Determining the current distribution of mosquitoes on the island of Maui
A Final Report

Submitted to the
Hawaii Invasive Species Council

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Executive Summary

Mosquitoes (Diptera: Culicidae) are known vectors of human diseases and nuisance pests that can negatively impact on human health and well-being. There are no native mosquitoes in Hawaii and many of the species present are competent vectors of disease. Yet, little is known about the distribution of mosquitoes within Hawai'i, particularly on the less populated island such as Maui. This project sought to fill a critical gap in knowledge through the deployment of oviposition traps and adult lure traps across the island. Every two months traps were set at 18 different locations around Maui for a total of six trapping events. An additional trap was set at Kahului airport in December 2017 and February 2018 following a confirmed detection of *Aedes aegypti* at the airport. The adult mosquitoes, eggs and subsequent hatching larvae were counted and where possible identified. These data were used to generate distribution maps of mosquitoes. Two species (*Culex quinquefasciatus* and *Aedes albopictus*) of mosquito were collected in the oviposition traps and four species (*Culex quinquefasciatus*, *Aedes albopictus, Wyeomia mitchelli* and *Aedes vexans*) were collected from the adult traps. The presence and abundance of these mosquitoes varied across the island. *Culex quinquefasciatus* and *A. albopictus* were widespread and consistently caught over the year. The other two species were detected infrequently. All four species were collected in Makawao and Kihei. It is recommended that continued trapping of mosquitoes occur across Maui although with greater trapping intensity in time and space to more effectively detect new incursions and delineate trends and patterns in distribution.

Approach and Findings

Trapping

Oviposition traps were placed around the island of Maui every two months for 3 days to collect eggs of ovipositing mosquitoes (Figure 1, Table 1). Two types of traps were set at each site: one containing filtered fresh water and the other contained water with a cut-grass infusion. On three occasions one of the traps at one of the sites was tipped over and no samples were able to be obtained. The eggs from each trap were counted and then placed in mosquito rearing chambers and hatching larvae were reared to fourth instar at the Kula Research Station, Maui. The larvae were then shipped to Oahu for identification.

Adult mosquitoes were trapped using BioGents Sentinel traps powered by a 24V battery for 24 hours during each of the sampling sessions over the course of the year at nine locations around Maui (Figure 1, Table 1). Mosquitoes were lured to the trap with light and both proprietry (BG lure) and octenol (1-Octen-3-ol) lures. Traps were placed in areas where they were not visible from the road and where possible in a secure, fenced area to reduce the probability of theft. Adults were shipped to Oahu for identification.

Figure 1. Sites where traps for mosquitoes were placed around the island of Maui.

