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DISTRIBUTION OF MOSQUITOES (DIPTERA: CULICIDAE) ON THE EAST FLANK OF MAUNA LOA VOLCANO, HAWAII[1]

By **M. Lee Goff[2] and Charles van Riper III[3]**

Abstract. Two species of mosquitoes, *Culex quinquefasciatus* and *Aedes albopictus,* were recovered from the east flank of Mauna Loa Volcano. Altitudinal range for *C. quinquefasciatus* is increased from 600 m to 1500 m. *A. albopictus* was only recovered below 300 m. Upper elevation distribution of *C. quinquefasciatus* was restricted to kipukas.

There have been 4 species of blood-feeding mosquitoes introduced into the Hawaiian Is. Two of these, *Aedes aegypti* (Linnaeus, 1762) and *Aedes albopictus* (Skuse, 1895), are day-biters and 2, *Aedes vexans nocturnus* (Theobald, 1903) and *Culex quinquefasciatus* Say, 1823, are night-biters. Four additional predatory species have been introduced for biological control (Hardy 1960): *Toxorhynchites amboinensis* (Doleschall), *Toxorhynchites brevipalpus* Theobald, *Toxorhynchites inornatus* (Walker), and *Toxorhynchites theobaldi* (Dyar & Knab). Of these 4 predators, only *T. amboinensis* appears to have become well established (Steffan 1968).

Culex quinquefasciatus has been implicated in the transmission of filariasis (*Wuchereria bancrofti*), dog heartworm (*Dirofilaria immitis*), avian malaria and fowl pox, and may possibly be implicated in transmission of several viral agents including Japanese B-type encephalitis (Hardy 1960). *Aedes albopictus* is a vector of dengue fever, dog heartworm, and Japanese B-type encephalitis (Hardy 1960) and is listed as a minor vector of avian malaria (*Plasmodium* sp.) by Boyd (1949). *Aedes aegypti* is the major vector of yellow fever as well as transmitting dengue and avian malaria (Hardy 1960, Boyd 1949). *Aedes vexans nocturnus* is a vector for dog heartworm, fowl pox (experimentally) and various encephalides (Joyce & Nakagawa 1963). The vector potentials listed above have resulted in a surveillance of these species in areas around human habitation by the Vector Control Branch, Hawaii State Dep. of Health. Their distribution in unpopulated areas of Hawaii is largely unknown, with the exception of work by Warner (1968) concerning *C. quinquefasciatus* on the island of Kauai.

Of these 4 blood-feeding species, only 3 are currently reported from the island of Hawaii: *A. albopictus, A. aegypti* and *C. quinquefasciatus.* No specimens of *A. aegypti* were recovered during the current study. The 4th species, *A. vexans nocturnus,* first reported

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2. Department of Entomology, Bishop Museum, P.O. Box 19000-A, Honolulu, Hawaii 96819, USA.
3. Cooperative National Park Resources Study Unit, University of California and Department of Zoology, Davis, California 95616, USA.

