Mosquitoes Collected on the Offshore Islets of Oahu, Hawaii[1]

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Four species of noxious mosquitoes, *Aedes aegypti* (Linnaeus), *A. albopictus* (Skuse), *A. vexans nocturnus* (Theobald), and *Culex quinquefasciatus* Say, are present in Hawaii (Nakagawa, 1964). Nakagawa and Hirst (1959) reported that *A. aegypti* had not been found on Oahu since about 1949, and it was the only species not detected during a thorough survey conducted on that island by C.J. Wells (1968). Several species of *Toxorhynchites* have been introduced to the Hawaiian Islands for biological control of *A. albopictus* (Nakagawa, 1963; Steffan, 1968). Members of this genus are not blood feeders and thus pose no public health problem. Species representing this group were found on Oahu during the survey reported by Wells in 1968.

We knew of no mosquito study that had been made on the small islands just off the east shore of Oahu, so the present study was conducted to determine if and when mosquitoes are present on any of these islets. The study also was made to determine if mosquitoes could become involved in maintaining or amplifying cycles of arboviruses introduced into the offshore islands by migratory birds.

Significant outbreaks of dengue fever, which is caused by a mosquito-borne arbovirus, have occurred in Hawaii (Nakagawa and Hirst, 1959; Nakagawa, 1964). All but one species *A.v. nocturnus)* of the blood-feeding Hawaiian mosquitoes are known to be capable of becoming infected with one or more of the following arboviruses: St. Louis encephalitis (SLE) (Chamberlain *et al.*, 1959; Sudia, 1959); western equine encephalitis (WEE) or eastern equine encephalitis (EEE) (Chamberlain *et. al.*, 1954); Japanese B encephalitis (JBE) (LaMotte, 1960); yellow fever (Philip 1962) and dengue (Lumley, 1943). Since *A. vexans* is capable of becoming infected with some encephalitis viruses such as EEE (Wallis *et al.*, 1960) and SLE (Hammon and Reeves, 1943), it is logical to suspect that *A.v. nocturnus* might also become infected with an arbovirus.

MATERIALS AND METHODS

Surveys of the islets off the east shore of Oahu were conducted periodically from March 1966 through March 1968. Efforts were made to collect as many mosquito

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TABLE 1. *Mosquitoes collected on the offshore islets of Oahu, Hawaii, during 1966, 1967, and 1968.*

Island	Date of survey	Species	Mosquitoes collected				
			Females			Males	Total
			Empty	Blood Engorged	Gravid		
	1966						
Manana	Mar. 31-Apr. 1	*C. quinquefasciatus*	12		5	5	22
	Apr. 15	None					
	Apr. 27-28	None					
	Aug. 24	None					
	Dec. 7	*C. quinquefasciatus*	24	14	8	30	76
	1967						
	July 21	*C. quinquefasciatus*			1	1	2
		A. v. nocturnus	1				1
	Aug. 18	None					
Mokolii	Aug. 31-Sept. 1	None					
Manana	Sept. 12-13	None					
Mokuauia	Oct. 17-18	None					
Mokulua (N.)	Oct. 23	None					
Mokulua (S.)	Nov. 15	None					
Mokulua (N.)	Nov. 15-16	None					
Popoia	Nov. 30	None					
Manana	Dec. 7	None					
	1968						
Mokolii	Jan. 26	*C. quinquefasciatus*	12			1	13
		A. albopictus				2	2
Manana	Jan. 30	*C. quinquefasciatus*	15	2	2	4	23
Kapapa	Jan. 30	*C. quinquefasciatus*	30	1	2	3	36
		A. v. nocturnus	4	1	1	2	8
Mokuauia	Feb. 7	*C. quinquefasciatus*	53		1	27	81
Popoia	Feb. 7	*C. quinquefasciatus*	75	1	5	271	352
		A. albopictus	1				1
Manana	Mar. 10	*C. quinquefasciatus*	5	4			9
		A. albopictus	1				1

larvae, pupae, and adults as possible in order to detect the species present and their relative abundance. Blood-engorged specimens were submitted for blood-meal determinations.

