Biological Control of Pamakani, *Eupatorium adenophorum*, in Hawaii by a Tephritid Gall Fly, *Procecidochares utilis*. 3. Status of the weed, fly and parasites of the fly in 1966-71 versus 1950-57[1]

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Pamakani, *Eupatorium adenophorum* Spreng., was introduced into the Ulupalakua area on the Island of Maui, Hawaii, by Captain James Makee about 1860 as an ornamental (Baldwin, 1956) but subsequently became a rangeland and roadside weed in many localities on the island in fairly moist to wet habitats from sea level to about 7,000 feet elevation and spread to the other major islands except to Kauai (Hosaka and Thistle, 1954). For many years mechanical methods were used to reclaim land overrun by the weed, but in 1945 a tephritid gall fly, *Procecidochares utilis* Stone, now known as the eupatorium gall fly, was introduced from Mexico by entomologists of the then Territorial Board of Agriculture and Forestry to combat the weed and it proved to be so effective that mechanical methods were discontinued. The biology of the fly and its progressive effects in reducing the abundance of the weed have been studied since 1949 and much of the information obtained during 1949–57 published in two papers (Bess and Haramoto, 1958; 1959). Four hymenopterous parasites commonly attack this introduced fly in Hawaii and very high parasitization occurs in some localities, especially during the summer and fall seasons.

The present paper, the third in a series on the biological control of pamakani by the authors, is concerned with the status of the weed, the fly and its parasites during the 1966–71 period and the comparison of it with that of the 1950–57 period.

METHODS

Attempts were made to collect samples of galls containing immature *P. utilis* and its parasites during the 1966–71 period semi-annually, January-April and June-October, from the same localities sampled in a similar manner during the earlier period. However, due to the elimination of *E. adenophorum* at several of the former sampling stations by the fly, galls could not be obtained in them during the 1966–71 period. In most cases each sample contained more than 100 galls. The galls were kept in the

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insectary on the University of Hawaii Campus for development and emergence of the adults of *P. utilis* and its parasites. Upon emergence, the adults were identified, sexed and their numbers recorded. In addition to the gall collections, population data on *P. utilis* eggs and galls were obtained in August, 1971 from Keanae, Kanaio, Iao Valley and Waihou on Maui where similar data were obtained in July, 1957. From each of these localities 100 six-inch terminals were collected at random, later examined under a microscope and the number of *P. utilis* eggs recorded for each terminal. The data on the intensity of galling caused by *P. utilis* were based on the total number of old and fresh galls on the terminal 6 inches of the stems on the plants within a 5 × 5-foot plot of pamakani at each of the above localities.

Results

The Weed, Pamakani

Pamakani has been gradually reduced in size and number of plants and eventually eliminated during the past 25 years in many areas by *P. utilis*, while in others no apparent change has taken place. It has not grown back on land freed of the weed, nor has it spread into new areas since about 1950.

The gradual elimination of the weed along the Hana-Kipahulu Coast and on the leeward slopes of Haleakala in the Waihou area has been

FIG. 1. Hillside at approximately 4,000 feet in elevation at Waihou on the Ulupalakua Ranch densely covered with pamakani. Photograph taken in 1949.

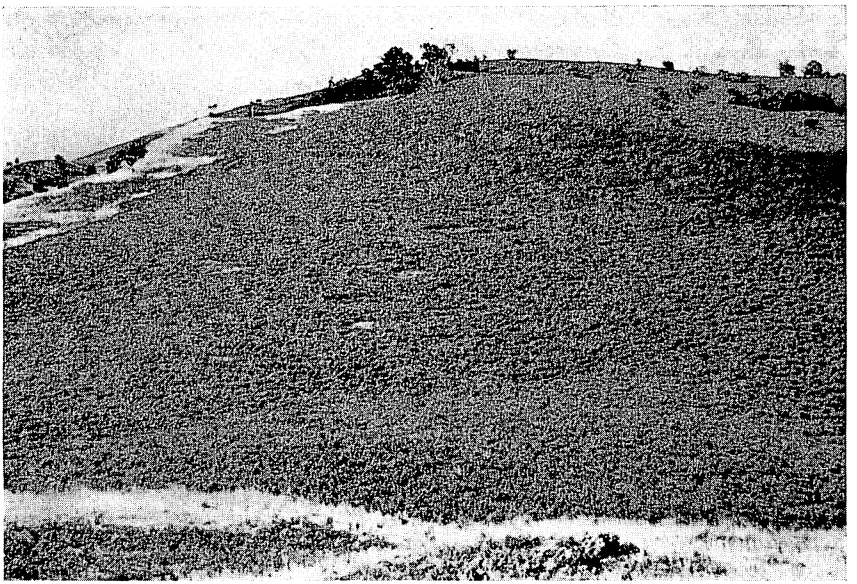

FIG. 2. Same hillside in 1957 as shown in Fig. 1. Density of pamakani considerably reduced, plants stunted and eliminated in places by *Procecidochares utilis*.