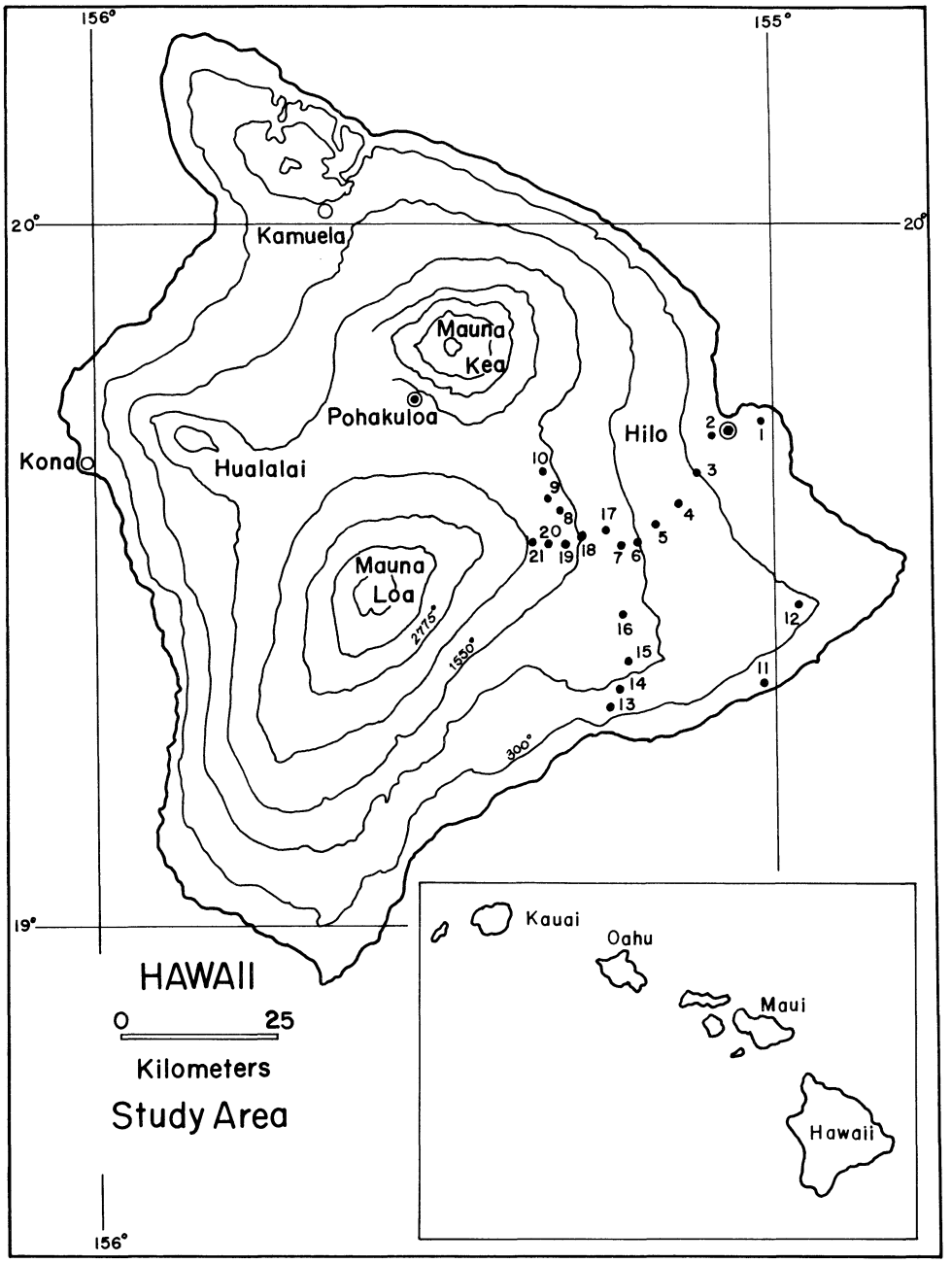

FIG. 1. Locations of sample stations on east flank of Mauna Loa Volcano. Numbers refer to TABLE 1.

in the Hawaiian Is in 1962, has not yet been recovered on Hawaii I. *Toxorhynchites amboinensis* has been reported from Hawaii I, but was not recorded during the present study.

MATERIALS AND METHODS

Twenty-one sample stations were established, as shown in FIG. 1, ranging from sea level to 2000 m. Sampling was done at monthly intervals from November 1977 thru March 1979, for a total of 17 months.

At each station, 9 artificial oviposition sites were provided consisting of 3 each of coconuts, #10 metal cans and styrofoam containers. Containers were checked for eggs, larvae and pupae each month, and the contents of 1 of each type container were removed for examination in the laboratory. At each station potential natural oviposition sites (ground pools, hapu'u stumps, treeholes, leaf axils, etc.) were located and checked for larval activity each month.

Monitoring of adult populations of *C. quinquefasciatus* for the island of Hawaii is carried out on a continuing basis by Vector Control Branch, Hawaii State Dep. of Health, using a series of 30 light traps operated 24 h per day. Counts from these traps were made available for this study. Supplemental trapping at each of the 21 stations was done on a monthly basis from November 1977 to March 1978, using Standard New Jersey Mosquito Light Traps, both unbaited and with a CO_2 attractant. Due to small catch and loss of traps through theft and vandalism, this sampling was discontinued in April 1978. Biting collections were made on a monthly basis for both *C. quinquefasciatus* and *A. albopictus*. Additional biting collections for *C. quinquefasciatus* were made by volunteers during July and December 1978 and February 1979.