Of the islets surveyed, the 67-acre Manana (often referred to as Rabbit Island) at Waimanalo is the largest. Mokuauia (Goat Island), Laie Bay, is 12.5 acres; North and South Mokulua (Twin Islands), Lanikai, are 12.4 and 11.7 acres, respectively; Kapapa, Kaneohe Bay, 7 acres; and Mokolii (Chinaman's Hat), Kaneohe Bay, 4 acres. Popoia (Flat Island), Kailua Bay, is the smallest with 3.6 acres. These islands extend along the Oahu coastline for about 30 miles from Waimanalo to Laie Bay and are located about 500 yards (Popoia) to 2 miles (Kapapa) offshore.

We reached the islets by inflatable rubber raft or by boat. Adult mosquitoes were collected with a "D-Vac" mechanical aspirator, and larvae were obtained by dipping and were preserved in 70% alcohol for later identification. Suspensions were made from blood-engorged female mosquitoes and were tested with antisera against a variety of avian and mammal groups. The mosquito blood-meal determinations were performed by the microcapillary-precipitin technique as previously described by Tempelis and Lofy (1963).

Results and Discussion

The survey dates and the results obtained during the 2-year study on the offshore islets of Oahu are given in Table 1. Three species of mosquitoes were found: *C. quinquefasciatus, A. albopictus,* and *A.v. nocturnus*. All three species were collected from Manana Island. Adult mosquitoes were obtained there in March 1966, December 1966, July 1967, January 1968, and March 1968. Larvae and pupae of *C. quinquefasciatus* were found on Manana in January 1968 and March 1968 in rain water that had accumulated in a red ammunition can (7″ × 11″ × 6″) lying in the crater. *C. quinquefasciatus* and *A. albopictus* adults were collected from Mokolii and from Popoia in January 1968 and February 1968, respectively. Larvae of *C. quinquefasciatus* were dectected in cavities in volcanic rock on Popoia Island during the February 1968 survey. Adult *C. quinquefasciatus* and *A.v. nocturnus* were obtained from Kapapa in January 1968. Only adult *C. quinquefasciatus* were found on Mokuauia Island, and that was during February 1968. No mosquito was found on either of the Mokuluas.

Twenty-three blood-engorged mosquitoes (22 *C. quinquefasciatus* and 1 *A.v. nocturnus*) were collected during the surveys, but only 12 *C. quinquefasciatus* specimens contained enough blood for blood-meal determinations. Seven specimens in the December 7, 1966, collection on Manana Island had fed on passeriform birds and two on undetermined types of birds; two other specimens collected there on March 10, 1968, had fed on charadriiform birds. The single engorged *C. quinquefasciatus* collected on Kapapa Island on January 30, 1968, had fed on a dog. Tempelis *et al.* (1970) studied the blood-feeding habits of mosquitoes on the Hawaiian Islands of Oahu, Kauai, Hawaii, and Molokai and found that *C. quinquefasciatus* fed primarily on birds, although feedings on mammals also were reported.

Because of the relatively small size of the islets surveyed, it is believed that mosquitoes were detected during the surveys when they were present. The collection records in Tables 1 and 2 show that mosquitoes were present on the islands periodically.

It is assumed that the primary source of mosquitoes was the nearby island of Oahu, although breeding on the islets provided some of the specimens collected.

TABLE 2. *Association between occurrence of "Kona Winds" and presence of mosquitoes on offshore islets of Oahu, Hawaii, 1966, 1967, and 1968.*

