Fruit Fly Parasites and Their Activities in Hawaii[1]

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(*Submitted for publication July, 1960*)

Intensive studies were made of the progress and status of the several entomophagous insects released in Hawaii to combat the Oriental fruit fly, *Dacus dorsalis* Hendel, the melon fly, *Dacus cucurbitae* Coquillett, and the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann). These studies were deemed essential to the effective development of the cooperative biological control program which was initiated in 1948. A total of 32 entomophagous species and varieties were released between 1947 and 1952 to supplement those which have been established here for many years (table 1). Thirteen of the recently-introduced species were recovered but only three, *Opius longicaudatus* (Ashmead)[4], *O. vandenboschi* Fullaway, and *O. oophilus* Fullaway, became widespread and abundant.

This paper presents an account of the progress of the recently released entomophagous insects which attack tephritid fruit flies, together with information about the status of those parasites which were present before the establishment of *D. dorsalis*.

PROCEDURE AND METHODS

Since all the parasites complete their development in and emerge from fruit fly puparia, their progress was followed by determining the parasite emergence from samples of puparia formed from maggots obtained from field collected fruits. Furthermore, since practically all the parasites attack and lay their eggs either in the eggs or maggots of the fruit flies, this made it practical to either remove the maggots from the fruits or recover the full grown maggots on emergence from the fruits. Most of the data obtained on the progress of the parasites were derived from fruits in the manner described below, however, field

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[1] Published with the approval of the Director of the Hawaii Agricultural Experiment Station as Technical Paper No. 318.

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[3] The authors are grateful to the many individuals in the Entomology Department of the University of Hawaii and those associated with the several cooperating agencies who have aided in this study.

[4] Fullaway (1953) described 4 varieties of *Opius longicaudatus* (Ashmead). The variety *malaiaensis* is the only one of the 4 that became numerous and unless stated otherwise, subsequent references to *O. longicaudatus* in this paper are to that variety.

TABLE 1. Parasites and predators released[1] in Hawaii from 1948 to 1952 to combat fruit flies.

	1948	1949	1950	1951	1952
Coleoptera					
Staphylinidae					
Thyreocephalus albertisi (Fauvel)	78	244	1,152		
Hymenoptera					
Braconidae					
Bracon fletcheri Silvestri			1,693		
Opius anastrephae (Viereck)[2]				231	
Opius angaleti Fullaway				1,764	
Opius bellus Gahan[2]				421	
Opius cereus Gahan[2]				1,044	
Opius compensans (Silvestri)				22,951	18,837
Opius deeralensis Fullaway			1,969		
Opius fijiensis Fullaway			247		
Opius fletcheri Silvestri				1,123	
Opius formosanus Fullaway			13,315	23,417	18,578
Opius incisi Silvestri	1,427	24,927	29,525	1,675	
Opius kraussi Fullaway			3,362	2,754	5,170
Opius longicaudatus var. *malaiaensis* Fullaway	41,772	78,679	9,985		
Opius longicaudatus var. *chocki* Fullaway			2,035		
Opius longicaudatus var. *novocaledonicus* Fullaway			5,630	14,080	18,953
Opius longicaudatus var. *taiensis* Fullaway				8,203	17,240
Opius makii Sonan				1,180	
Opius oophilus Fullaway[3]			4,275	937	
Opius persulcatus (Silvestri)[2]				1,115	
Opius phaeostigma Wilkinson				328	
Opius skinneri Fullaway					
Opius vandenboschi Fullaway[4]	1,547	18,643	8,024	200	
Opius watersi Fullaway			114,662	100	
Hedylus giffardii Silvestri, *Opius concolor* Szepligeti, *Opius vevesi* Brues		4,396			
Chalcididae					
Dirhinus giffardii Silvestri			68,053	700	
Cynipidae					
Trybliographa daci Weld		1,765	13,528	14,583	5,140
Eulophidae					
Syntomosphyrum indicum Silvestri[5]			8,800	67,300	127,700
Tetrastichus dacicida Silvestri			19,845		
Tetrastichus giffardianus Silvestri			21,490	12,744	

[1] Entomologists employed by the State Board of Agriculture and Forestry were responsible for releases and kindly supplied these data.