RESULTS AND DISCUSSION

Eggs

Egg rafts were collected from two 189-liter water drums located at Kipuka Ki (Station 18) from November 1977 through October 1978, at which point the drums were removed by the National Park Service. *Culex quinquefasciatus* was the only mosquito species ovipositing at this station. During this period 46 egg rafts were removed from the drums. A mean of 171 eggs/raft was calculated with a range from 91 to 273 eggs/raft. No annual variation in numbers of eggs/raft was observed and monthly mean values ranged from 146 to 193 eggs/raft. Four *C. quinquefasciatus* egg rafts were removed from artificial oviposition sites at Kipuka Nene (Station 15) in January 1978. A mean of 177 eggs/raft was calculated for this collection, with a range of 130 to 213 eggs/raft. Eggs rafts were collected from ground pools near sea level from November 1977 through October 1978. During this period 52 egg rafts were collected. A mean of 179 eggs/raft was calculated for this collection with a range from 120 to 260 eggs/raft. Thus there was no significant difference in numbers of eggs per raft, with

TABLE 1. Larval mosquito collections at stations on the east flank of Mauna Loa Volcano, Hawaii I.†

STATION	ELEV (m)		1977		1978												1979
			Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
1	0	Hilo Airport	A,C	A,C	C	C	C	C	C	C	C	A,C	C	C	C	C	C
2	150	Hilo Zoo	N	N	—	—	—	—	A	A	A	A	A	A	A	A	A
3	300	Lower Kulani	A	A	A	A	A	A,C	A	—	A	A,C	A,C	A,C	A	—	A
4	600	Upper Kulani	—	—	—	A	—	—	—	—	—	—	A,C	A,C	A	—	A
5	900	Lower Volcano	—	—	—	A	—	—	—	—	—	A	C	C	C	—	A
6	1050	Upper Volcano	—	—	—	C	—	—	—	—	—	—	—	—	—	—	—
7	1200	Avian Disease Lab.	C	—	C	C	C	C	C	C	C	C	C	C	A,C	C	C
8	1350	Lower Keauhou	—	—	—	—	—	—	—	—	—	C	—	C	—	—	—
9	1500	Upper Keauhou	C	C	C	*	*	—	—	C	*	C	C	C	C	*	C
10	1650	Kilauea Forest Res.	—	—	—	—	—	—	—	—	—	C	—	—	—	—	—
11	0	Kalapana	N	N	A	A	A	A,C	A	A	A	A	A	A	A	A	A
12	300	Keaouhana Forest	N	N	A	A	A	A	A	A	A	A	A	A	A	A	A
13	600	Lower Hilina Pali	—	—	—	—	—	—	—	*	*	—	*	*	—	—	—
14	600	Hilina Pali	—	—	C	C	—	—	—	*	*	C	*	*	—	—	—
15	900	Kipuka Nene	—	C	C	C	—	—	—	*	*	—	*	*	—	—	—
16	1050	Kokoolaau	—	—	—	—	—	—	—	*	*	C	—	—	—	—	—
17	1200	Kilauea Military Camp	—	—	—	—	—	—	—	*	*	—	—	—	—	—	—
18	1350	Kipuka Ki	C	C	C	C	C	C	C	C	—	C	C	C	C	C	*
18a	1350	Kipuka Ki (lava)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
19	1500	Strip Road (aa)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
20	1650	Keamoku Flow	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
21	2000	Top of Strip Road	—	—	—	—	—	—	—	*	*	—	—	—	—	—	—

† A = *Aedes albopictus* larvae; C = *Culex quinquefasciatus* larvae; N = station not yet established; — = no larvae collected; * = oviposition sites disturbed, no data.

