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THE BIOECOLOGY OF *PSYLLA UNCATOIDES* IN THE HAWAII VOLCANOES NATIONAL PARK AND THE *ACACIA KOAIA* SANCTUARY

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PREFACE

The study described in the following report was begun on May 15, 1971 and the report covers research completed through September 10, 1972. The research was funded under subproject C-5 "The Effects of Sap-Sucking Homoptera on the Stability and Fragility of Hawaiian Ecosystems" of the U. S. International Biological Program, Island Ecosystems Integrated Research Program.

ABSTRACT

Psylla uncatoides is a recent accidental introduction to the Hawaiian Islands. Its population densities are closely tied to the flush phenology of *Acacia* spp. The psyllid was studied on *Acacia koa* on the southeastern slope of Mauna Loa above 4000 ft. and on *Acacia koaia* on the southern slope of Kohala Mt. (3200 ft.). Psyllid counts were broken down into four categories: eggs, small nymphs, large nymphs, and adults. Terminal samples were taken to obtain egg and nymphal population estimates. Adult populations were estimated from three minute D-VAC samples. The percent new terminal growth was estimated at the time of each sample. A strong relationship between peak psyllid populations and flush die-back was observed. It was suspected that the psyllid is aiding in the spread of koa rusts, as 63% of 179 psyllid adults observed had rust spores on their integument. Several predatory insects, principally coccinellid beetles and Neuroptera, were found associated with psyllid infestations, but none were satisfactorily controlling the psyllid. No parasites or diseases of the psyllid were found in the State. We plan to evaluate the effectiveness of additional natural enemies which are being introduced from Australia, the apparent native home of the psyllid. Possible associations of other insects with the psyllid have been observed and will be investigated.

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INTRODUCTION

Nine species of Homoptera are listed as being associated with native *Acacia* spp. on the island of Hawaii (Beardsley 1971). Five of these are endemic to the Hawaiian Islands and four have been accidentally introduced. *Psylla uncatoides* (Ferris & Klyver) (Sternorhyncha: Psylloidea: Psyllidae), a recent accidental introduction, is the only psyllid presently known to attack *Acacia* spp. in Hawaii. This psyllid is exerting the most profound influence of all the Homoptera on the ecology and phenology of the *Acacia* spp. and the other organisms associated with these plants. The emphasis of this study has therefore revolved around the ecology and population dynamics of this insect.

P. uncatoides was first collected on Oahu in a mosquito light trap near the Honolulu International Airport in March, 1966 (Joyce 1967). In April 1967 the psyllid was found established on the introduced *Acacia confusa* at Puu Ualakaa Wayside, Tantalus-Round Top, and at the Pali Golf Course, Kaneohe, and on *A. confusa* and *Acacia koa* in Kalihi and Nuuanu Valleys (Funasaki 1968a). New island records for the psyllid were reported for Maui and Kauai in June and July 1967 respectively (Funasaki 1968 b, c). In July 1970 the psyllid was first reported on the island of Hawaii although it had been observed there five months earlier (Davis & Kawamura 1970). Gagné (1971) reported great numbers of the psyllid on the ground at the summit of Mauna Kea on July 28, 1970. The presence of *P. uncatoides* at the summit of Mauna Kea was interpreted as an indication of the high populations of the psyllid on *A. koa* at lower elevations since the summit is devoid of vegetation and they would have had to migrate to reach it. Beardsley (in press) found the psyllid on Lanai in February 1971.

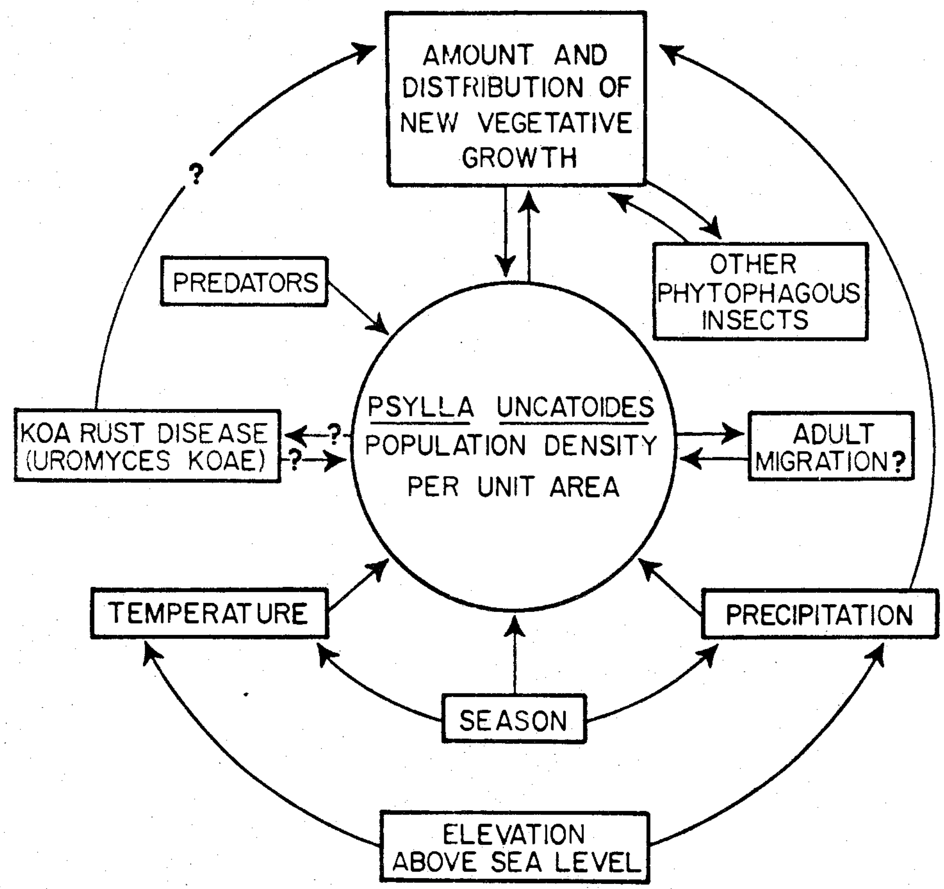
P. uncatoides was first described from specimens collected in New Zealand where acacias are exotic and was discovered in California in 1954 (Koehler, Kattoulas, & Frankie 1966). The psyllid was suspected of being endemic to Australia, but was not found there until 1971 by Beardsley. Beardsley and Hagen (unpublished) later found several encyrtid parasitoids and three predators: a green lacewing (Chrysopidae) and two coccinellid beetles. The parasitoids and predators were subsequently introduced to California in an attempt to control P. uncatoides in that State.