[2] First introduced in 1936.

[3] Confused with *vandenboschi* until 1950.

[4] Apparently mixed with *oophilus*.

[5] Three small lots of this parasite were liberated in 1938.

observations on parasite adults were also useful, especially during the first few months after releasing the parasites. The methods of study were modified from time to time as the work progressed, therefore, it seems reasonable to describe them in the order in which they were developed.

Immediately following the first large-scale releases of parasites in the summer and early fall of 1948, following the small releases of 1947, periodic observations were made of adult parasites at the release points on Oahu, but very few fruits were collected for several weeks. However, parasite recoveries were made from the few fruits collected, and it was soon evident from the enormous numbers of adult parasites seen near the release points that the parasites were developing in fruit fly maggots in the field. The rapidity of spread of the parasites around these release points was studied during the fall and winter of 1948 by searching for adult parasites at intervals of ¼ mile in different directions away from the release points. These adult parasite observations made it possible to obtain information on the increase and spread of the parasites during these first few months when it was deemed inadvisable to collect fruits.

In December, 1948, nearly 5 months after the first extensive parasite releases, collections of various kinds of fruits were begun on a systematic basis at a number of points on the island of Oahu. Since November, 1949, the fruit collections have been largely restricted to guava (*Psidium guajava* L.) taken at established collection points. Guava covers vast acreages of uncultivated land and the fruits are a favored fruit fly host. Furthermore, guava fruits are available in varying abundance throughout the year. For these reasons the bulk of the data presented in this paper were obtained from guavas. On Oahu the fruit collections were made at monthly intervals, while on Hawaii, Kauai, Lanai, Maui, and Molokai they were made less frequently. In addition to the guava collections, coffee berries (*Coffea arabica* L.) were collected at three points in Kona, Hawaii, monthly from August, 1949 through December, 1953. Many supplementary collections of other fruits such as balsam apple (*Momordica balsamina* L.), false kamani (*Terminalia catappa* L.), Jerusalem cherry (*Solanum pseudocapsicum* L.), loquat (*Eriobotrya japonica* (Thunb.) Lindl.), mango (*Mangifera indica* L.), papaya (*Carica papaya* L.), peach (*Prunus persica* (L.) Batsch.), rose apple (*Eugenia jambos* L.), and Surinam cherry (*Eugenia uniflora* L.) were also made to obtain information on parasitization of fruit fly maggots within all kinds of fruits on all the islands. However, these collections of miscellaneous fruits were not as well standardized as were those of guavas.

The regular guava collections were usually composed of freshly fallen ripe fruits. Occasionally, when fruits were scarce and unobtainable from the ground, ripe fruits were collected from the trees.

During the first several months after fruit collecting was begun, large numbers of fruits were collected at each point, but as time progressed smaller collections were found to be feasible. The reduction in the size of the collections was due in part to the change in methods of handling the fruits in the insectary. At first,

TABLE 2. Summary of data obtained from regular guava collections made on Oahu, 1948 to 1953.

	1948	1949	1950	1951	1952	1953
Number of fruit collections	16[1]	165	321	325	341	599
Number of collections that contained *D. dorsalis* maggots	16	165	303	242	263	....
Percentage of fruits infested	....	....	53	37	37	47
Number of maggots per fruit	9.0[2]	11.9[2]	5.8	2.5	2.9	6.6
Number of flies emerged	1,323	25,113	16,969	2,927	3,177	3,496
Number of parasites emerged						
O. longicaudatus var. *malaiaensis*	158	4,428	1,972	138	64	2
O. vandenboschi	4	4,092	10,583	196	7	8
O. oophilus	0	10	12,034	10,256	6,829	6,969
O. incisi	0	8	30	66	31	14
O. compensans	0	0	0	1	0	0
O. longicaudatus var. *novocaledonicus*	0	0	0	2	44	12
O. tryoni	0	0	0	0	0	1
Total parasites	162	8,538	24,619	10,659	6,975	7,006
Per cent parasitization	11	25	59	78	69	67

[1] All 16 collections were made during December.
[2] Based on puparia recovered from fruits held by the bulk holding box method. The number of maggots present in the fruits at the time of collection was without doubt several times that of the puparia recovered.

the fruits were placed on coarse wire screen inside wooden "holding boxes" with sand in the bottom into which the larvae entered and formed puparia after emerging from the fruits. Two to three times a week the sand was sifted and the puparia and maggots removed, placed in vials, and held until the adult flies and parasites emerged. However, there was considerable mortality among the larvae and puparia, and a better rearing method was sought.