TABLE 2. Larval mosquito collections at stations on the east flank of Mauna Loa Volcano, by elevation.†

ELEVATION (m)	STATIONS	1977		1978												1979
		Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
0	1, 11	A,C	A,C	A,C	A,C	A,C	A,C	A,C	A,C	A,C	A,C	A,C	A,C	A,C	A,C	A,C
150	2	—	—	—	—	—	A	A	A	A	A,C	A	A	A	A	A,C
300	3, 12	A	A	A	A	A	A,C	A	A	A	A,C	A,C	A,C	A	A	A
600	4, 13, 14	—	—	—	A	—	—	—	*	*	C	A,C	A,C	A,*	A	A
900	5, 15	—	—	C	A,C	C	—	—	*	*	A	*,C	*,C	C	—	A
1050	6, 16	—	—	—	C	—	—	—	—	—	—	—	—	—	—	—
1200	7, 17	C	C	C	C	C	C	C	*,C	*,C	C	C	C	A,C	C	C
1350	8, 18	C	C	C	C	C	C	C	C	*	C	C	C	C	C	*,C
1500	9, 19	C	C	C	*	*	*	*	*,C	*	C	C	C	C	*	C
1650	10, 20	—	—	—	—	—	—	—	—	—	C	—	—	—	—	—
2000	21	—	—	—	—	—	—	—	*	*	—	—	—	—	—	—

† A = *Aedes albopictus* larvae; C = *Culex quinquefasciatus* larvae; — = no mosquito larvae collected; * = oviposition sites disturbed, no data.

elevation from sea level to 1350 m in the present study ($t = 1.67$; $df = 96$; $P > 0.05$). No egg rafts were recovered at stations above 1350 m in the current study.

Eggs of *A. albopictus* were not sampled during the present study.

Larvae and pupae

Larvae and pupae of *C. quinquefasciatus* were recovered from artificial oviposition sites at stations from sea level to 1650 m (TABLE 1 & 2). Breeding populations were present at sea level (Station 1), 1200 m (Station 7) and 1350 m (Station 18) during the entire study period. Station 9 (1500 m), located on Keahou Ranch, had a breeding population present during all months for which data were available. During the months from February through May and July 1978, the artificial oviposition sites were destroyed by activities of cattle and pigs. Sampling of natural oviposition sites at Station 9 revealed larvae present in a treehole during March, April and July. Thus, larvae were not observed at Station 9 for only 2 sample periods, February and May. Stations at 900 m (Stations 5 & 15) showed larval activity, but not on a continuous basis. At Station 15 the relatively constant strong winds, relatively low rainfall and few natural oviposition sites available would tend to limit mosquito activity. Larvae were collected here during the months of January through March, corresponding with annual period of increased rainfall (December through April). Vegetation at Station 15 consisted primarily of grasses, scattered shrubs and trees (*Metrosideros* sp. and *Acacia koa*). Lava substrate at this station was too porous to maintain ground pools sufficient for larval development. Ground pools were not observed at this station except during the period December 1978 through February 1979, when there was an unusually heavy rainfall, resulting in flooding over a major portion of the island. Potential natural oviposition sites could not be located at Station 15. A similar situation was encountered with regard to rainfall, vegetation and natural oviposition sites at Station 14. Here *C. quinquefasciatus* larvae were taken only in February and March 1978. Station 5 was located in a rain forest with an abundance of potential natural oviposition sites, including ground pools, hapu'u stumps and treeholes. However, *C. quinquefasciatus* larvae were recovered from this station only during September–October 1978.

Culex quinquefasciatus larvae were recovered on an irregular basis from artificial oviposition sites at stations from 150 m to 600 m, but were observed regularly in natural oviposition sites at all stations except Station 14, as previously noted.

Although *C. quinquefasciatus* larvae were recorded only once in the artificial oviposition sites provided at 1650 m (Station 10), other records are available from higher elevations on the island of Hawaii. Sweezy & Williams (1932) reported egg rafts from a rain barrel at 1829 m on Mt Hualalai and larvae in a pool at 1981 m at Nauhi, Mauna Kea. Komatsu (1966) reported both egg rafts and larvae from concrete pools at the Pohakuloa Nene Farm at 1981 m. While these records do not indicate a permanent breeding population of *C. quinquefasciatus*, results of larval samples in the current study indicate a permanent population at 1500 m.