Munro (1965) gives a table of occurrence of P. uncatoides on Acacia spp. and Albizia spp. in California. Two host species found in Hawaii are not listed: A. confusa, which generally supports light to moderate psyllid infestations in Hawaii, and Acacia koaia, which is often heavily infested. The biology of P. uncatoides has been studied in California (Koehler, Kattoulas, & Frankie 1966; and Madubunyi 1967).

The investigations on Hawaii have been concerned mainly with the population dynamics and environmental interactions of P. uncatoides (see MODEL 1). During 1973 additional natural enemies will be introduced by the Entomology Division, State of Hawaii Department of Agriculture, in an attempt to achieve biological control of the psyllid. These natural enemies are species which were found in close association with P. uncatoides on Acacia spp. in southeastern Australia where this psyllid is believed to be endemic. The biology and ecology of these natural enemies was studied in Australia during 1971-72 (Beardsley and Hagen, unpublished). The natural enemies selected for introduction include two species of parasitoid wasps of the family Encyrtidae and two species of coccinellid beetles. The encyrtid wasp (undescribed species of Psyllaphagus) are both highly host specific and attack only Psylla uncatoides and other closely related Psylla spp. on Acacia spp. in Australia. Since none of the endemic Hawaiian Psyllidae infest Acacia spp. and all belong to a different subfamily of Psyllidae, there

MODEL I

POSSIBLE P. UNCANTOIDES ENVIRONMENTAL INTERACTIONS TO BE INVESTIGATED*



* AS DRAWN UP BY DR. J. W. BEARDSLEY

appears to be no possibility that these wasps will attack native Hawaiian psyllids. Both of the coccinellid species to be introduced are specialized psyllid predators which feed primarily on the exposed eggs and young nymphs. While it is possible that these predators may feed on other sessile, colonial insects such as aphids (all species of which are introduced pests in Hawaii), we do not believe that they will exert any appreciable effect on endemic Psyllidae as the immature stages of the latter occur in cryptic situations (e.g.: within plant galls or under bracts) where they are protected from predation by coccinellids. Furthermore, population densities of endemic psyllids are generally maintained at relatively low levels by endemic parasitoid wasps, and it is probable that even if these psyllids were accessible to coccinellids, the populations would be too sparse to be attractive to these predators.

The study will be continued during and after the introduction of natural enemies from Australia. We plan to continue evaluating the effect of the psyllid on the *Acacia* spp. ecosystems and the effectiveness of the introduced biological control agents in controlling *P. uncatoides*.

STUDY SITES

A. koa is naturally distributed between about 4000 and 6600 ft. along the Mauna Loa Strip Road. Planted trees occur at lower elevations within the Hawaii Volcanoes National Park but research on *P. uncatoides* was restricted to naturally occurring *A. koa* communities. Study sites at 4300, 5300, and 6600 ft. (I.B.P. site numbers 4, 6, and 9 respectively) were set up along the Mauna Loa Strip Road in May 1971. A study site at the *A. koaia* Sanctuary, Kawaihae Uka, Kohala Mt. (3200 ft.) was established at the same time. And, in January 1972 a study site was established just outside the I.B.P. study site in the Bishop Estate owned

Kilauea Forest Reserve (5400 ft.). I. B. P. weather stations are located at all the study sites except at the A. koaia Sanctuary. We plan to erect a weather station there in early 1973.

SAMPLING METHODS

Since P. uncatoides has been the primary insect of interest in this study, sampling methods were designed to attain the best population estimates of the different stages of that insect and its natural enemies. Other arthropods collected have been sorted to order and stored for future reference.

P. uncatoides counts were broken down into four categories: eggs, small nymphs, large nymphs, and adults. Catling (1969) used the same categories in his work on Trioza erytreae (Del Guercio). Instars one through three were lumped together as small nymphs, while instars four and five were considered as large nymphs. Koehler et. al. (1966) show a frequency distribution of head-width measurements which graphically illustrates the difference between small and large P. uncatoides nymphs.