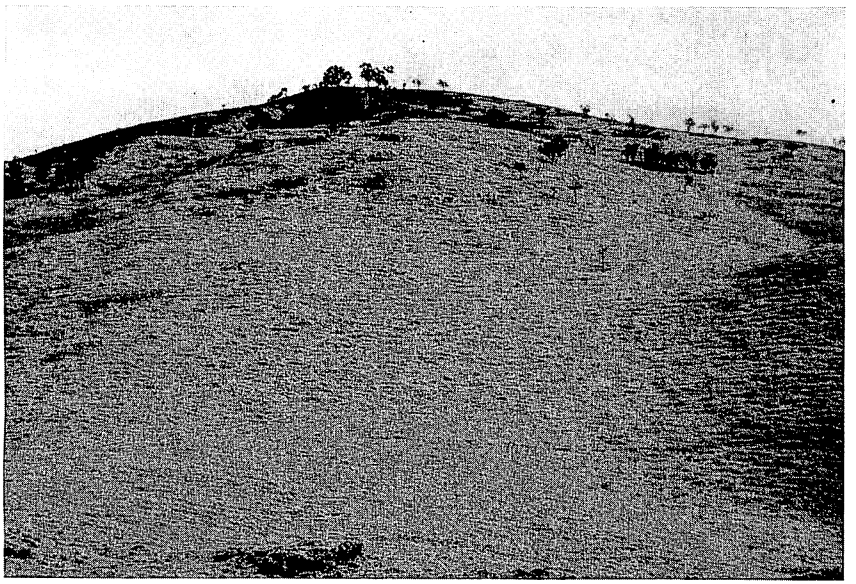

FIG. 3. Same hillside in 1971 as shown in Figs. 1 and 2. Pamakani plants completely eliminated by *Procecidochares utilis* and now covered by kikuyu grass.

particularly spectacular. Although several collections were made along the Hana-Kipahulu Coast in the 1950–57 period, the last collection was made near Kipahulu with difficulty in 1959 and not a single plant could be found in 1971. In the Waihou area dense stands of the weed covered the hillside from an elevation of 2,500 feet and above in 1949 (Fig. 1), but by 1957 many of the plants had become reduced in size or had been completely eliminated (Fig. 2) and in 1971 not a single pamakani plant could be found in the area between 2,500 to 5,000 feet in elevation. Consequently, in order to get samples in 1971 it was necessary to go further up the northerly slope of the mountain with the aid of a 4-wheel drive vehicle to an elevation of approximately 5,500 feet. At this site there were dead plants, obviously killed by *P. utilis*, and the remaining living ones were heavily galled, stunted and relatively sparse, less than 1 plant per 500 square feet.

Pamakani continues to persist as stunted individual plants and in small clumps with many dead stems killed by *P. utilis* (Fig. 4) at an elevation of around 2,000 feet in the Kanaio-Ulupalakua area. In this area plants are now confined primarily to gullies and depressions, but during the 1950–57 period isolated plants in a similar stunted condition were also common outside the gullies and depressions. There were 5 to 6 six-inch or longer stems per square foot in August, 1971, about one-half what it was in July, 1957.

FIG. 4. Clump of pamakani plant in a gully at Kanaio that has been under persistent attack by *Procecidochares utilis* for several years. Note the many dead stems due to the activities of the fly.

Photograph taken in 1971.

Along the Haiku-Hana Coast and in Iao Valley pamakani continues to grow luxuriantly in many of the gulches and along roadsides at about the same status as it did during the 1950–57 period. In the denser stands found in these areas in August, 1971, there were 15 to 18 six-inch or longer stems per square foot and the tallest plants were 54 to 60 inches in height.

In addition to the above differences in the growth and condition of pamakani in the different localities, pronounced differences in flowering and "flushes" in the growth of the plants were observed. The plants along the Haiku-Hana Coast and in Iao Valley were growing vigorously and had relatively few flowers. On the other hand the plants at Kanaio-Ulupakalua and Waihou had distinct "flushes" of new growth and flowering was seasonal and profuse.

