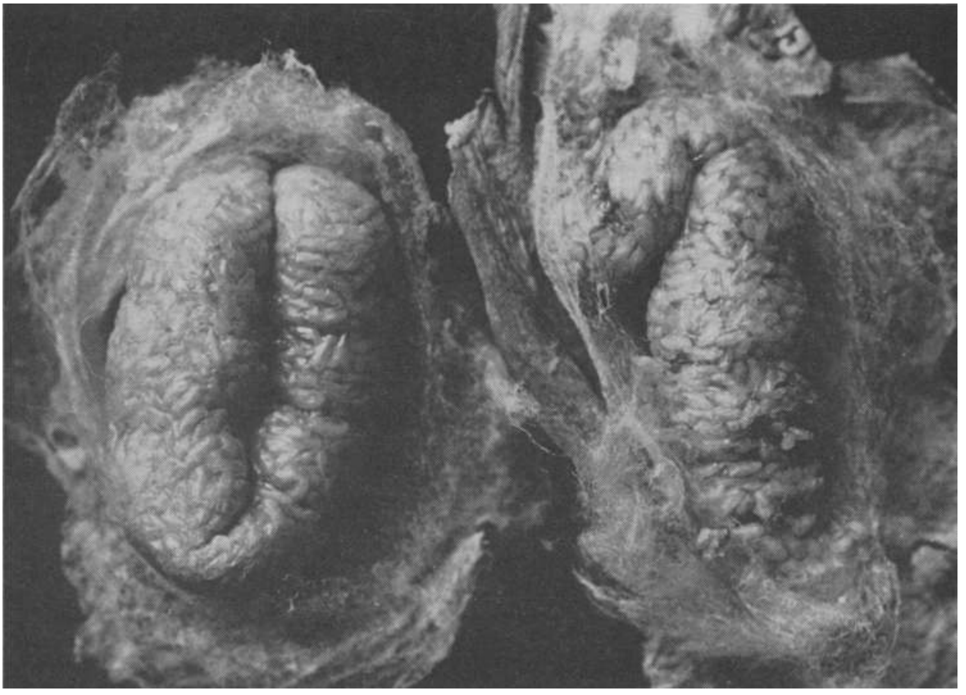

Fig. 23. Parasitized mature cabbage looper larvae inside cocoons opened to show each host filled with hundreds of *Copidosoma truncatellum* pupae.

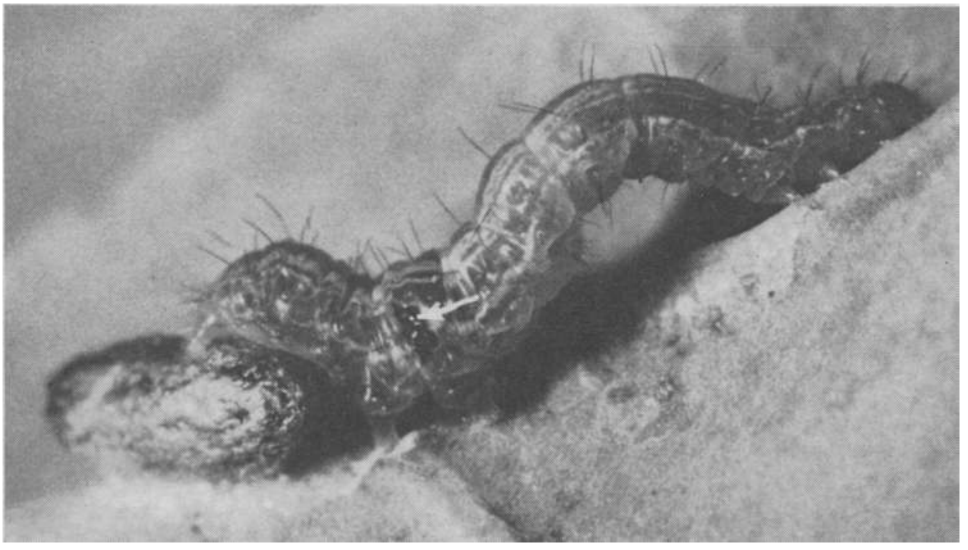

Fig. 24. Cocoon of *Microplitis* sp. parasite on a cabbage leaf underneath the anal prolegs of a cabbage looper larva from which the parasite larva had emerged (exit hole shown by arrow).