P. uncatoides nymphs tend to cling to the foliage when disturbed while the adults tend to jump and fly away. These differences in habit necessitated the use of two sampling techniques. The counts of eggs and nymphs were made by taking ten, four-inch samples at each study site. The samples were placed individually in plastic bags and chilled in a refrigerator until they could be observed under a dissecting microscope and the counts made. Adult populations were sampled by means of a "D-VAC, Model 24" vacuum collecting apparatus. Three minutes was selected as a convenient time unit for D-VAC samples. After completing a sample the excess debris was removed, the arthropods killed with ethyl-acetate and stored in 70% ethyl-alcohol until they could be sorted. The counts obtained for the various life history intervals are given in TABLE 1. Analyses of psyllid population fluctuations will be completed when weather data from the different study sites and data on the impact of newly introduced natural enemies have been collected.

ACACIA SPP. FLUSHING PHENOLOGY

Most psyllids breed on the new terminal growth, or "flush," of their host plants. Consequently, a strong positive correlation between flushing phenology and the population dynamics of the psyllids exists. The amount of flush available can be considered as a density controlling factor in that it directly affects total psyllid populations in a given area. Similarly, psyllid population levels have a density dependent effect upon die-back of flush growth. However, the amount of new growth produced at the time of flushing may to some extent reflect psyllid population levels which were present during preceding growth flushes. Thus, the repeated flush die-back caused by heavy psyllid populations may have a cumulative debilitating effect on host plants.

The percentage of total terminals in flush was estimated for each sample site at the time the samples were taken. This estimate was arrived at by averaging the percentage of terminals with new growth in three counts of 100 terminals each. Aspect on a tree did not appear to play a part in the amount of flush. TABLE 2 gives the percent flush data collected at each study site. Lamoureux (personal communication) is using another method to estimate the percent flush in his phenologic study of *A. koa*. We are pleased that the data from shared study sites are in close agreement.

FIGURES 1 through 4 show the close correlation between flushing and psyllid population density at the *A. koaia* and the Mauna Loa Strip Road study sites.

TABLE 1. *P. uncatoides* life stage counts for each study site.

Date*	4300 ft. MLS					5300 ft. MLS				
	Adults	Large Nymphs	Small Nymphs	Total Nymphs	Eggs	Adults	Large Nymphs	Small Nymphs	Total Nymphs	Eggs
5/15/71	--	4335	16057	20392	28889	--	471	1432	1903	4041
6/14/71	5500	199	873	1072	157	3000	1	9	10	12
7/19/71	750	0	1	1	1	1000	0	0	0	30
8/2/71	453	0	1	1	14	840	3	9	12	22
9/1/71	195	0	3	3	1	312	2	10	12	66
10/3/71	28	0	1	1	3	243	6	6	12	55
10/31/71	14	--	--	0	--	193	--	--	6	--
12/5/71	126	--	--	--	--	183	--	--	--	--
1/7/72	91	--	--	--	--	558	--	--	--	--
2/9/72	303	6	54	60	130	540	93	629	722	562
3/5/72	4300	181	861	1042	1250	1030	91	266	357	540
4/1/72	2160	169	1415	1584	5304	1830	75	835	910	3093
4/30/72	2850	271	1371	1642	1967	1050	59	609	668	795
5/16/72	--	--	--	--	--	1050	4	28	32	140
6/1/72	3450	148	5845	6093	5666	825	0	23	23	98
6/16/72	--	--	--	--	--	328	0	6	6	11
7/2/72	750	0	0	0	3	115	1	5	6	4
7/16/72	--	--	--	--	--	65	--	--	--	--
7/29/72	--	--	--	--	--	--	--	--	--	--
9/10/72	13	2	1	3	5	13	0	0	0	0

*Samples taken ± 4 days of date listed.

TABLE 1 Continued.

Date*	6600 ft. MLS Adults	Large Nymphs	Small Nymphs	Total Nymphs	Eggs	3200 ft. Kohala Mt., *A. koaia* Adults	Large Nymphs	Small Nymphs	Total Nymphs	Eggs
5/15/71		12	146	158	215		24	65	89	370
6/14/71	101	8	15	23	99		9	37	46	51
7/19/71	657	26	377	403	447	214	3	17	20	57
8/2/71	576	1	403	404	582	775	2	21	23	82
9/1/71	464	73	238	311	713	1800	37	246	283	1097
10/3/71	224	0	10	10	15	4800	1	52	53	107
10/31/71	79	--	--	3	--	1800	--	--	12	--
12/5/71	20	--	--	--	--	900	--	--	--	--
1/7/72	93	--	--	--	--	2200	--	--	--	--
2/9/72	202	14	103	117	242	9000	80	682	762	2063
3/5/72	191	6	83	89	316	14400	466	5956	6422	6092
4/1/72	750	6	40	46	463	7500	16	83	99	195
4/30/72	402	20	525	545	1177	3500	19	86	105	258
5/16/72	--	--	--	--	--	--	--	--	--	--
6/1/72	288	39	616	655	887	425	11	26	37	30
6/16/72	--	--	--	--	--	--	--	--	--	--
7/2/72	600	0	98	98	341	700	10	152	162	337
7/16/72	--	--	--	--	--	--	--	--	--	--
7/29/72	--	--	--	--	--	4650	--	--	--	--
9/10/72	25	0	6	6	43	2160	1	40	41	20

*Samples taken ± 4 days of date listed.

TABLE 2. Estimated percent flush on *Acacia* spp. at each study site.