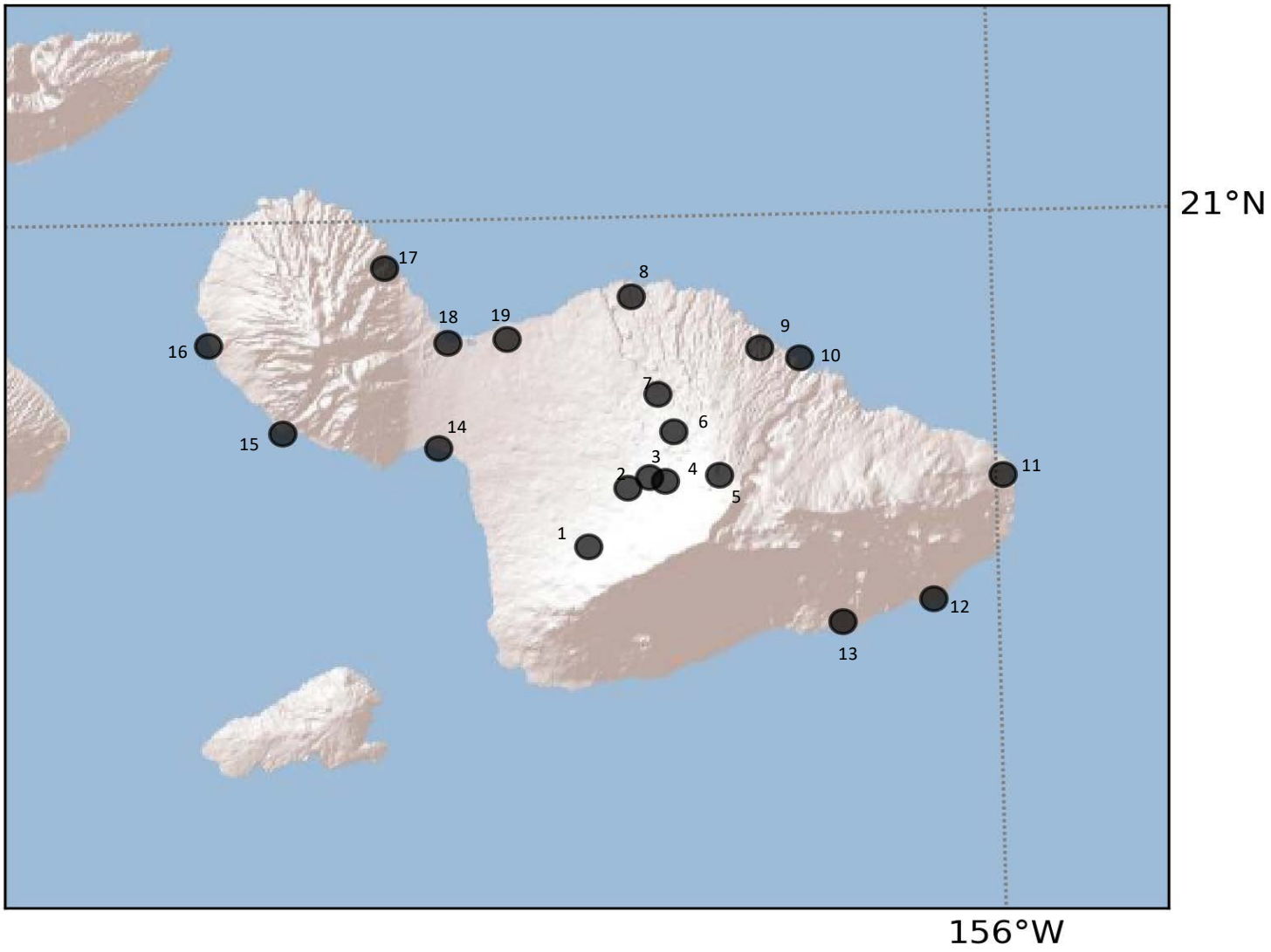


Table 1. Site information and trap (O=oviposition; A = adult) placement.

Site	Name	Latitude	Longitude	Elevation (m)	O	A
1	Keokea	20.70573	-156.35677	844.255	Y	Y
2	Kula	20.757617	-156.32103	975.878	Y	Y
3	Haleakala Road 2	20.76689	-156.302	1131.110	Y	N
4	Haleakala Road 1	20.76264	-156.28824	1443.392	Y	N
5	Haleakala National Park	20.767487	-156.2413	2050.527	Y	N
6	Maui Forest Bird Recovery, Makawao	20.806919	-156.2804	1152.609	Y	Y
7	Maui Invasive Species Council, Makawao	20.840894	-156.29374	660.021	Y	Y
8	Wakina, Haiku Pauwela	20.928694	-156.31458	88.871	Y	N
9	Hana Hwy 1	20.881008	-156.2042	234.346	Y	N
10	Kaumahina State park, Hana Hwy	20.871663	-156.16936	135.522	Y	N
11	Hana Health	20.763534	-155.99442	62.594	Y	Y
12	Kipahulu	20.6529	-156.0572	92.354	Y	N
13	Kaupo	20.63463	-156.13658	49.987	Y	Y
14	Kealia Pond, Kihei	20.795928	-156.48574	19.978	Y	Y
15	Olowalu	20.811112	-156.62107	20.117	Y	Y
16	Lahaina	20.890853	-156.68395	18.593	Y	N
17	Waihee	20.958035	-156.52969	261.596	Y	N
18	Kahului	20.889865	-156.47573	19.507	Y	Y
19	Kahului Airport	20.8924	-156.424	18.593	Y	N

Mosquito presence on Maui

A total of 746 eggs were collected across all sites and sampling periods (Table 2). The largest number of eggs was collected in Lahaina (63%) with the peak oviposition occuring in June and August and the Forest Bird Recovery Center in Makawao (16%) in August (Table 2).