Eventually a method was devised whereby the fruits were dissected and the maggots removed and reared in a papaya medium. The maggots were counted when they were transferred to the rearing medium, and a record was made of the infested and noninfested fruits. These collections of maggots were reared in a controlled temperature room (80–85° F.). The number of fruits collected for dissection from each point varied considerably but was often as many as 100 when the method was first adopted. Later only 20 fruits were used as a sample from each point.

A further change was made in the sampling methods on Oahu in January 1953. The number of collection points was increased from 40 to a total of 60, and the number of fruits collected at each point reduced to 4. These were dissected and the maggots held in the manner described above; in addition, the fragments of the dissected fruits were held to recover individuals missed during dissection. The data obtained from these 4-fruit samples were useful in constructing an index of the parasitization on Oahu as a whole, but they could not be used to determine the parasitization or larval population per fruit at each collection point.

The miscellaneous fruit collections (peaches, coffee, kamani, etc.) were held for adult parasite and fly emergence by the method referred to locally as the "USDA funnel method." The fruits were placed in a large funnel-shaped hopper held in place with a rubber gasket over a 5-quart jar which contained sand and a small jar placed directly underneath the tip of the funnel to catch the liquid that dripped from the fruits. The adult flies and parasites emerged in the jars and were usually not removed and counted until they had died. There was less mortality in rearing containers of this type than in the bulk holding boxes.

Puparia were also collected from the soil in several localities to obtain further information on parasitization. In addition, decomposing fruits and litter were examined to determine whether the predaceous staphilinid beetle, *Thyreocephalus albertisi* (Fauvel), was established.

Recoveries

Of the 32 entomophagous insects released since 1947 to combat the three species of fruit flies present in Hawaii, the following have been recovered: *Opius vandenboschi*, *O. oophilus*, *O. longicaudatus* var. *malaiaensis* Fullaway, *O. longicaudatus* var. *taiensis* Fullaway, *O. longicaudatus* var. *novocaledonicus* Fullaway, *O. incisi* (Silvestri), *O. watersi* Fullaway, *O. formosanus* Fullaway, *O. compensans* (Silvestri), *O. kraussi* Fullaway, *Tetrastichus dacicida* Silvestri, *Syntomosphyrum indicum* Silvestri, and *Thyreocephalus albertisi* (Fauvel). The first three parasites were recovered in large numbers from both *D. dorsalis* and *C. capitata*.

In addition to the above, the following parasites, which were introduced in 1913–14 to combat *C. capitata* and in 1916 to combat *D. cucurbitae*, were recovered during the course of study: *O. tryoni* (Cameron) and *O. fullawayi* (Silvestri) from *C. capitata; O. fletcheri* Silvestri from *D. cucurbitae*; and *Tetrastichus giffardianus* Silvestri, *Spalangia philippinensis* Fullaway, and *Dirhinus giffardii* Silvestri from all three species of fruit flies. Some of these, particularly *T. giffardianus*, *D. giffardii*, and *O. fletcheri*, have been reported to be established for a number of years. However, they were re-introduced during this recent campaign.

History of Parasitization and Status of Parasites

Only three species of parasites; *Opius longicaudatus*, *O. vandenboschi*, and *O. oophilus*, in that order, became readily established, increased rapidly, and spread to adjacent areas soon after they were released. The others which were introduced either failed to become established or have never become abundant. The progress and history of parasitization by the different parasites, which were followed closely on Oahu and less intensively on the other islands, are discussed below.