Date*	Study sites				
	4300	5300	6600	*A. koaia*	Kilauea** Forest
5/15/71	59.8	73.0	73.0	15.0	
6/14/71	0	0	67.6	81.3	
7/19/71	0	0	70.6	88.0	
8/2/71	0	0	69.3	96.0	
9/1/71	0	0	66.3	95.0	
10/3/71	0	0	0	81.0	
10/31/71	0	0	0	61.6	
12/5/71	7.5	60.3	45.3	66.6	
1/7/72	15.0	68.0	39.3	71.0	0
2/9/72	32.3	79.6	68.6	93.3	0
3/5/72	32.0	82.0	76.3	56.6	0
4/1/72	52.6	73.0	77.3	0	50.0
4/30/72	48.0	78.0	73.3	0	81.0
5/16/72	--	78.6	--	--	--
6/1/72	15.0	72.6	77.0	77.0	84.3
6/16/72	--	46.0	--	--	--
7/2/72	15.0	39.3	77.3	90.0	82.3
7/16/72	--	15.0	--	--	--
7/29/72	--	--	--	95.0	--
9/10/72	0	24.6	15.0	88.0	34.6

*Samples taken $\pm$ 4 days of date listed.

**Sampling started January 1972.

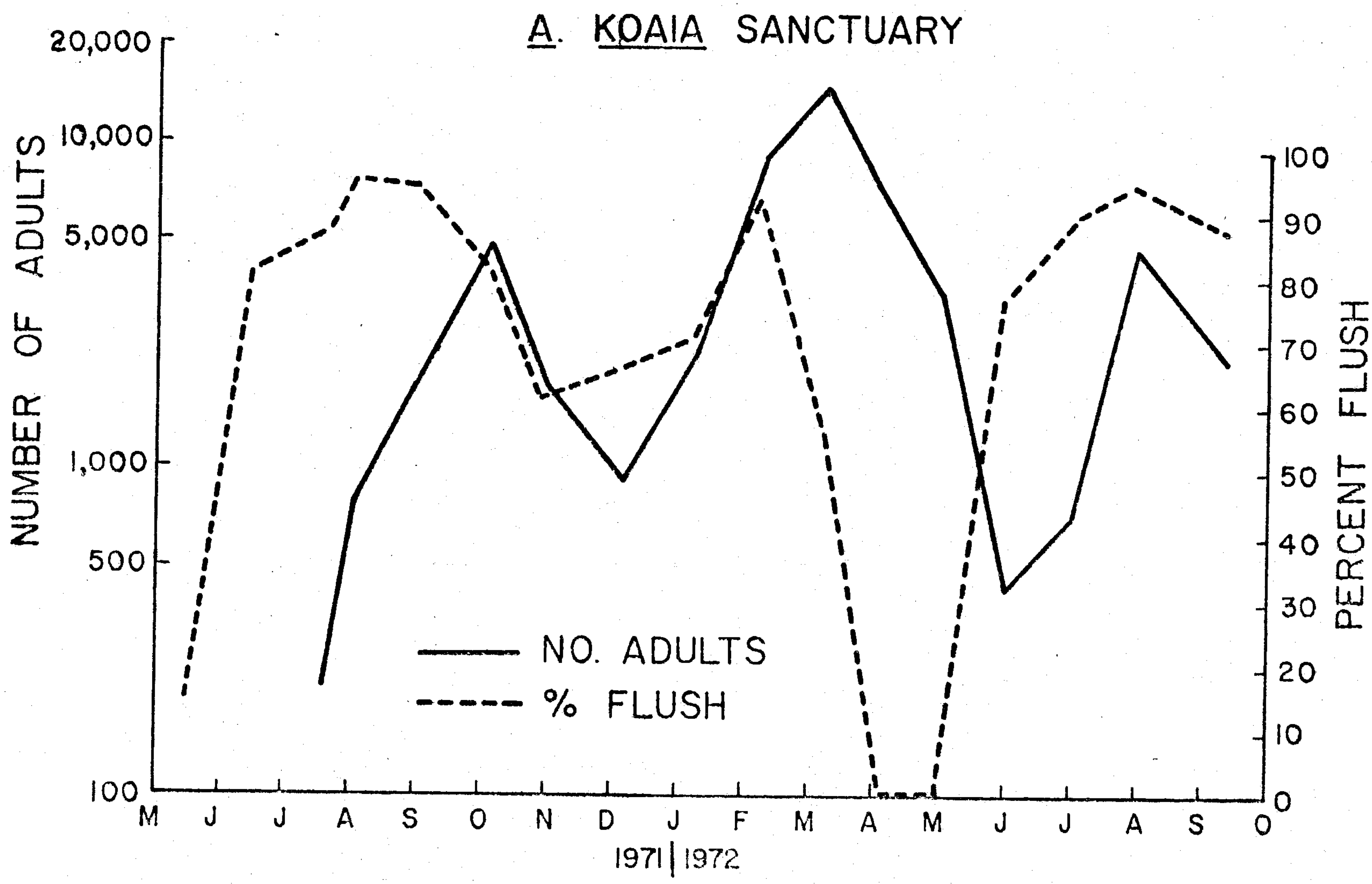


FIG. 1. Correlation between flushing and psyllid populations at the *Acacia koaia* Sanctuary.