The Eupatorium Gall Fly

The eupatorium gall fly was well established and widespread by the time the first samples of galls were collected on Maui in 1949, Lanai, Molokai and Oahu in 1951 and Puuwaawaa, Hawaii in 1952. It has

TABLE 1. *Summary of flies and parasites reared from gall samples from 4 localities on Maui in* 1966–71 *and* 1950–57.

Locality	*Number of adults obtained from samples*					
	Proceci-dochares utilis	*Eupelmus cushmani*	*Eurytoma tephritidis*	*Bracon terryi*	*Opius tryoni*	*Total*
		1966–71				
Haiku-Hana						
Jan.–Apr.	1075	53	260	99	0	1487
June–Oct.	399	284	474	399	0	1556
Iao Valley						
Jan.–Apr.	452	13	32	30	0	527
June–Oct.	39	289	148	112	0	588
Kanaio-Ulupalakua						
Jan.–Apr.	830	807	328	952	49	2966
June-Oct.	152	422	222	400	6	1202
Waihou						
Jan.–Apr.	68	0	0	5	0	73
June–Oct.	126	2	1	311	0	440
		1950–57				
Haiku-Hana						
Jan.–Apr.	1965	282	186	560	0	2993
June–Oct.	1456	635	264	920	1	3276
Iao Valley						
Jan.–Apr.	1962	135	271	448	0	2816
June–Oct.	101	285	200	177	0	763
Kanaio-Ulupalakua						
Jan.–Apr.	2195	138	340	2121	0	4794
June–Oct.	1055	542	1273	795	0	3665
Waihou						
Jan.–Apr.	8528	57	199	4208	0	12992
June–Oct.	4973	77	173	1899	0	7122

FIG. 5. Stem of pamakani galled by *Procecidochares utilis* from Iao Valley, Maui. Note that the galls are small, simple, and widely distributed on the stem.

FIG. 6. Stem of pamakani galled by *Procecidochares utilis* from Kanaio, Maui. Note that the galls are massive, coalesced and close to each other.

TABLE 2. *Relative abundance of* P. utilis *eggs at* 4 *localities on Maui, August* 1971 *and July* 1957.

Locality	*Percent of tips of main stems with* 1 *or more eggs*		*Number of eggs per tip of main stem*	
	August 1971	*July* 1957	*August* 1971	*July* 1957
Keanae	33	20	1.4	.7
Iao Valley	9	20	.3	.4
Kanaio	49	—	2.5	—
Waihou	93	90	9.5	6.7

been present in varying abundance for the past two decades in all localities where pamakani has persisted and many thousands of flies have been reared from samples of galls (Table 1).

Indices of *P. utilis* abundance based on eggs and galls obtained in August, 1971, at the localities on Maui where similar samples were obtained in July, 1957, varied between localities but were essentially the same at each in 1971 as in 1957. Ninety per cent of the terminal stems at Waihou contained eggs between the young paired leaves at the growing tip, with an average of 9.5 eggs per tip. About 50 per cent of the tips at Kanaio contained eggs, with an average of 2.5 eggs per tip. In contrast, at Keanae and Iao Valley egg abundance was less than 15 per cent of that at Waihou (Table 2). Gall abundance was also directly related with egg abundance. At Waihou and Kanaio 95 and 99% of the stems contained 1 or more galls with an average of 5.2 and 5.4 galls per stem, while at Iao Valley and Keanae 68 and 30% of the stems were galled with an average of 1.3 and 3 galls per stem, respectively. Galled stems typical of those in the

TABLE 3. *Parasitization by different parasites at* 4 *localities on Maui during different seasons and periods,* 1966–71 *and* 1950–57.

Locality	*Percent parasitized*[1]									
	Eupelmus cushmani		*Eurytoma tephritidis*		*Bracon terryi*		*Opius tryoni*		*Total*	
	1966 –71	1950 –57	1966 –71	1950 –57	1966 –71	1950 –57	1966 –71	1950 –57	1966 –71	1950 –57
Haiku-Hana										
Jan.–Apr.	3.6	9.4	17.5	6.2	6.7	18.7	0	0	27.7	34.3
June–Oct.	18.3	19.4	30.5	8.1	25.6	28.1	0	0.03	74.4	55.6
Iao Valley										
Jan.–Apr.	2.5	4.8	6.1	9.6	5.7	15.0	0	0	14.2	30.3
June–Oct.	49.1	37.4	25.2	26.2	19.0	23.2	0	0	93.4	86.8
Kanaio-Ulupalakua										
Jan.–Apr.	27.2	3.4	11.1	7.1	32.1	44.2	1.7	0	72.0	54.2
June–Oct.	35.1	14.8	18.5	34.7	33.3	21.7	.5	0	87.4	71.2
Waihou										
Jan.–Apr.	0	.4	0	1.5	6.8	32.4	0	0	6.8	34.4
June–Oct.	.5	1.1	.2	2.4	70.7	26.7	0	0	71.4	30.2

[1]Based on adult emergence.