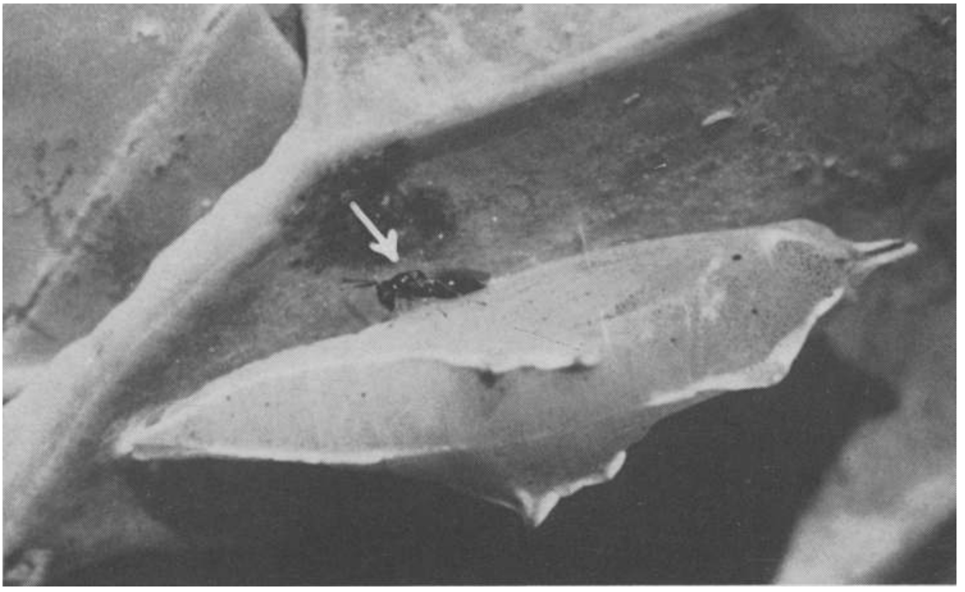

Fig. 25. *Pteromalus puparum* adult (arrow) parasitizing an imported cabbageworm pupa on a cabbage leaf.

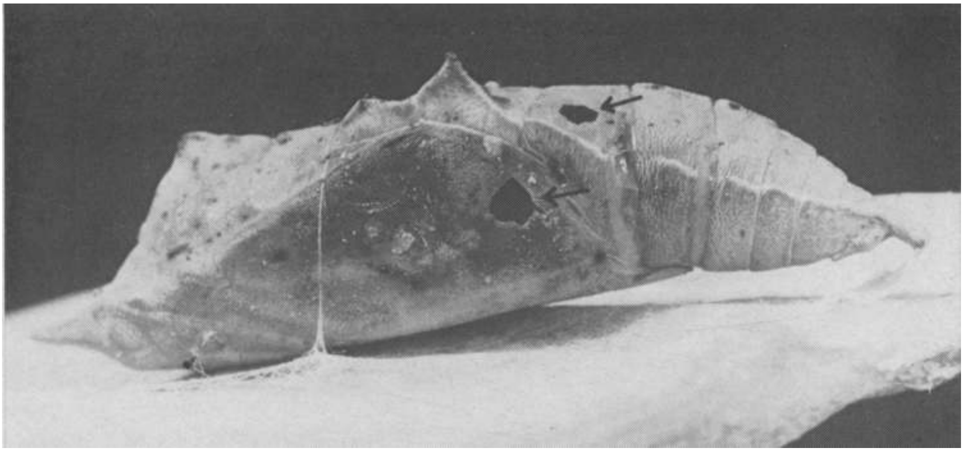

Fig. 26. Parasitized imported cabbageworm pupa on a cabbage leaf, showning exit holes (arrows) from which *Pteromalus puparum* adults had emerged.

of those parasitized. *Hyposoter exiguae* (fig. 21) was most common during May and June, and *C. texanus* was the most common during October and November. The tachinids were present throughout the year, especially *L. archippivora*, which was reared from four of the lepidopterous pests (table 4). Butler (1958) found that *L. archippivora* was the most abundant tachinid in crop areas in Arizona, and that it had the widest host range of all tachinids recovered from lepidopterous larvae in that state. Bryan *et al.* (1968) observed that it was one of the most widespread parasites of lepidopterous larvae in