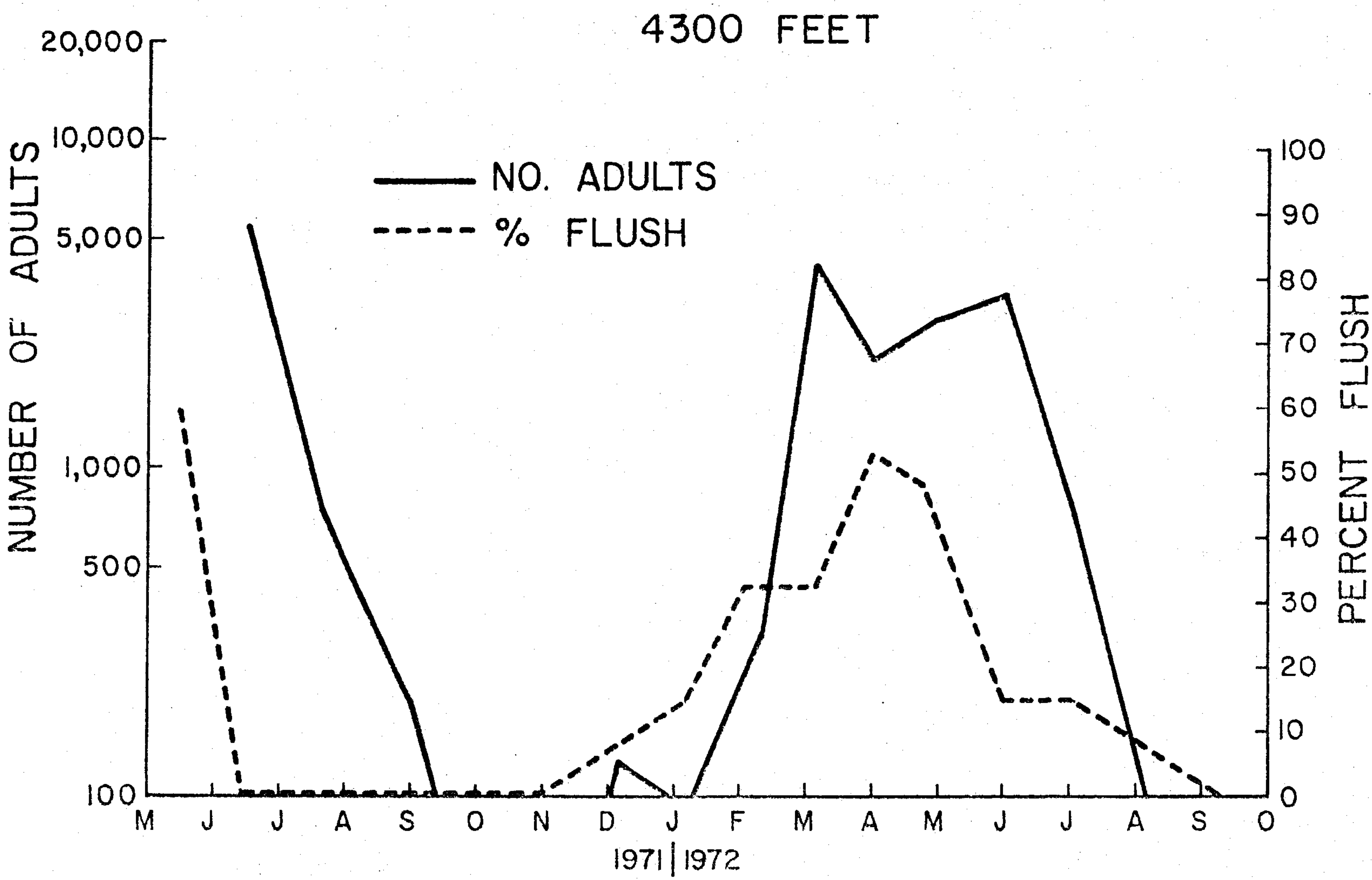


FIG. 2. Correlation between flushing and psyllid populations at 4300 ft. Mauna Loa Strip Road.