A total of 694 larvae hatched from eggs collected in oviposition traps, a 93% hatching rate. The majority of larval hatch occurred in August with 70% of larvae hatching from eggs collected at this time and 16% hatched for the prior collection in June. No larvae hatched from any sample in February. Only two species of mosquito hatched from eggs, *C.quinquefasicatus* (87%) and *A. albopictus*.

A total of, 322 adult mosquitoes were collected and identified. The vast majority of adults (92%) were identified as *A. albopictus*, with 4% being *C. quinquefasciatus*, 3% were *W. mitchellii,* and the remaining 1% were *A. vexans* (Table 3). We did not collect any *A. japonicus*, although they have been reported on Maui (inaturalist.org, web). We did not collect any *A. aegypti*, although there was a verified report that larvae of this species had been collected from the airport in Kahului in November 2017.

The highest average number of adult mosquitoes (42%) was collected in June 2017 with an average of 15 mosquitoes in each trap across all sites (Table 3). The majority (95%) of these were *A. albopictus*. The very low numbers of adults collected in December relative to the other sampling periods is likely due to the heavy rains that led to island-wide power outages at that time (Table 3 and 4). The highest number of mosquitoes collected at this time were in Kahului.

Over the whole year, the majority (30%) of the adult mosquitoes were collected from the trap placed in Hana (Hana Health clinic) followed by the trap placed in Kahului (22%) (Table 4). Adult mosquitoes were generally, consistently collected in Kula, Hana, Olowalu and Kahului, although the numbers varied over the year (Table 4).

Table 2 . Number of eggs in oviposition traps set at sites around Maui over the course of a year from April 2017 to February 2018. N/A indicates sites where traps were not set. An asterisk indicates that one of the oviposition traps went missing.

Site	April	June	August	October	December	February	Total
Haleakala National Park	0	0	0	0	0	0	0
Haleakala Road 2	0	0*	0	0	0	0	0
Haleakala Road 1	0	0	0	0	0	0	0
Hana Health	0	0	2	31	25	0	58
Hana Hwy 1	0	0	7	2	0	0	9
Kahului	0	0	0	0	0	0	0
Kahului Airport	N/A	N/A	N/A	N/A	10	0	10
Kaumahina State Park, Hana Hwy	0	8*	1	3	1	0	13
Kaupo	3	0	0	0	0	0	3
Kealia Pond, Kihei	0	5	0	0	0	1	6
Keokea	2	0	0	0	0	0	2
Kipahulu	0	6	1	0	0	0	7
Kula	0	0	0	0	0	0	0
Lahaina	0	110	360	0	0	0	470
Maui Forest Bird Recovery, Makawao	0	0	115	7	0	0	122
Maui Invasive Species Council, Makawao	0	1	2	0	0	1	4
Olowalu	2	0	0	0	0*	0	2
Waihee	3	0	0	0	0	0	3
Wakina, Haiku Pauwela	0	2	15	2	18	0	37
Grand Total	10	132	503	45	54	2	746

Table 3 . The total and mean number of adult mosquitoes collected in traps (9 traps total) on the island of Maui during six trapping sessions over a one year period from April 2017 to February 2018.

	C. quinquefasciatus	*A. albopictus*	*A. vexans*	*W. mitchellii*	*Total (%)*	*Mean/trap*
April	6	44	1	1	52 (16%)	5.8
June	4	127	3	0	134 (42%)	14.9
August	0	26	0	5	31 (10%)	3.4
October	2	59	0	1	62 (19%)	6.9
December	1	15	0	0	16 (5%)	1.8
February	1	24	0	2	27 (8%)	3
Total	14 (4%)	295 (92%)	4 (1%)	9 (3%)	322	35.8

Table 4. Number of adult mosquitoes (all species) and mean/sample collected at each site over the course of one year.