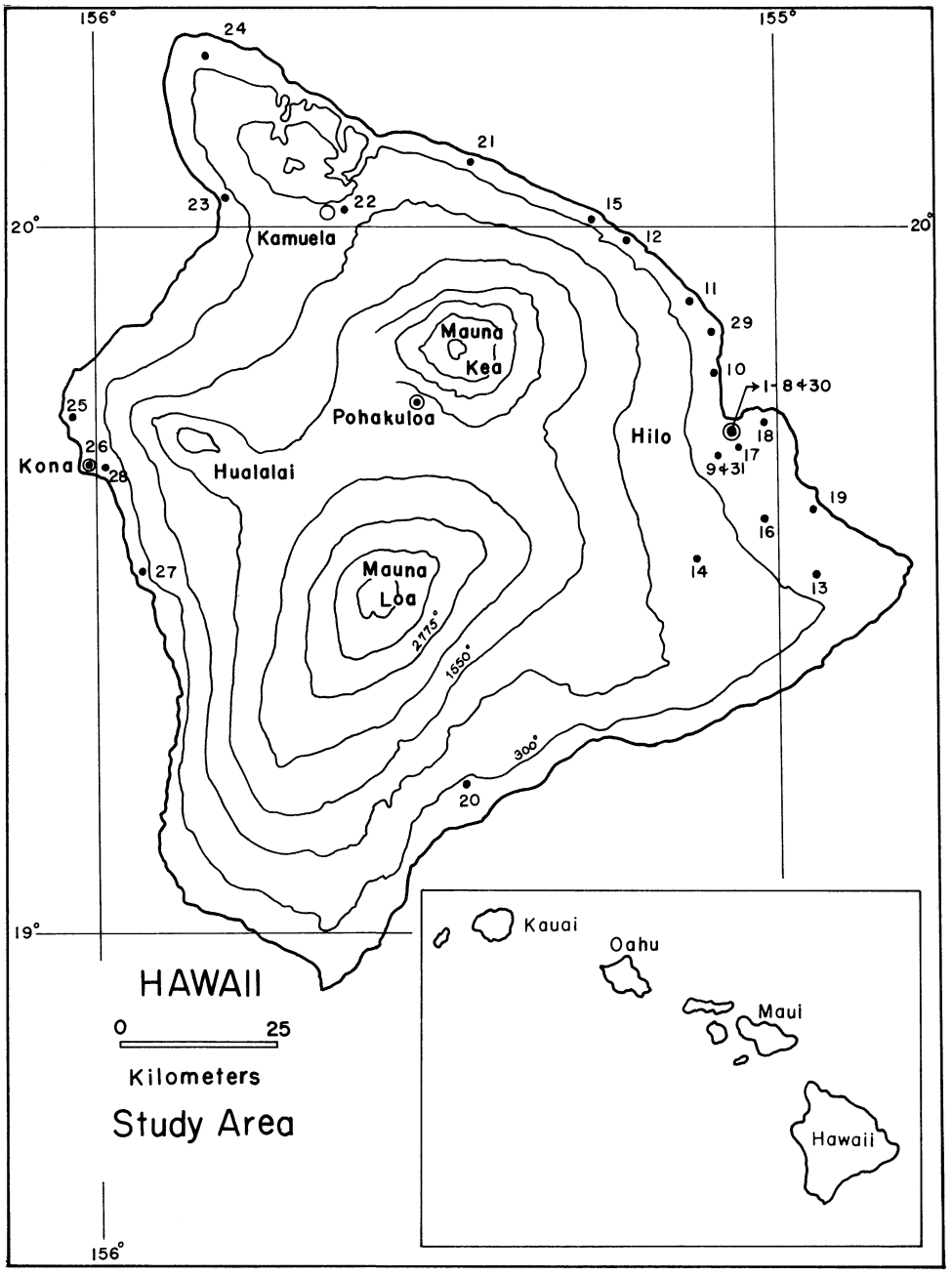

FIG. 2. Location of light traps operated by Vector Control Branch, Hawaii State Department of Health. Numbers refer to TABLE 2.

Larvae and pupae of *A. albopictus* were recovered from artificial oviposition sites and in "natural" oviposition sites, primarily discarded cans, tires and human refuse, up to 300 m for all months of the study. Recoveries of *A. albopictus* larvae at 600 m (Station 4) and 900 m (Station 5) were associated with areas of human activity (construction equipment). Larvae were present at these elevations only for the period of the activity and were not recovered from artificial oviposition sites during sampling either prior to or following such activity. No *A. albopictus* larvae were recovered at stations above 900 m.