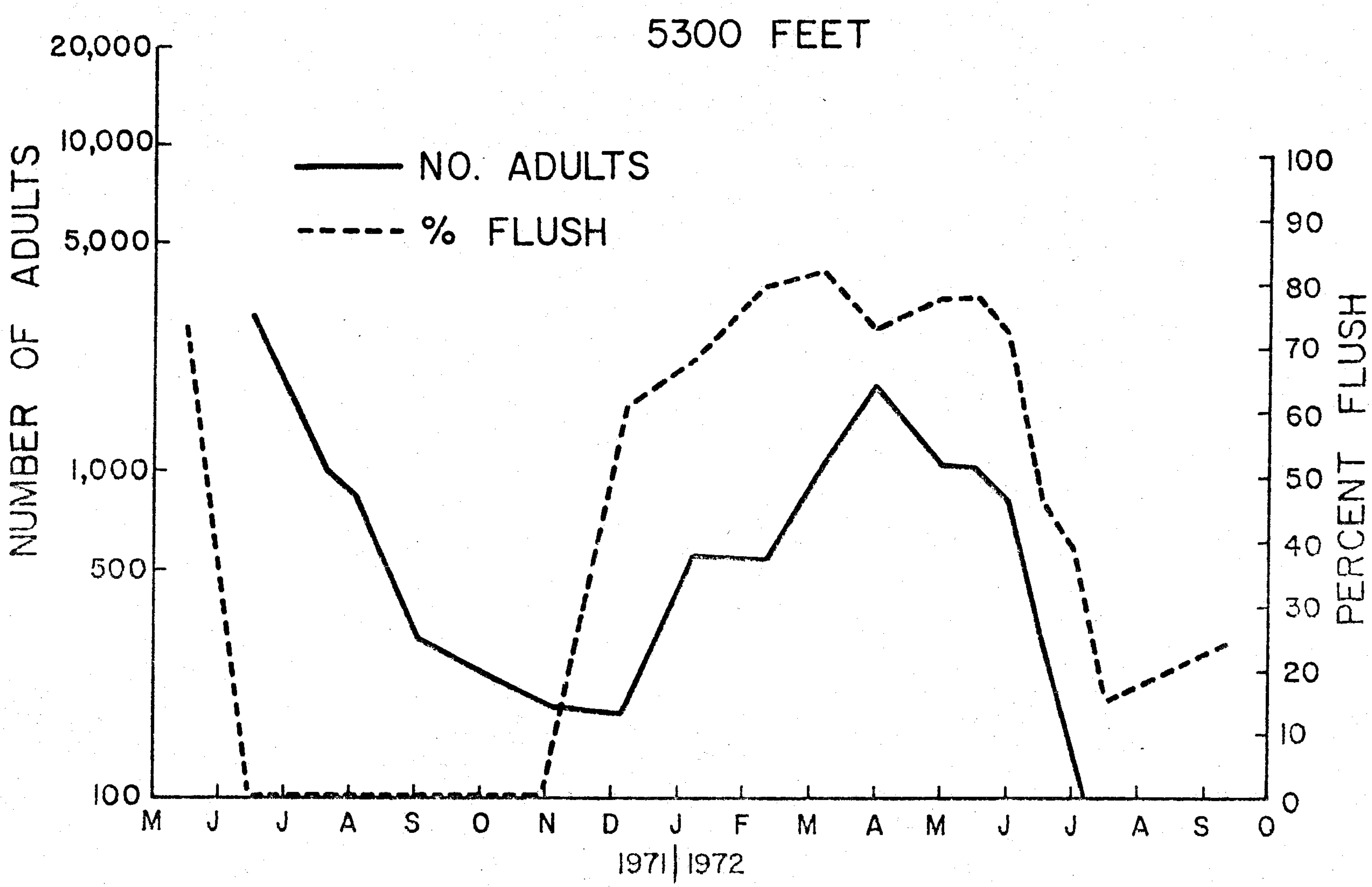


FIG. 3. Correlation between flushing and psyllid populations at 5300 ft. Mauna Loa Strip Road.

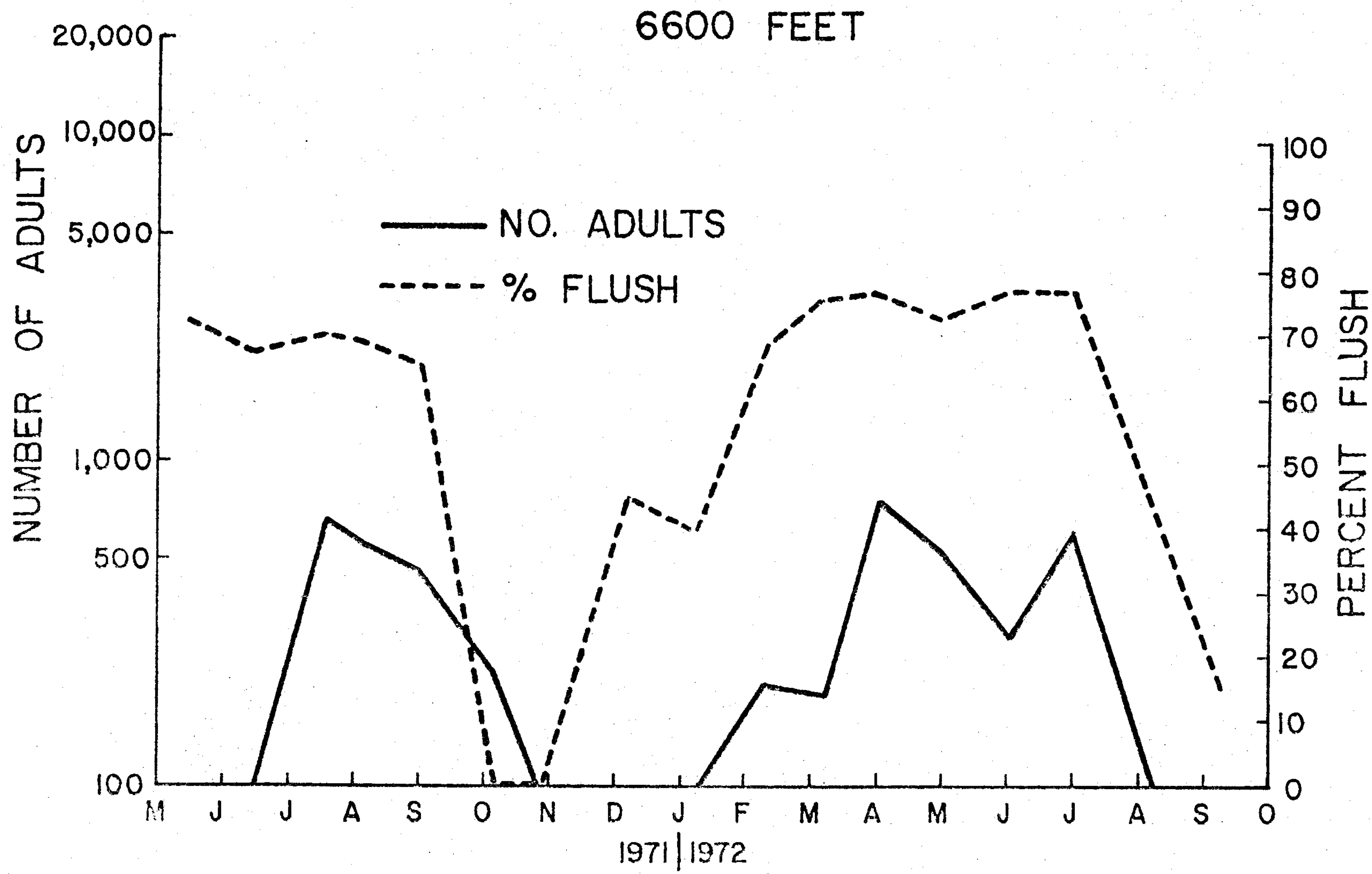


FIG. 4. Correlation between flushing and psyllid populations at 6600 ft. Mauna Loa Strip Road.