O. longicaudatus was the first of the parasites to become numerous. About 41,000 adults of this species were liberated in the Hawaiian Islands during 1948, mostly in guava areas. During the fall of 1948, guava fruits were abundant and heavily infested with *D. dorsalis*, which undoubtedly provided favorable conditions for immediate establishment and increase in abundance of *O. longicaudatus*. Adults were readily observed in the immediate vicinity of the liberation sites within a few weeks after the releases, and had spread at least ¼ mile within 2 months and 1 to 4 miles in 4 months. Of the 16 fruit collections made at and near release points in December, 1948, ten (over 50 per cent) produced this parasite. At this time two or more adults were often seen on individual fruits throughout the island of Oahu, and they were so abundant throughout the Hawaiian Islands by the summer of 1949 that further mass breeding of this species for release was deemed unnecessary. Between December, 1948 and August, 1949, parasitization, as determined by fly and parasite emergence from guava fruits on Oahu, averaged about 20 per cent, primarily by *O. longicaudatus*. However, there was a gradual decline in the abundance of *O. longicaudatus* when *O. vandenboschi* became numerous in the fall of 1949, and since November, 1950, it has made up less than 1 per cent of the parasites reared from collections of coffee and guava fruits (table 3 and figure 1).

Although *O. vandenboschi* was released before *O. longicaudatus*, it increased and spread more slowly than the latter. This may be attributed to the smaller numbers of the former species released in 1948. By June, 1949, *O. vandenboschi* had spread at least 1 mile in the Kaneohe area and 2 miles in the Waimanalo area on Oahu. During the late spring and summer of 1949, this species was extremely numerous in several guava areas. In these localities hundreds of adults, predominantly males, were seen hovering over and resting on low vegetation. By the end of 1949, this species occurred in over 90 per cent of the guava samples collected, and it remained the predominant parasite for the next 8 months (figure 1).

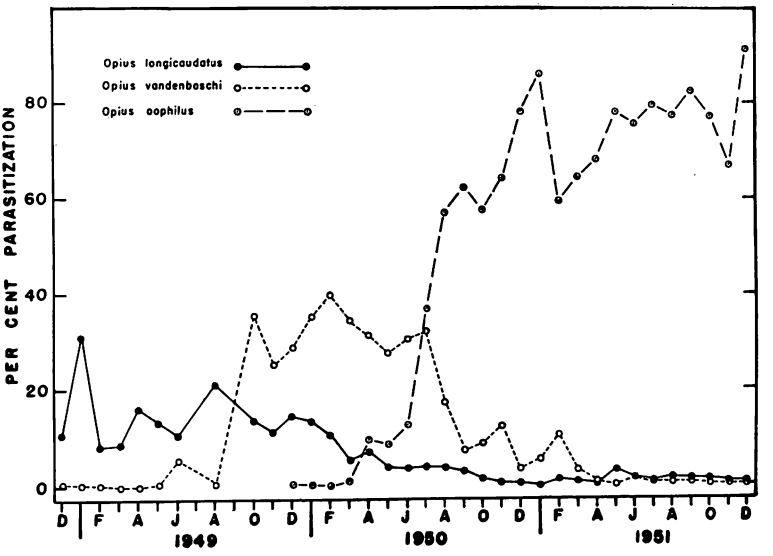

FIG. 1 Successive changes in predominance of three parasites of *D. dorsalis*.

Total parasitization averaged 45 per cent between September, 1949 and June, 1950, and *O. vandenboschi* alone parasitized about 30 per cent of the maggots (figures 1 and 2). Populations of *O. vandenboschi* dropped abruptly in the fall of 1950, concurrently with the sudden increase in abundance of *O. oophilus*, and since the spring of 1951 parasitization by the former has been less than 1 per cent (figure 1).

O. oophilus was not recognized as a distinct species until several months after it had already become established on Oahu (van den Bosch and Haramoto, 1951). This parasite had spread rapidly following its recovery in December, 1949, and was present in over 50 per cent of the guava collections made in April, 1950. By July, 1950, it had become the dominant parasite and was present in over 90 per cent of the guava collections made at that time. There was a decided step-up in parasitization when *O. oophilus* became prevalent, and from August, 1950 to February, 1954, total parasitization averaged around 70 per cent, most of which was due to this species (figures 1 and 2).