Keanae-Iao Valley are shown in Figure 5 and of those in Kanaio-Waihou in Figure 6. From external examination it was difficult to determine the number of galls on a stem where massive coalesced galls, typical of the Kanaio and Waihou areas, were present. Dissections and rearings confirmed that these compound galls contained different aged larvae and also many more individuals per gall than the smaller simple galls typical of the Keanae and Iao Valley areas which usually contained only 1 or 2 individuals.

Based on a total of 3,141 *P. utilis* adults reared from the four major sampling areas during the 1966–71 period, the ratio of females to males was 0.9: 1, but the ratio varied from a low of 0.7: 1 to a high of 1.2: 1 between the samples from the different localities. These ratios and those of 1950–57 period were similar (Table 4).

Parasites of the Eupatorium Gall Fly

In the 1966–71 period 4 of the 5 hymenopterous parasites known to parasitize *P. utilis* in Hawaii were reared from the gall samples. Out of a total of 5,698 parasite adults reared from the gall samples from the four regular collecting localities or districts on Maui 2,308 were *Bracon terryi* (Bridwell), 1,870 *Eupelmus cushmani* (Crawford), 1,465 *Eurytoma tephritidis* Fullaway and 55 *Opius tryoni* Cameron (Table 1). All 4 species were also

TABLE 4. *Sex ratios of the fly and different parasites in the samples from* 4 *localities on Maui during different seasons and periods,* 1966–71 *and* 1950–57.

	Sex ratio—♀♀/♂♂							
	Procecidochares utilis		*Eupelmus cushmani*		*Eurytoma tephritidis*		*Bracon terryi*	
Locality	1966 –71	1950 –57	1966 –71	1950 –57	1966 –71	1950 –57	1966 –71	1950 –57
Haiku-Hana								
Jan.–Apr.	.9	1.1	1.9	4.3	1.0	1.3	1.8	1.1
June–Oct.	1.0	.9	3.7	4.4	1.1	1.3	.9	1.0
Iao Valley								
Jan.–Apr.	1.2	1.1	12.0[1]	3.7	1.3	1.2	1.7	1.3
June–Oct.	1.0	.8	2.6	3.8	.8	.9	.7	1.0
Kanaio-Ulupalakua								
Jan.–Apr.	.8	.8	1.8	1.9	1.1	.8	.8	1.1
June–Oct.	.7	1.0	3.5	4.4	1.2	1.1	.9	1.1
Waihou								
Jan.–Apr.	.8	.9	—	1.5	—	1.0	1.5	1.1
June–Oct.	.9	.8	—	1.7	—	.8	.8	.9
All[2]								
Jan.–Apr.	.9	.9	1.8	3.0	1.1	1.0	.9	1.1
June–Oct.	.9	.9	3.2	4.0	1.1	.9	.9	1.0

[1]Based on only 13 individuals.

[2]*Opius tryoni* was .8, based on a total of 56 individuals from these localities. However, she ratio was 1.0 for the total 185 reared from 1950–1971.

reared from samples collected on Lanai and Molokai during the 1966–71 period. *O. tryoni* was recovered at only a few localities, but the other 3 species were reared from all of the localities where collections were made on these islands. However, their abundance varied from locality to locality, seasonally and each of the 3 species outnumbered the other in certain localities (Table 1). *B. terryi* was by far the predominant species at Waihou, with *E. cushmani* and *E. tephritidis* accounting for less than 1 per cent of the total number of parasites reared from the gall samples from this locality. It was also the predominant species in the Kanaio-Ulupalakua area in the January-April samples, but not in the June-October samples due to the increase in numbers of *E. cushmani* and *E. tephritidis* during these warmer months. Both of these species were more numerous at all localities during the warmer months, June-October, than during the cooler months, January-April.