Catling (1969) showed a similar relationship for Trioza erytreae on citrus. No evidence of such a relationship was found in the Kilauea Forest. This is probably due to the higher rainfall in that area which is believed to inhibit the development of large P. uncatoides populations. Wilde (1962) reported a similar effect of high rainfall on pear psyllid, Psylla pyricola Foerster, populations.

At favorable sites nymphal stages reach high numbers on flush terminals and their excessive feeding is thought to be the cause of die-back. Our data on nymphal population levels are incomplete. However, since P. uncatoides develops from egg to adult in about one month, adult psyllid counts provide an index of the nymphal population levels which were present earlier and which were responsible for die-back conditions observed at the time counts were taken.

KOA RUSTS: their association with P. uncatoides

Koa rusts, Uromyces spp. are native rust fungi specific to A. koa. Because of the close association of both the rusts and P. uncatoides with A. koa and frequent observations of adult and nymphal psyllids on rust-infected terminals, it was decided to investigate a possible association between the two (see MODEL 1). C. J. Davis, State Entomologist, Hawaii State Department of Agriculture, has observed that koa rusts appear to be spreading at a faster rate since the introduction of P. uncatoides (personal communication).

Koa rusts are disseminated in spore form, and wind is thought to be the primary mechanism of spread. P. uncatoides may aid in the spread of the disease organisms by providing avenues of entry into the plant via feeding and oviposition wounds and may also act as a disseminator of the spores. As the spores are too large for the psyllids to ingest, dissemination of the disease by P. uncatoides could only occur through spores carried on their integument; a form of mechanical transmission. To investigate this possibility we checked psyllid integuments for spores. Whole psyllids were individually placed on a glass slide and observed under a compound microscope, at 100 power, by means of light directed on the specimen from below and two sides.

Psyllids were collected at 5300 ft., Mauna Loa Strip Road, because both P. uncatoides and Uromyces spp. were present. The psyllids were aspirated from non-rust terminals, killed, and observed for spores immediately. Out of the 179 psyllids observed, 113 (63%) were found to be carrying one or more Uromyces spp. spores. Dr. Baker, a mycologist in the University of Hawaii Botany Department, confirmed that the spores observed were koa rust spores. This evidence implicating P. uncatoides in the transmission of Uromyces spp. and the general lack of knowledge concerning koa rusts emphasizes the need for more research by plant pathologists and entomologists on these diseases.

NATURAL ENEMIES

Several insect orders are represented by species that are predacious on P. uncatoides in Hawaii. They are not, however, effective in controlling the psyllid. Satisfactory biological control will not be achieved until flush die-back due to excessive psyllid feeding is significantly reduced.

Two predacious Diptera species have been found. The larvae of a syrphid, Allograpta obliqua (Say), were found in low numbers at all the study sites and were observed feeding on P. uncatoides eggs. Madubunyi (1967) reared this syrphid on P. uncatoides but doubted that it, and other syrphids present in California, were effective in controlling the psyllid. We concur with his opinion. The second predacious fly larva was identified by Hardy and Delfinado (personal communication) as a Cecidomyiidae, possibly *Trisopsis* sp., but has not been reared on *P. uncatoides* and the nature of the relationship between the two is uncertain.

Fourteen species of Coccinellidae (Coleoptera) have been separated from the D-VAC samples. TABLE 3 gives a breakdown of the coccinellid species collected at the study sites. The *A. koaia* study site had the highest populations, the greatest diversity of species, and the only immature coccinellids collected. *Lindorus ventralis* (Erich.) was never collected at the *A. koaia* study site, yet was collected at the 5300 ft. and 6600 ft. study sites along the Mauna Loa Strip Road. Several other coccinellid species were collected only once or twice at the *A. koaia* study site. Also, larvae of only 4 of the 13 species present at that site were collected. The larvae were neither collected with regularity nor in great numbers, except in one sample when 10 *Olla abdominalis* (Say) larvae were obtained. In comparison to the 13 coccinellid species found at the *A. koaia* study site, 1, 4, and 5 species were found at the Kilauea Forest, 5300 ft. and the 6600 ft. study sites respectively. No coccinellids have been found at the 4300 ft. study site.

The Neuroptera are represented by both the Chrysopidae and the Hemerobiidae. TABLE 4 gives a breakdown of the Neuroptera found at each of the study sites. The endemic *Anomalochrysa hepatica* McLachlan and the introduced *Hemerobius pacificus* Banks were the principle species collected for their respective families. No reliable means of identifying Hawaiian Neuroptera larvae any further than to family has yet been developed. Moreover, first instar Hemerobiidae could not be differentiated from the Chrysopidae and were therefore included under the Chrysopidae undetermined spp. grouping. Zimmerman (1957) listed the presence of *Chrysopa lanata* Banks, later shown by Adams (1963) to be a synonym of *Chrysopa comanche* Banks, on Hawaii as questionable. Prior to our collecting

TABLE 3. Total numbers of Coccinellids, by species, found at each of the study sites.