Adults

Results of light traps operated by Vector Control Branch, Hawaii State Dep. of Health, at localities indicated in FIG. 2, are given in TABLE 3. These traps were primarily operated in areas of human activity and at elevations below 900 m. These results show a population of *C. quinquefasciatus* present in all localities sampled on a year-round basis, although more numerous from April through October. As expected, species of *Aedes* were not taken in light traps. Standard New Jersey Mosquito Light Traps were placed at stations monthly from November 1977 through April 1978. Results from these traps were negative when used either with a CO_2 attractant or without an attractant. During this period *C. quinquefasciatus* adults were frequently observed at stations with lower elevations, and eggs, larvae and pupae were recovered. Both male and female *C. quinquefasciatus* were observed regularly at Kipuka Ki (Station 18, 1350 m) in the vicinity of oviposition sites. Biting collections at all stations during this same period were negative for *C. quinquefasciatus.* Biting collections of *A. albopictus* were made in early morning at stations up to 300 m. Bites ranged from 15–30 in a 10-min period with no significant variation observed for the study period, although higher numbers tended to occur in the warmer summer months. Adult females of *A. albopictus* were observed biting, but were not collected, in December 1977 and January 1978 at Kipuka Ki (Station 18) and 1 female was observed at Kilauea Forest Reserve in April 1978.

Discussion

Warner (1968) indicates, based on studies conducted on Kauai, that distribution of *C. quinquefasciatus* is restricted to elevations below 700 m. Results of the current study on Hawaii present a considerably different picture. Collections of eggs, larvae and pupae indicate breeding populations of *C. quinquefasciatus* present for the entire year at elevations up to 1500 m. Adults of *C. quinquefasciatus* were observed monthly at Kipuka Ki (Station 18) with an elevation of 1350 m. Distribution of *C. quinquefasciatus* was, however, by no means uniform throughout its altitudinal range, but varied corresponding to degree of volcanic activity in the study area on the east flank of Mauna Loa Volcano. Stations in the present study below 1100 m were located in areas with a relatively uniform vegetation cover and with many available oviposition sites. Above this elevation, irregularities in patterns of lava flows from recent erup-

TABLE 3. Adult *Culex quinquefasciatus* from light traps on the island of Hawaii.

MAP NUMBER	LOCALITY	1977		1978												1979
		Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
1	Kapiolani	19	30	55	15	11	33	104	54	184	80	17*	16	23	32	11*
2	Keaau	104	181	97	35	241	751*	980	205	373	1941	323	361	147	184	36
3	Waiakea H. C.	11	10	4	1	7*	14	25	52	15	27	14	18	24	8	3*
4	Hilo Wharf	9	4	25	8	3	1*	5	7	33	13	8	30	14	14	2*
5	Old Airport	13	10	7	1	2	1*	0	0	2	3	1	0	1	1	3
6	Piihonua	8	3	0	6	2	3	16	6	9	0	2*	13	13	8	3
7	Keaukaha	8	11	17	2	6*	22	70	103	21	113	16*	92	13	76	21
8	Kaumana	5	11	12	3	11	18	42	12	27	95	32*	7*	1*	*	0
9	Muni. Golf Course	86	46	33	9	19	152	348	409	461	980	507	531	91	167	22
10	Kalanianaole	23	17	27	82	76	193	42	43	360	237	25	26	51	51	44*
11	Hakalau	14	7	27	0*	10	29	13	25*	13	2	3	1	1*	0	4*
12	Laupahoehoe	22	41	67	2	4	4	7	2	12	0	4	31	24	42	17*
13	Pahoa	0	6	4	0	5	63	98*	31	119	257	65	117	6*	0	14
14	Mountain View	4	10	15	3	7	37	24	25	83	82	15	57	18	8	11
15	Ookala	72	45	31	16	15	21	11	21	44	34	48	476	86	21	23*
16	Keaau	95	343	263	67	523	121	52	7	20	57	53	74	24	38	7
17	J. Serain	73	15	56	3	5*	42	170	36	91	234	117	11*	0*	84	63*
18	Hilo Airport	141	70	74	6	362	1040	1617	649	428*	2428	272	456	461	399	79
19	Okamoto	21	34	28	3	44	249	247	105	51	237	92	182	144	189	35
20	Pahala	0	3	0	0	12	4	0	0	0	0	0	4	7	7	2
21	Honokaa	2	0	0	0	5	2	2	0	0	1	0	0	0	3	0
22	Waimea Airport	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0
23	Kawaihae Harbor	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0
24	Kohala Hospital	2	1	1	1	1	2	1	0	0	26	0*	0	0	6	2
25	Keahole Airport	1	0	4	2	1	10	47	98	176	75	52	1	2	25	17
26	Kailua School	0	0	0	0	0	3	8	15	27	10	3	0	2	2	2
27	Kona Health Cntr.	3	1	6	5	3	8	22	35	26	14	11	5	7	10	16
28	Kona County Garage	1	2	6	5	4	9	28	40	31	33	26	7	5	16	20
29	Pepeekeo	82	64	36	6	414	156*	290	433	467	402	319	105	413	716	264*
30	U. H. Hilo	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0
31	C. Granat	24	55	57	11	21	19	discontinued								
Total for island		843	1020	952	293	1814	3015	4269	2413	3074	7381	2025	2621	1578	2111	721