The information obtained from the less frequent guava collections made on the other islands indicates that the progress, successive changes in the status, and history of parasitization of the three parasites followed a pattern similar to that on Oahu. However, developments on these islands lagged a few months behind those on Oahu, probably due to the greater number of parasites released on Oahu during the early months of the program. The parasitization of *D. dorsalis* in guava fruits on the islands of Hawaii, Maui and Molokai is shown in figure 3.

TABLE 3. Emergence data from coffee fruits collected monthly[1] at Captain Cook (2,500 feet elevation), Kona, Hawaii.

	Number of puparia	*D. dorsalis*	*C. capitata*	*O. fullawayi*	*O. longi-caudatus*	*O. tryoni*	*O. vanden-boschi*	*O. oophilus*	Percentage parasitization
1949									
Aug.-Sept.	110	3	53	5	4	...	...	...	14
Oct.-Dec.	323	72	212	24	6	...	...	...	10
1950									
Jan.-Mar.	506	109	248	27	67	1	3	...	22
Apr.-June	393	54	236	25	36	4	20	...	23
July-Sept.	267	3	163	26	26	...	14	3	29
Oct.-Dec.	272	...	54	63	10	1	1	12	36
1951									
Jan.-Mar.	675	7	282	63	1	...	32	196	50
Apr.-June	200	5	68	2	...	...	4	90	57
July-Sept.	28	...	6	2	...	...	...	14	73
Oct.-Dec.	8	...	6	...	...	...	...	2	25
1952									
Jan.-Mar.	106	...	38	...	...	...	...	66	63
Apr.-June	107	1	39	...	...	...	...	62	61
July-Sept.	70	...	18	...	...	...	...	57	72
Oct.-Dec.	39	...	6	...	...	...	...	32	84
1953									
Jan.-Mar.	126	2	36	...	...	...	...	84	69
Apr.-June	103	4	24	1	1	...	...	68	71
July-Sept.	27	...	3	...	...	...	...	21	88
Oct.-Dec.	20	...	7	...	...	...	...	13	65

[1] Each monthly collection contained 300 coffee fruits, therefore, each quarter as summarized above contained 900 fuits, except in the August-September 1949 collections, which contained only 600 berries.

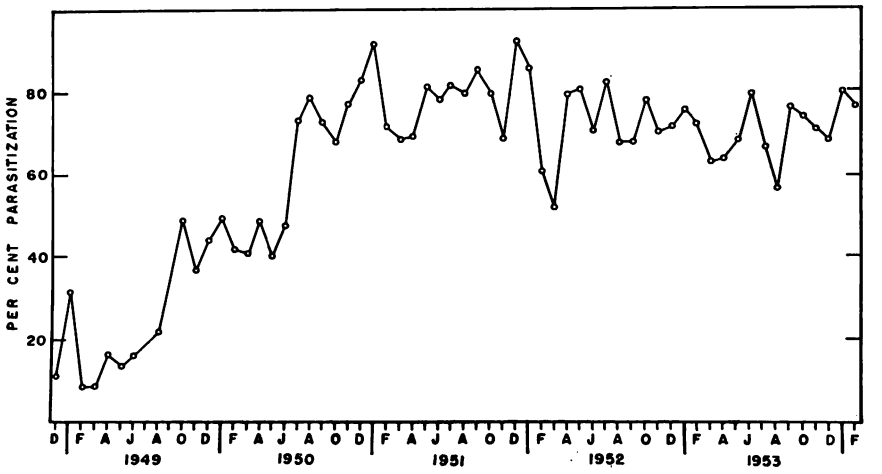

FIG. 2. Parasitization of *D. dorsalis* in guava fruits on Oahu.