		Mosquitoes found		Occurrence of "Kona Winds"[a]			
				Honolulu international airport	Mokapu point		
					velocity (m.p.h.)		
Islands	Date of survey	Adults	Larvae	No. days	Fastest gust	Mean Value	Fastest[b] gust
Manana	Mar. 31-Apr. 1, '66	+		8	31	8.2	48
	Apr. 15, '66			6	16	7.1	14
	Apr. 27-28, '66			7	16	7.4	14
	Apr. 24, '66			0	0	0	0
	Dec. 7, '66	+		3	29	7.6	28
	July 21, '67	+		4	16	5.2	18
	Aug. 18, '67	+		3	16	5.6	18
	Sept. 12-13, '67			0	0	0	0
	Dec. 7, '67			3	14	3.8	9
	Jan. 30, '68	+	+	16	31	7.0	45
	Mar. 10, '68	+	+	21	32	6.7	43
Mokolii	Aug. 31-Sept. 1, '67			0	0	0	0
	Jan. 26, '68	+		15	31	7.2	50
Mokuauia	Oct. 17-18, '67			1	14	4.8	7
	Feb. 7, '68	+		17	29	6.5	50
Mokulua (N)	Oct. 23, '67			1	14	4.8	7
	Nov. 15-16, '67			2	14	4	9
Mokulua (S)	Nov. 15, '67			2	14	4	9
Popoia	Nov. 30, '67			3	14	3.8	9
	Feb. 7, '68	+	+	17	29	6.5	50
Kapapa	Jan. 30, '68	+		16	31	7.0	45

[a] Wind data for the 8-week period before the respective surveys began.

[b] Records of only the fastest gusts recorded from Mokapu Point (Kaneohe Marine Corps Air Station) are presented because the records for that area are sketchy.

Adult mosquitoes could have been introduced from Oahu by flight, dispersion by wind, or transportation by man. The latter possibility seems quite unlikely because of the improbability of their gaining access by the small craft which are the only means of transportation to the islets. Purposeful flight to the islets seems a possibility. In a flight range study conducted on Oahu, Bonnet and Worcester (1946) found that 177 of a total of 183 recaptured *A. albopictus* were recovered at a distance of 200 yards or less from the point of release; the maximum distance recorded was 475 yards. The mean distance traveled for all recaptured *A. albopictus* was 68.7 yards. The authors concluded that these mosquitoes will normally travel 200 yards or less during their lifetime. Clarke (1943) in Illinois found that 36 of 41 *A. vexans* had traveled 5-14 miles from a release site. Some blood-engorged species of *Aedes* and *Culex* mosquitoes are capable of flying at least 1 mile (Edman and Bidlingmayer, 1969). Fussell (1964) made a study to determine the flight range of *C. quinquefasciatus* from Waipio Peninsula on Oahu toward the Pearl Harbor area. Of 634 tagged specimens that he recovered, 614 were collected in light traps up to 0.5 miles from the release point, 12 between 0.75 miles and 1.3 miles from the point of release, and 8 were recovered between 2.5 miles and 3.5 miles from the point of release. Ten specimens had crossed bodies of water which were at least 800 feet wide. The direction in which the tagged mosquitoes were recovered coincided with the direction in which the prevailing winds blew. Shanon and Davis (1930) showed that *A. aegypti* is capable of dispersing more than 1000 yards over water but that the flight range of this species over land was quite short with distances of less than 131 yards being the rule and 361 yards being the maximum reported. In a study conducted in a residential area of Savannah, Georgia, Morlan and Hayes (1958) reported the dispersion of *A. aegypti* up to 191 yards. These authors, however, pointed out that this distance represented the outer edge of the survey area and that some mosquitoes dispersed beyond the survey boundaries. *Toxorhynchites* have been reported to disperse 3-4 miles from points of release in Hawaii, and a maximum of about 15 miles has been documented (Nakagawa, 1963).

Freeman (1945) pointed out that insects exhibit more aerial activity during periods of low wind velocities than during periods of high wind velocities. He showed that insect population densities generally increased when the wind velocity ranged from 6 to 12 m.p.h. and they decreased when the velocities were greater. Bailey *et al.* (1965) noted that wind velocities above 6 m.p.h. seem to discourage *Culex tarsalis* flight and reduce the likelihood of their dispersion. Bonnett and Worcester (1946) believe that wind has little influence on the dispersion of *A. albopictus* because that species normally flies close to the ground. However, Garrett-Jones (1950) reported that *Anopheles pharoensis* suddenly became abundant downwind from strong winds occurring at night when the moon was full in the western desert of Egypt. He noted that mosquito dispersion may also be subject to the lunar cycle. In a study conducted in Holland, Swellengrebel (1929) concluded that winds played a significant role in the dispersion of *Anopheles maculipennis* in the direction in which the wind blew.