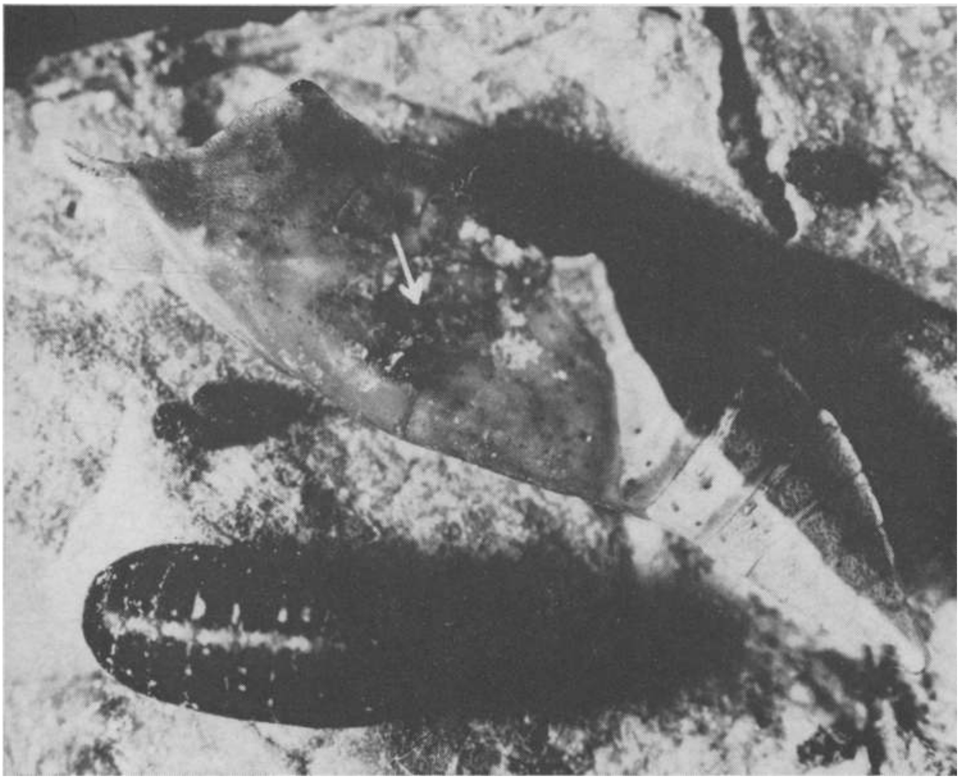

Fig. 27. Tachinid parasite puparium on a cabbage leaf next to an imported cabbageworm pupa from which the parasite larva had emerged (exit hole indicated by arrow).

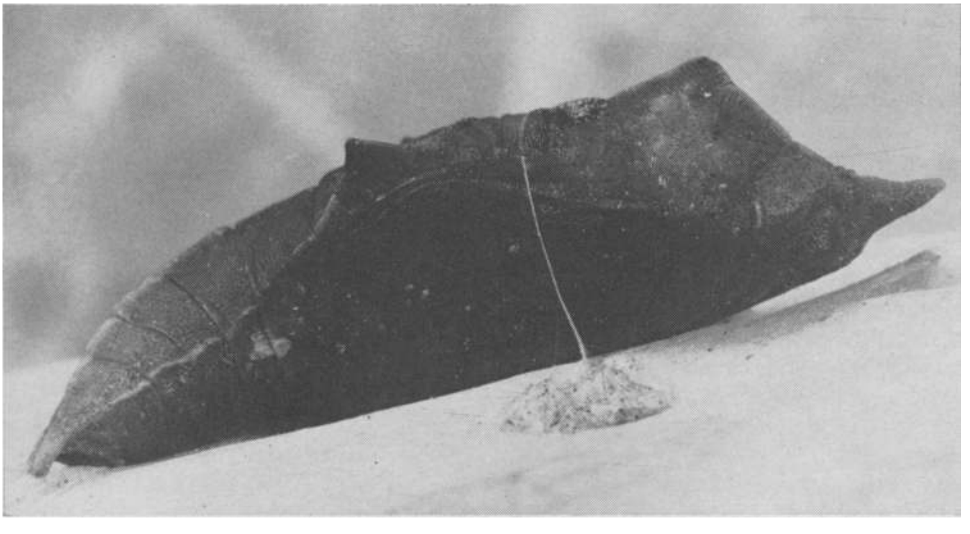

Fig. 28. Dead and abnormally dark imported cabbageworm pupa on a cabbage leaf. Such pupa contain a blackish liquid containing bacteria.

Fig. 29. Diamondback moth pupa (top) inside its cocoon on a cabbage leaf and adjacent to a second cocoon (bottom) which was opened to expose a *Diadegma* sp. parasite cocoon.