Each of the three above-mentioned *Opius* species was reared from many kinds of fruits infested by *D. dorsalis* and/or *C. capitata*. In fruits where there was a preponderance of *C. capitata*, parasitization by these three species was similar to that in fruits where *D. dorsalis* was the only fly involved (tables 2 and 3). Laboratory studies have shown that the three important parasites of *D. dorsalis* can develop successfully on *C. capitata*, but not on *D. cucurbitae* (Clancy, 1951; Nishida and Haramoto, 1953). The successive replacement of one species by another which took place in guava fruits also occurred in other kinds of fruits, but parasitization (total and by each species) was usually higher in certain fruits than in others. For example, after *O. oophilus* assumed the predominant role in all kinds of fruits, *O. longicaudatus* and *O. vandenboschi* were recovered more frequently from fruits such as mango and false kamani than from guava or coffee. This indicates a certain degree of fruit preference on the part of the individual species of *Opius*.

Other species of parasites, such as *O. incisi*, *O. formosanus*, *O. compensans*, and *S. indicum*, although known to be established, have parasitized less than 1 per cent of the several thousands of *D. dorsalis* and *C. capitata* maggots reared from all kinds of fruits. *O. incisi* was liberated in larger numbers and over a longer period of time than *O. vandenboschi* and *O. oophilus* combined, but it was never recovered in large numbers. However, rearings from rose apple and Surinam cherry have yielded a relatively high proportion of *O. incisi*.

Some of the reported recoveries are questionable establishments since they may have been only first generation progeny of the adults released. One such species is *O. watersi* Fullaway, a parasite of *D. cucurbitae* introduced from India, which was mass bred in the laboratory for many generations and released in

large numbers on all of the main islands. A few early recoveries of this species were reported from one locality (Marucci, 1952), but it does not appear to have become permanently established.

Of the fruit fly parasites released prior to 1947, *O. fletcheri* remains as the only one of significance. *O. fletcheri*, introduced and established in Hawaii in 1916 (Willard, 1920), was found to parasitize between 20 and 40 per cent of *D. cucurbitae* maggots in wild *Momordica* fruits collected from a number of places on Oahu during 1950 and 1951. However, it was seldom recovered from infested fruits of cultivated plants. Several specimens of the long-established opiines, *O. tryoni* and *O. fullawayi* (but none of *O. humilis* Silvestri) were reared from

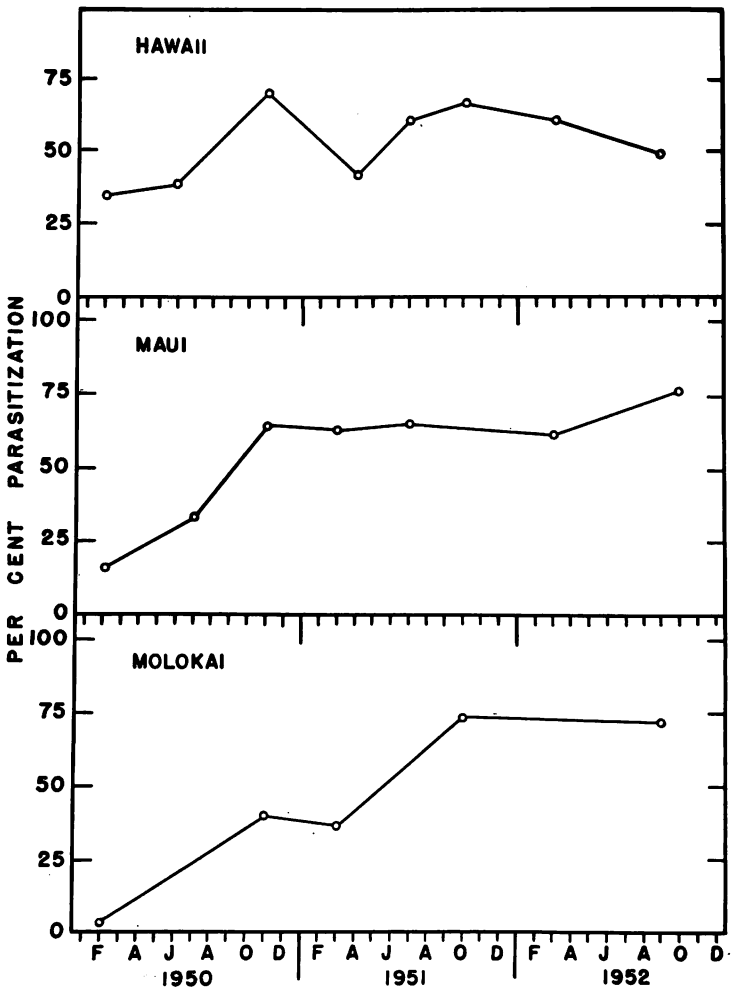

FIG. 3. Parasitization of *D. dorsalis* in guavas on Hawaii, Maui, and Molokai.