The westerly winds, locally referred to as "Kona Winds," blow from the direction of the Oahu mainland toward the offshore islets. Table 2 includes climatological data obtained from the Environmental Science Services Administration, U.S. Department of Commerce, Honolulu, and from the Meterology Branch, U.S. Marine Corps Air Station, San Francisco. The data indicate that the presence of mosquitoes on the islets was associated with (1) stronger gusts of "Kona Winds," (2) greater number of days in which they blew, and (3) higher mean velocities. The highest values for these conditions occurred within a 2-month period prior to each

islet survey in which mosquitoes were found, with the exception of the July 21, 1967, survey on Manana when 3 mosquitoes were found. It seems probable that the periodic blowing of these winds toward the offshore islets of Oahu might contribute to the periodic occurrences of *C. quinquefasciatus* on the islets. It is possible that the Hawaiian mosquitoes are aerially active during periods of low wind velocities and that they are caught "off guard" by gusts of "Kona Winds" which blow them toward the offshore islets. According to Felt (1925), when wind currents are obstructed by a mountain barrier they can split as they go over; one part may go over at a relatively high altitude and the other may immediately turn downward. The Koolau mountain range on Oahu separates the leeward from the windward sides of that island, and the type of wind action described by Felt could carry mosquitoes to the offshore islands from either the eastern (windward) or the western (leeward) side of Oahu. The *Aedes* species may be blown onto the islets, but it is also possible that they are permanently established on some of them. If this is the case, adult *Aedes* could be present periodically, depending upon the occurrence of the biological conditions needed for the occasional hatching of their egg broods. Assuming either that the proper conditions for the hatching of *A. aegypti* did not occur during the period of this study or that the species is not permanently established on these small islands, the failure to find this mosquito there is attributed to its apparent absence on Oahu (Nakagawa, 1964; Wells, 1968). No *Toxorhynchites* were found on the islets, possibly because that species inhabits vegetated areas where winds have little effect on their dispersal.

That mosquitoes are attracted to these islets by the presence of the migrating pelagic birds which breed there seems unlikely. An unpublished 1968 Smithsonian Institution report indicates that large numbers of Wedgetailed Shearwaters *(Puffinus pacificus),* Sooty Terns *(Sterna fuscata),* and Brown Noddies *(Anous stelidus)* breed on the islets and as a result are found there from March through November. However, the greatest numbers of mosquitoes were found on the islets from December through February; mosquitoes were found during only three of the 14 surveys made from March through November.

Tempelis *et. al.* (1970) concluded from their studies on the inhabited islands of Oahu, Kauai, Hawaii, and Molokai that the four blood-feeding mosquito species in Hawaii might serve as enzootic vectors of arboviruses. Our survey results indicate that if an arbovirus was introduced by migrant birds or by other means to the small offshore islets studied, the virus probably would not become established because of the small number of mosquitoes on those islets.

Summary

A. albopictus, A.v. nocturnus, and *C. quinquefasciatus* were periodically found on the offshore islets of Oahu. Mosquitoes were collected from the islets of Kapapa, Manana, Mokolii, Mokuauai, and Popoia. Our data suggest that strong westerly winds might contribute to their presence. Because of the small numbers of mosquitoes on the off-shore islands, they are probably of no public health importance.

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REFERENCES CITED

Bailey, S.F., Eliason, D.A., and Hoffmann, B.L. 1965. Flight and dispersal of the mosquito *Culex tarsalis* Coquillet in the Sacramento Valley of California. Hilgardia 37: 73-113.

Bonnet, D.D., and Worcester, D.J. 1946. The dispersal of *Aedes albopictus* in the territory of Hawaii. Amer. J. Trop. Med. 26: 465-476.

Chamberlain, R.W., Corristan, E.C., and Sikes, R.K. 1954. Studies on the North American arthropod-borne encephalitides. V. The extrinsic incubation of eastern and western equine encephalitis in mosquitoes. Amer. J. Hyg. 60: 269-277.