Species	Study sites: *A. koaia*	4300 ft.	5300 ft.	6600 ft.	Kilauea* Forest
Coelophora inaequalis (Fab.)	166A3L			1A	
Curinus caeruleus Mulsant	16A6L				
Cryptolaemus montrouzieri Mulsant	81A			1A	
Olla abdominalis (Say)	35A3P20L				
Scymodes lividigaster (Mulsant)	1A				
Orcus chalybeus (Bois.)	154A19L				
Lindorus lophanthae Blaisd.	1A		1A		
Scymnus notescens Blackburn	28A				
Scymnus loewii Mulsant	13A		3A		1A
Lindorus ventralis (Erich.)			4A	10A	
Rodolia cardinalis Mulsant	1A		3A	2A	
Hippodamia convergens Guerin	2A			1A	
Scymnus sp.	1A				
Coccinellidae?	1A				

*Sampling started Jan. 1972.

A: adult
P: pupa
L: larva

TABLE 4. Total numbers of Neuroptera, by species, found at each of the study sites.

Species	*A. koaia*	4300 ft.	5300 ft.	6600 ft.	Kilauea* Forest
	Study sites				
Chrysopidae spp.?	8L	22L	38L	15L	8L
Anomalochrysa hepatica McLachlan	3A	37A	39A	4A	6A
Anomalochrysa frater Perkins		15A			
Anomalochrysa fluvesens fluvesens? (Perkins)	2A				
Chrysopa comanche Banks	8A				
Hemerobiidae spp.?	2L	7L	55L	21L	3L
Hemerobius pacificus Banks	2A	55A	143A	41A	6A
Nesomicromus vagus Perkins		4A	1A	1A	
Nesobiella hospes (Perkins)		1A	1A		

*Sampling started Jan. 1972.

A: adult
L: larva

8 adults over a 4-month period, it had not been recorded from that island. C. comanche is present and probably established in the Kawaihae Uka area, representing a new island record for the species.

The Hemiptera are represented among possible psyllid predators by the Miridae and the Nabidae. Mirid populations can occasionally become high but it is not known whether the species present on the Acacia spp. are plant feeders, predators, or both. Spiders and mites are also possible psyllid predators which occur in the Acacia spp. ecosystems, but these appear to be of very minor importance.

It is obvious that despite the presence of a variety of actual and possible predators, they are not, singularly or collectively, capable of controlling the psyllid. Also, no parasites or diseases of P. uncatoides have been found in the Hawaiian Islands.

Several species of natural enemies which were found in association with Psylla spp. on Acacia spp. in Australia have been introduced to California (Beardsley & Hagen, unpublished). Because these natural enemies were obtained from endemic Psylla and Acacia communities in Australia, we believe that they have a greater potential for controlling P. uncatoides populations in Hawaii than any of the psyllid enemies presently established in the State.

Several of the biological control agents which were found in Australia will not be introduced into Hawaii due to their lack of host specificity. Those insects intended for release are highly host specific parasitoid wasps of the family Encyrtidae and coccinellids that are specialized psyllid predators. The endemic Psyllidae of Hawaii belong to a different subfamily (Triozinae), occur on different hosts, and have life history habits different from P. uncatoides and therefore should not be affected by the introductions. It is possible that minor predation of the endemic Cicadellidae and Delphacidae found on *Acacia* spp. may occur. The life history habits of these insects should limit significant predation to their rare population explosions when predation would be considered beneficial.

From our phenologic study of the psyllid on Hawaii we have determined that early February, when the psyllid populations start to increase, is the ideal time to introduce these biological control agents. A release program, to be carried out in collaboration with the Hawaii State Department of Agriculture, will begin in early 1973. At that time two coccinellids, a *Diomus* sp. and *Harmonia conformis* (Boisduval), and perhaps one or more species of Encyrtidae will be introduced.

OTHER INSECTS

For the most part analyses of insect populations other than *P. uncatoides* and its predators have not been made. The material collected is being stored for future analyses. In sorting the material, a few possibly significant relationships have become evident. Certain introduced and endemic insect populations, the Psocoptera and Miridae for example, increased following increases in the *P. uncatoides* populations. In other instances, the psyllid may be forcing endemic insects, such as the Delphacidae, from their specific niches. Before it can be determined if there are any correlations between the population dynamics of other insects and that of the psyllid, *P. uncatoides* will have to be controlled and the population dynamics of the insects involved monitored for several years.

The relationship of ants to the psyllid and to the stability of the endemic *Acacia* spp. ecosystems is another important factor which should be considered. Certain ants tend honeydew producing insects to the mutual advantage of both. The ants obtain food and offer protection to the honeydew producer. *Pheidole* (*P.*)

megacephala (F.) is found in low numbers, associated with *P. uncatoides*, at the *A. koaia* study site. *Iridomyrmex humilis* (Mayr) is well established and associated with the psyllid at 4000 ft., Mauna Loa Strip Road, and has the potential to spread up to 6600 ft. Continued spread of this ant probably would be of benefit to the psyllid and place an added burden on the ecosystems involved since the ants would offer the psyllids protection from predation. We plan to plot the present distribution of *I. humilis* and to resurvey the distribution at intervals to follow its spread, and to assess its effects on the *A. koa* ecosystems.

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