The total parasitization was much higher during the warmer months than during the cooler months. The parasitization, based on total numbers of flies and parasites, for the June-October gall samples was 81.5%, with a range of 71.4 to 93.7%, and for the January-April samples 47.8%, with a range of 6.8 to 68.5% for the four localities shown in Table 3. In general, the variations in parasitization in respect to localities, seasons and parasites during the 1966–71 period were similar to those in the 1950–57 period. However, parasitization during June-October of the 1966–71 period was somewhat higher than during these months of the 1950–57 period (Table 3).

The sex ratio of *E. tephritidis*, *B. terryi* and *O. tryoni*, as well as of *P. utilis*, was ca. 1: 1 and varied very little between localities, months, or the two periods, 1966–71 and 1950–57 (Table 4). However, the sex ratio of *E. cushmani* was greatly in favor of females and varied significantly as to individual collections or samples, localities, months and periods. In 69 collections, each of which contained 20 or more individuals of *E. cushmani*, the range in sex ratio for the individual samples was from 1.2: 1 to 20.5: 1, with an average of 3.1: 1. The variation in sex ratio as to locality was from a high of 4.1: 1 at Haiku-Hana to a low of 1.6: 1 at Waihou. As to seasons it was 3.7: 1 for June-October and 2.2: 1 for January-April and as to the two periods it was 3.7: 1 for the 1950–56 period and 2.4: 1 for the 1966–71 period.

Discussion

Over the past two decades or more we have witnessed the progressive reduction in the abundance of pamakani, *E. adenophorum*, by the activities of the eupatorium gall fly, *P. utilis*, on the islands of Lanai, Maui, Molokai and Oahu and the complete elimination of this rangeland weed in many localities. Elimination of dense continuous stands as well as isolated

patches and individual plants occurred at a very rapid rate in leeward low rainfall areas, however, control advanced at a noticeably slower rate in situations where there was more ground moisture available, such as, in gulches and shaded areas. On the other hand, control has been negligible in high rainfall areas.

On Maui in the general Waihou area on the leeward side of Haleakala where extensive dense stands of pamakani were present from an elevation of 2,500 feet elevation and above in 1949, biological control of the weed by the fly has been especially successful. According to Baldwin (1956) about 10,000 acres in this area were freed of the weed due to the activities of the fly between 1946 and 1956. This land is now in kikuyu grass, *Pennisetum clandestinum* Hochst., and is a highly productive pasture. Today, there are no extensive thickets of pamakani as there were formerly in the Waihou and Kanaio-Ulupalakua areas, but in oasis-like situations in these areas where soil moisture remains relatively high throughout the year, such as, in gullies and gulches, heavily galled plants of pamakani continue to persist. On the other hand, in the high rainfall areas of Haiku-Hana and Iao Valley the population of the fly is relatively low and pamakani continues to persist in essentially the same condition in respect to abundance and vigor as in the earlier years of the study. Since the fly has been present for over 25 years it would appear that it is not too well adapted to very moist conditions and will not in the foreseeable future exert a significant influence in high rainfall areas. Control of pamakani has not been of urgent concern in these high rainfall areas for the plant is only a minor constituent of the vegetation and it occurs primarily on non-agricultural lands.

The eupatorium gall fly, *P. utilis*, has confined its activity to only one species, *E. adenophorum*, although other species of *Eupatorium* are present in Hawaii. *P. utilis* is undoubtedly the most important agent responsible for the reduction and control of *E. adenophorum* in Hawaii even though other control measures, such as, mechanical and chemical clearing of pamakani infested land, were used prior to 1945, and also other organisms, including leaf-feeding Lepidoptera, snails, mites and a leaf-spot disease attack this plant.

The 5 parasites, *E. cushmani*, *E. tephritidis*, *B. terryi*, *O. tryoni* and *O. longicaudatus* (Ashmead), reared from *P. utilis* in Hawaii are exotic species, non-host specific to this fly, and all of them were first reared in the State from insects other than *P. utilis*. Besides *P. utilis*, anthribid (Pemberton, 1954; Sherman and Tamashiro, 1956; Fullaway, 1957), bruchid (Swezey et al., 1939; Hinckley, 1960) and curculionid (Swezey et al., 1939) beetles are hosts of *E. cushmani* and other species of tephritids are hosts of the remaining 4 parasites. The 2 opiines, *O. tryoni* and *O. longicaudatus*, were introduced to combat tephritid fruit flies and the former species played a significant role in the control of *Ceratitis capitata* (Wiedemann) and the

latter species of both *C. capitata* and *Dacus dorsalis* Hendel.