Chamberlain, R.W., Sudia, W.D., and Gillett, J.D. 1959. St. Louis encephalitis virus in mosquitoes. Ibid. 70: 221-236.

Clarke, J.L. 1943. Studies of the flight range of mosquitoes. J. Econ. Entomol. 36: 121-122.

Edman, J.D., and Bidlingmayer, W.L. 1969. Flight capacity of blood-engorged mosquitoes. Mosq. News 29: 386-392.

Felt, E. P. 1925. The dissemination of insects by air currents. J. Econ. Entomol. 18: 152-158.

Freeman, J.A. 1945. Studies in the distribution of insects by aerial currents. J. Anim. Ecol. 14: 128-154.

Fussell, E.M. 1964. Dispersal studies on radioactive-tagged *Culex quinquefasciatus* Say. Mosq. News 24: 422-426.

Garrett-Jones, C. 1950. A dispersion of mosquitoes by wind. Nature (London) 165(1490): 285.

Hammon, W. McD., and Reeves, W.C. 1943. Laboratory transmission of St. Louis encephalitis virus by three genera of mosquitoes. J. Expt. Med. 78: 241-253.

LaMotte, L.C., Jr. 1960. Japanese B encephalitis virus in the organs of infected mosquitoes. Amer. J. Hyg. 72: 73-87.

Lumley, G.F. 1943. Dengue. Part 1. Med. Univ. Sydney, Sch. Pub. Hlth. and Trop. Med. Number 3. Australasian Med. Pub. Co., Glebe, New South Wales. 171p.

Morlan, H.B. and Hayes, R.O. 1958. Urban dispersal and activity of *Aedes aegypti*. Mosq. News 18: 137-144.

Nakagawa, P.Y. 1963. Status of *Toxorhynchites* in Hawaii. Proc. Hawaiian Entomol. Soc. 18: 291-293.

_____. April, 1964. Mosquito control in Hawaii. Pest Control, 32: 24, 27, 28, 30.

Nakagawa, P.Y., and Hirst, J.M. 1959. Current efforts in mosquito control in Hawaii. Mosq. News. 19: 64-67.

Philip, C.B. 1962. Transmission of Yellow Fever virus by aged *Aedes aegypti* and comments on some other mosquito-virus relationships. Amer. J. Trop. Med. Hyg. 11: 697-701.

Shannon, R.C., and Davis, N.C. 1930. The flight of *Stegomyia aegypti (Aedes aegypti)*. Amer. J. Trop. Med. 10: 151-156.

Smithsonian Institution. July, 1968. Oahu, Kauai, and offshore islands summary. Unpublished report. 100p.

Steffan, W.A. 1968. Hawaiian *Toxorhynchites* (Diptera: Culicidae). Proc. Hawaiian Entomol. Soc. 20: 141-155.

Sudia, W.D. 1959. The multiplication of St. Louis encephalitis virus in two species of mosquitoes: *Culex quinquefasciatus* Say and *Culex pipiens* Linnaeus. Amer. J. Hyg. 70: 237-245.

Swellengrebel, N.H. 1929. On the influence of the wind in the spread of *Anopheles maculipennis*. Amer. J. Hyg. 10: 419-434.

Tempelis, C.H., Hayes, R.O., Hess, A.D., and Reeves, W.C. 1970. Blood-feeding habits of four species of mosquito found in Hawaii. Amer. J. Trop. Med. Hyg. 19: 335-341.

Tempelis, C.H., and Lofy, M.F. 1963. A modified precipitin method for identification of mosquito blood-meals. Amer. J. Trop. Med. Hyg. 12: 825-831.

Wallis, R.C., Taylor, R.M., and Henderson, J.R. 1960. Isolation of eastern equine encephalomyelitis virus from *Aedes vexans* in Connecticut. Proc. Soc. Expt. Biol. Med. 103: 442-444.

Wells, C.J. 1968. Past northern regional supervisor, *Aedes aegypti* Eradication Project, Florida. Personal communication.