North America. Egg masses of the beet armyworm were parasitized by *Trichogramma pretiosum,* although the cottony material which composed the mass usually permitted only a few of the outer eggs to be affected. The beet armyworm larval population averaged 0.8 per plant on September 19, 1963, and again on November 2, 1964.

The remaining miscellaneous lepidopterous larvae were: 102 cabbage webworms, 35 saltmarsh caterpillars and 17 cutworms. None of the cabbage webworm larvae were parasitized. About 40 per cent of the saltmarsh caterpillars and cutworms died during rearing. Of those remaining, 36.4 per cent and 20.0 per cent were parasitized, respectively. The cabbage webworm population averaged 0.6 larva per plant on September 9, 1963, and the saltmarsh caterpillar averaged 0.3 per plant on October 10, 1964, at their peaks during the two-year study.

Serpentine leaf miner

The serpentine leaf miner was the principal dipterous species feeding on the cabbage plants, being present throughout each year (figs. 30 and 31). The larval population (based on weekly cumulative total number of mines) reached peaks averaging 178.8 mines per plant on August 6, 1963, and 47.6 per plant on August 25, 1964 (fig. 30). The adult population (based on suction samples) reached peaks one week earlier, indicating that mine counting was a relatively effective technique for estimating the serpentine leaf miner population. In general, the population was low from December through March, building up in April and remaining at a relatively high level from June through October (figs. 30 and 31).

The method used for determining per cent parasitization resulted in only 14.4 per cent yield of adult leaf miners

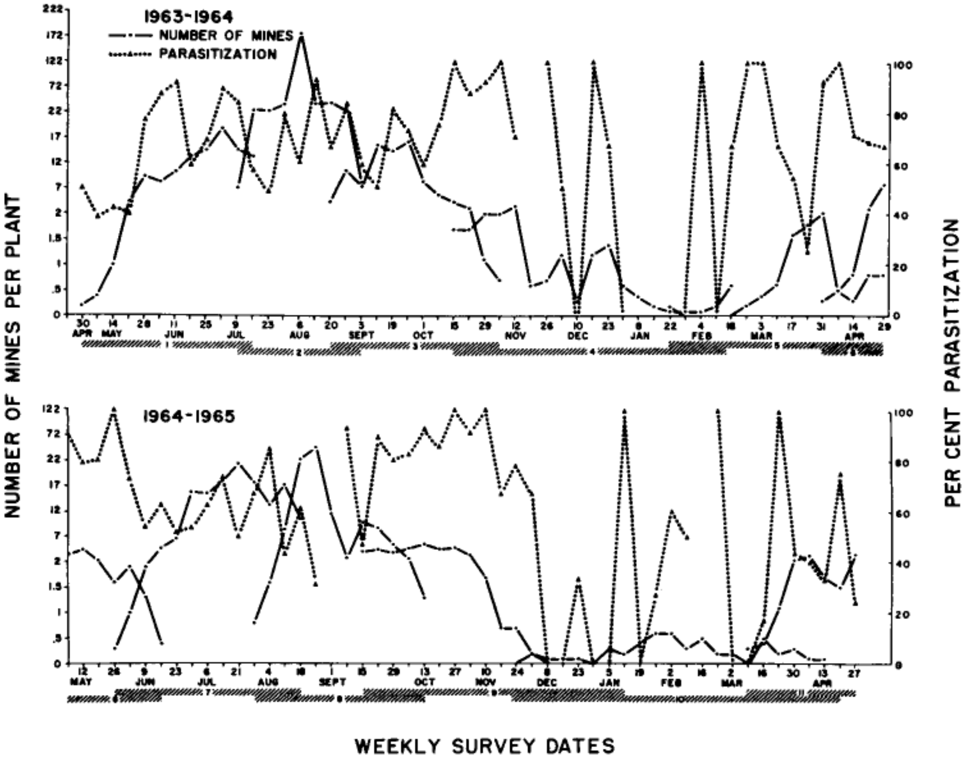

Fig. 30. Population trends and per cent parasitization of the cabbage leafminer on cabbage during 1963–1965 study. Successive cabbage plantings shown by numbered horizontal bars.

and parasites. On this basis, 67.5 per cent of the larval population was parasitized during the study, being highest during the October-December quarter at an average of 80.9 per cent and lowest during the January-March quarter at 49.6 per cent. Parasitization during the April-June and July-September quarters averaged 64.6 per cent and 69.6 per cent, respectively. Parasitization was lowest in January at 26.7 per cent and highest in October at 84.1 per cent (fig. 30). Eleven species of parasites in four families were reared from the serpentine leaf miner during the course of the study:

Eulophidae
- *Diglyphus begini* (Ashm.)
- *Diglyphus intermedius* (Girault)
- *Diglyphus* sp.
- *Derostenus arizonensis* Cwfd.
- *Derostenus punctipes* Cwfd.
- *Derostenus* sp.
- *Chrysocharis petiolata* (Girault)
- *Chrysocharis* sp.