Two of the species, *E. cushmani* and *E. tephritidis* were continuously more abundant in the lower elevation warmer localities than in the higher elevation cooler ones and also more abundant during the warmer than the cooler months. On the other hand, *B. terryi* occurred in sizeable numbers in both the lower and higher elevation localities at all seasons and accounted for most of the parasitization in the Waihou samples, all of which were collected at an elevation of 4,000 to 5,500 feet. *O. tryoni* was reared from far fewer samples and in much fewer numbers than either of the above 3 parasites. Most of the *O. tryoni* were reared from collections of galls made at certain localities where *C. capitata*, the principal host of this parasite in Hawaii, commonly infests fruits of loquat, *Eriobotrya japonica* (Thunb) Lindl., peach, *Prunus persica* (L.) Batsch., or guava, *Psidium guajava* L., particularly during the cooler months. Although *O. tryoni* parasitizes both *P. utilis* in galls on pamakani and *Eutreta xanthochaeta* Aldrich in galls on lantana, *Lantana camara* L., these are incidental hosts which are only parasitized in numbers where they occur in close association with *C. capitata*. Although 1 specimen of *O. longicaudatus* was reared from a *P. utilis* gall collected on Oahu by Weber (1950) none was reared from any of our numerous gall samples collected on the various islands. Since the eupatorium gall fly, *P. utilis*, is in this case a beneficial species, it may be fortunate that the other opiine parasites, especially *Opius oophilus* Fullaway, which is widely distributed and has maintained a high level of parasitization throughout the year for more than two decades (Bess and Haramoto, 1961; Haramoto and Bess, 1970), do not parasitize the eupatorium gall fly.

The total parasitization by all species of parasites was exceedingly high and it is rather astonishing that despite this heavy drag on *P. utilis* during the entire period, the fly was able to bring about the spectacular control of the weed over a large part of the area previously infested by it. Perhaps if the parasitization had been as high throughout the year as it was during the warmer months, the fly may well have been more severely curtailed and less successful in the control of pamakani.

Summary

Biological control of pamakani, *Eupatorium adenophorum* Spreng., by the eupatorium gall fly, *Procecidochares utilis* Stone, introduced from Mexico in 1945 has been an outstanding success in Hawaii. *P. utilis* became readily established, increased to large numbers, spread to all areas on the Islands of Hawaii, Maui, Molokai, Lanai, and Oahu where pamakani occurred, and showed immediate promise of success under certain ecological conditions. Control of pamakani by *P. utilis* proceeded at a rapid rate in habitats of low moisture and has continued at a slower rate in habitats of moderate

moisture. In these low to moderate moisture areas, such as, at Waihou, Kanaio, Ulupalakua, and Kipahulu on Maui, thousands of acres of valuable rangeland have been freed of the weed by the fly. In high rainfall areas, however, such as along the Haiku-Hana Coast and in Iao Valley, *P. utilis* has had negligible effect on the weed even though it has been in these areas for more than 25 years, and thus, periodic mowing and spraying of weedicides to control the weed from roadsides are needed to this date.

E. adenophorum has been completely eliminated by *P. utilis* from several of the sites selected in 1950 to study the status of the weed, fly and parasites of the fly. Surveys of these sites and their immediate vicinities during 1966–71 have shown that pamakani has not grown back in areas freed of the weed during 1950–57 despite the many seeds produced by *E. adenophorum* which are readily disseminated by wind. A series of three photographs taken in 1949, 1957 and 1971 of the same hillside at Waihou where biological control of *E. adenophorum* has been most spectacular is presented to depict the change in the status of this weed over the past 21 years. Here, as well as in other areas of low to moderate rainfall, *P. utilis* has been effective in controlling *E. adenophorum* despite the continued tremendous drag placed on this fly almost immediately after its establishment by four species of parasites; *Bracon terryi* (Bridwell), *Eupelmus cushmani* (Crawford), *Eurytoma tephritidis* Fullaway and *Opius tryoni* Cameron. Parasitization of *P. utilis* by them varied between 6.8 and 93.4% in respect to localities, was much higher during June-October than January-April, and averaged 49.6% during 1950–57 and 55.9% during 1966–71.

The sex ratio of *P. utilis*, *E. tephritidis*, *B. terryi*, and *O. tryoni* was about 1 : 1 and varied very little in respect to localities, seasons, or the two periods, 1950–57 and 1966–71. However, the sex ratio of *E. cushmani* was greatly in favor of females (3.1 : 1) and varied significantly as to samples, localities, season, and periods.

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