* Indicates trap malfunction.

tions have resulted in the formation of kipukas, or pockets of undisturbed vegetation surrounded by relatively barren lava flows. Within the kipuka there are oviposition sites for mosquitoes and vegetation providing both food and roosting sites for bird and mammal hosts. Predictably, *C. quinquefasciatus* activity observed in this study was concentrated in these kipukas. This is well illustrated by the larval collections at Stations 18 and 18a. Station 18 was located in Kipuka Ki at an elevation of 1350 m. Vegetation cover consisted of *Acacia koa* and *Metrosideros* sp. trees with an understory of *Styphelia* sp. and grasses. *C. quinquefasciatus* was recorded from this station in oviposition sites provided, as well as natural sites, including hapu'u stumps, treeholes and ground pools. The major breeding sites at this station were treeholes. Station 18a was located on exposed lava with invading grasses and low *A. koa* trees some 50 m outside of the kipuka. As shown in TABLE 1, no larvae were recovered from artificial oviposition sites provided. Additionally, no natural breeding sites could be located in the immediate vicinity of Station 18a and there were minimal indications of any host activity, although 50 m distant there was a stable breeding population of *C. quinquefasciatus* and considerable host concentration. A similar situation was observed for other kipukas in the study area. Thus distribution of *C. quinquefasciatus* at elevations above 1100 m coincided with the presence of kipukas caused by volcanic activity. This distribution combined with the increased bird and mammal activities associated with a kipuka would appear to increase the vector potential of even a small population of *C. quinquefasciatus.* It is of interest to note that the main natural breeding sites for *C. quinquefasciatus* at Station 18 were treeholes. This was observed also at other stations. Taylor & Maffi (1978) indicate that ground pools, ditches and large artificial containers were the principal breeding sites for *C. quinquefasciatus* in the South Pacific. Lack of permanent ground pools, due to the porous nature of the lava substrate, precludes this as a breeding site at most of the stations above 1100 m. Standing water in treeholes and hapu'u stumps at stations located in kipukas is abundant and serves here as the main natural breeding sites. Additional breeding of *C. quinquefasciatus* was observed in large oil drums and water troughs placed in the kipukas by the National Park Service.

Aedes albopictus on the east flank of Mauna Loa Volcano was primarily associated with human activities and to elevations below 300 m. Although there were 3 females observed biting at elevations of 1350 m and 1650 m, no permanent populations appeared to exist and these incidents were in areas associated with human activity.

Thus, patterns of distribution for *C. quinquefasciatus* given by Warner (1968) for Kauai do not apply to Hawaii I. The current study suggests that the "mosquito-free sanctuary" above 600 m for Hawaiian birds does not exist on the east flank of Mauna Loa and that, in fact, due to the concentrating mechanism of the kipuka at elevations above 1100 m, the birds and mosquitoes live in close association, thus providing an ideal situation for transmission of avian malaria and other such diseases among the endemic and introduced birds. Distribution of *A. albopictus* is, at present, in localities associated with human activities and below 300 m.

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