Pteromalidae
- *Halticoptera patellana* (Dalman)

Cynipidae
- *Ganaspidium* sp.

Braconidae
- *Opius* sp. (near *complicans*)

Diglyphus begini was by far the most common parasite parasitizing the larval stage and *H. patellana,* the pupal stage.

Leaf injury caused by the mining larvae was insignificant. On the young cabbage plants, this was probably due primarily to rapid plant growth and increasing per cent parasitization. On older plants, the mining activity is confined primarily to the older, outer, wrapper leaves—most of which dry up and drop off as the heads mature, thus contributing indirectly to the regulation of the serpentine leaf miner population.

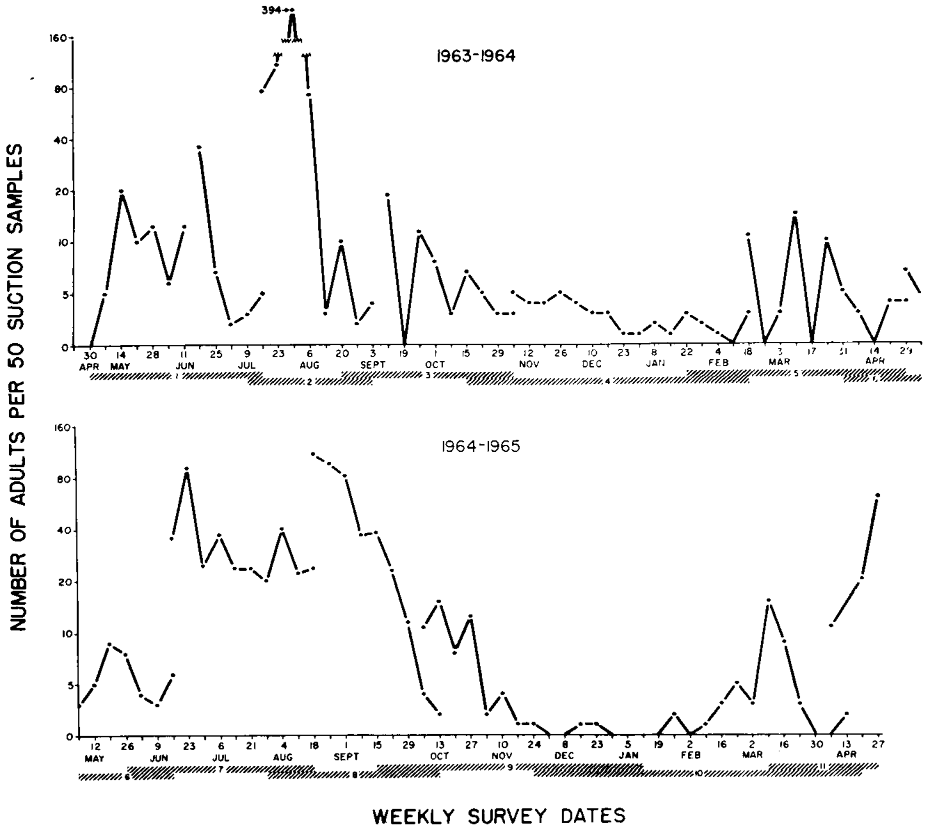

Fig. 31. Population trends of cabbage leafminer adults on cabbage during 1963–1965 study. Successive cabbage plantings shown by numbered horizontal bars.

CONCLUSIONS

As an ecological community in a pesticide-free environment, cabbage supports an extensive and varied insect fauna in southern California with the cabbage aphid, imported cabbageworm, cabbage looper, and diamondback moth the predominating phytophagous species. Each of these four species are attacked by several species of natural enemies, some of which are quite specific. However, this study indicates that when conditions are favorable, insect populations on cabbage plants increase to levels which require supplemental control measures to prevent severe injury to the plants. Cabbage grown during August and September are particularly subject to injury by the imported cabbageworm and cabbage looper (fig. 32), and that grown in February and March by the cabbage aphid. In general, it appears that commercial production of cruciferous crops in southern California is not economically feasible without applications of pesticides to control aphids in winter and spring and lepidopterous larvae in summer and fall.