C. capitata infested fruits collected between 1948 and 1953. Up to about the end of 1950, before *O. oophilus* became the predominant parasite of *C. capitata*, both *O. tryoni* and *O. fullawayi* were readily recovered from such fruits as coffee (table 3) and peach. Since then they have become extremely scarce and have accounted for less than 1 per cent parasitization. At one time *O. tryoni* was suspected of developing on *D. dorsalis*, as females of this species were frequently observed probing in fruits infested solely by that fly. Subsequent investigations revealed that *O. tryoni* cannot develop in maggots of *D. dorsalis* as its eggs become encysted within the host larvae soon after deposition. It was found that most of the adults observed in the field were developing on *Eutreta xanthochaeta* Aldrich and *Procecidochares utilis* Stone, two tephritid gall flies which attack weeds commonly found growing in the same general area as the host plants of *D. dorsalis* and *C. capitata*.

Summary

The progress of the several parasites recently introduced into Hawaii to combat fruit flies [*Dacus dorsalis* Hendel, *D. cucurbitae* Coquillett, and *Ceratitis capitata* (Wiedemann)] was followed closely month by month on Oahu and less intensively on the other islands. Guava fruits from established collecting points were used for the basic quantitative studies on the establishment, increase, spread, and status of the parasites involved. Guava fruits were used because they are a good host of both *D. dorsalis* and *C. capitata*, are available throughout the year, and occur on vast areas of uncultivated land under diverse ecological conditions on all the islands. In addition, many collections of various kinds of fruits were made to obtain supplementary information. The information obtained from the monthly guava collections on Oahu gave a comprehensive picture of the progress of the different parasites on this island, and guava collections from the outer islands made two to three times a year indicated that the progress of the parasites on the other islands was, in general, similar to that on Oahu.

A total of 32 species and varieties of fruit fly enemies were released between 1947 and 1952. Thirteen of these were recovered, but only three, *Opius longicaudatus* var. *malaiaensis* Fullaway, *O. vandenboschi* Fullaway, and *O. oophilus* Fullaway, became abundant on *D. dorsalis* and *C. capitata*.

O. longicaudatus, a parasite of second and third instar maggots, became abundant at the release points within 2 months after the first releases were made in August 1948, and by the following summer it was widespread and abundant on all the islands. *O. vandenboschi*, a parasite of first instar maggots, was first released in July 1948. This parasite was recovered only in small numbers during the next several months, but in the fall of 1949 it became widespread and abundant throughout the islands. The first known recovery of *O. oophilus*, an egg-larval parasite, was made in December, 1949, but it is not known when this species was initially released, as it was confused for some time with *O. vanden-*

boschi. *O. oophilus* spread rapidly in the spring and summer of 1950, and became abundant throughout Hawaii that fall.

Not only did the above species become widespread and abundant in the order mentioned, but *O. longicaudatus* decreased in abundance following the increase of *O. vandenboschi* and the latter species became scarce soon after the increase of *O. oophilus*. From the spring of 1951 to February of 1954 *O. oophilus* accounted for well over 90 per cent of the total parasitization of *D. dorsalis* in guavas and averaged around 70 per cent for the period. Parasitization of *C. capitata* was considerably higher than it was prior to the introduction of these important *D. dorsalis* parasites. None of the parasites, other than *O. fletcheri* Silvestri, has been effective on *D. cucurbitae*. At one time there was considerable optimism about *O. watersi* Fullaway, many thousands of which were reared in the laboratory and released, but it apparently failed to become established.

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