Biological control of the cabbage aphid offers little promise, since most of the natural enemies usually associated with the species, including the principal

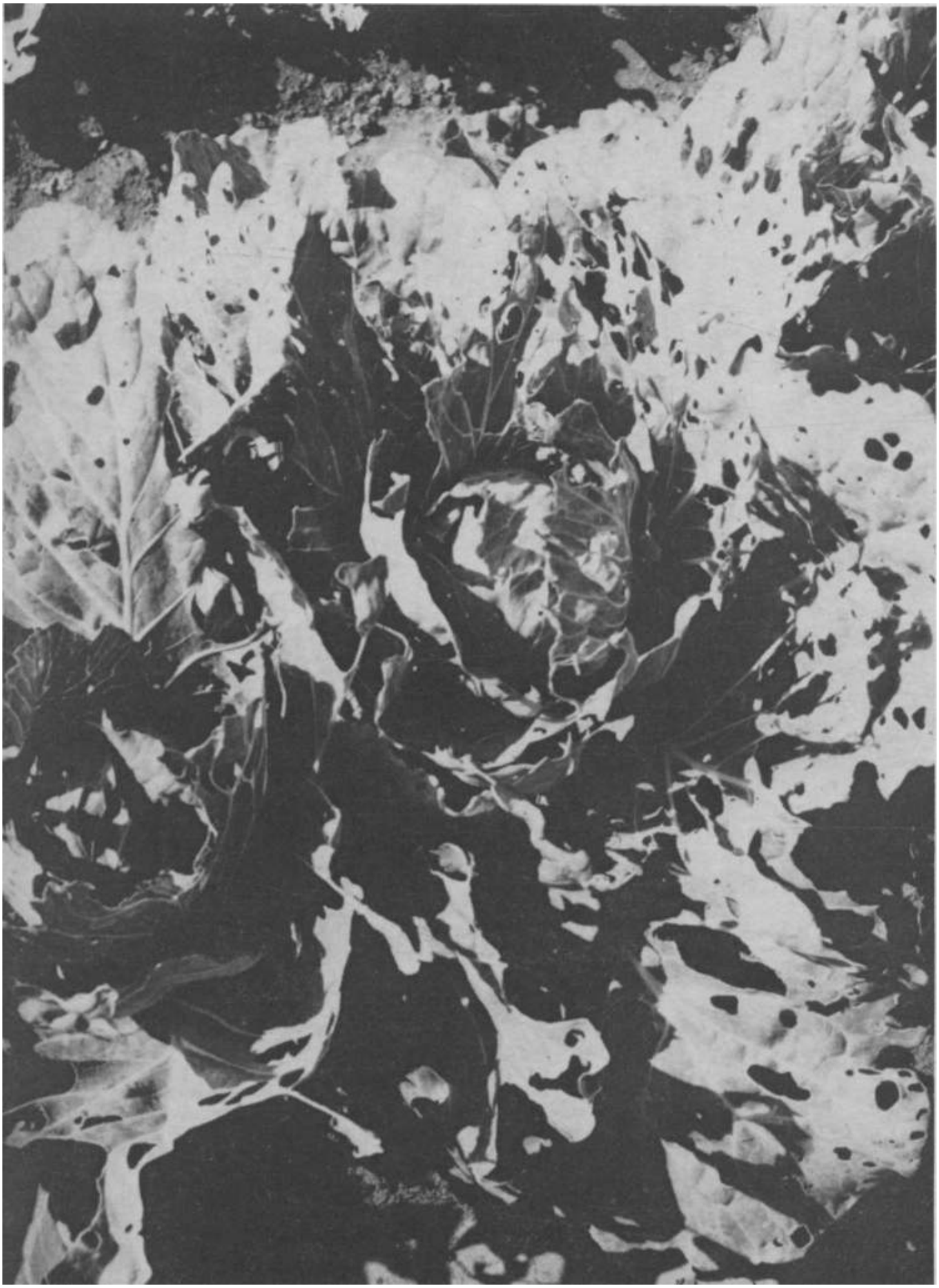

Fig. 32. Cabbage plants severely injured primarily by feeding of imported cabbageworm and cabbage looper larval populations in September.

parasite in its native area, are already present. However, populations of the imported cabbageworm and diamond-back moth could be further reduced with the establishment of more effective natural enemies. This, together with the conservation and augmentation of those affecting the native cabbage looper, would aid materially in developing an effective, integrated control program for cruciferous crops in southern California.

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