Site	April	June	August	October	December	February	Total (%)	Mean / sample
Kealia Pond, Kihei	2	3	0	0	0	2	7 (2%)	1.2
Maui Invasive Species Council, Makawao	0	0	1	25	0	2	28 (9%)	4.7
Maui Forest Bird Recovery, Makawao	5	10	6	1	0	0	22 (7%)	3.7
Kula	13	23	3	8	1	1	49 (15%)	8.2
Hana Health	8	57	18	9	2	3	97 (30%)	16.2
Kaupo	4	0	0	10	0	0	14 (4%)	2.3
Keokea	0	0	0	0	0	2	2 (<1%)	0.3
Olowalu	10	1	1	3	4	10	29 (9%)	4.8
Kahului	10	40	2	6	9	7	74 (23%)	12.3
Total	52	134	31	62	16	27	322	

Aedes albopictus

Aedes albopictus was widely distributed across the island of Maui (Figure 2) and consistently throughout the year in Kahului, Kula, Hana and Olowalu (Table 5). No *A. albopictus* were detected at Haleakala National Park or on the two sites along the Haleakala Park road or on the west end of Maui in Lahaina (Table 5). Larvae were present consistently throughout the year at the Wakina site and in the Hana area and occasionally at other sites (Table 6).

Only 2 adults (of *A. albopictus*) were collected from the site in Keokea (Table 7). There was a surge in mosquito numbers at the MISC, Makawao site in October (Table 4). These were all *A. albopictus* (Table 7).

Figure 2. Distribution of *Aedes albopictus* collected from adult and oviposition traps set at sites around Maui over the course of a year from April 2017 to February 2018.

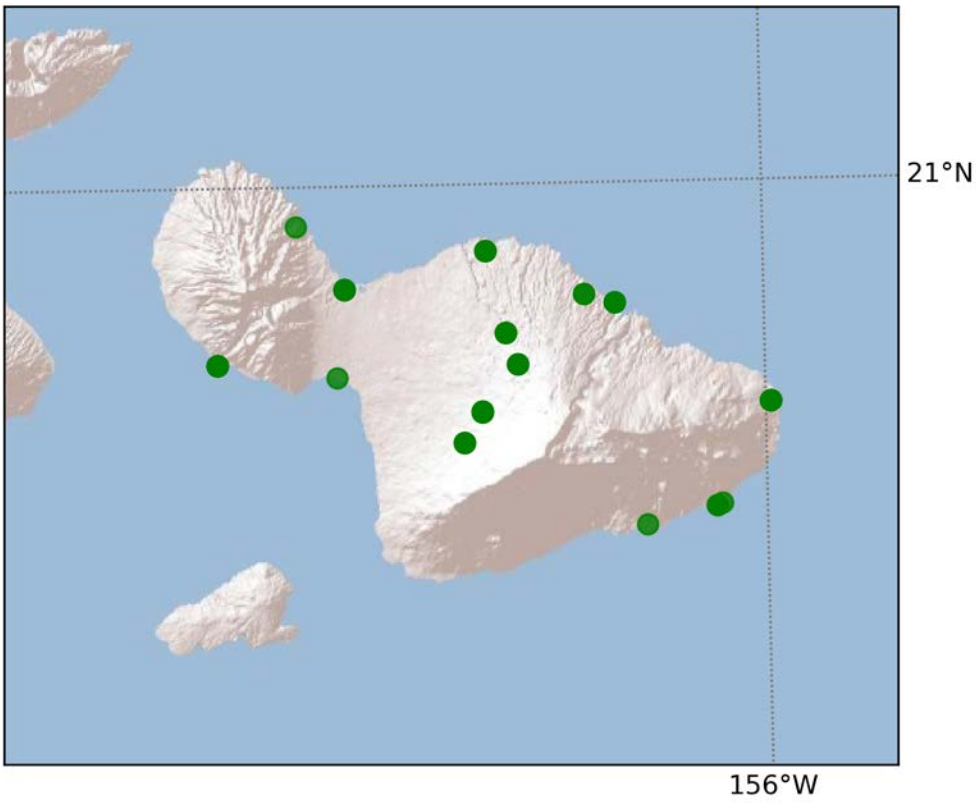


Table 5 Presence (1) and absence (0) of *Aedes albopictus* (as collected in adult and oviposition traps) at different sites throughout the year.

Site Name	April	June	August	October	December	February
Haleakala National Park	0	0	0	0	0	0
Haleakala Road 2	0	0	0	0	0	0
Haleakala Road 1	0	0	0	0	0	0
Hana Health	1	1	1	1	1	1
Hana Hwy 1	0	0	1	1	0	0
Kahului	1	1	1	1	1	1
Kahului Airport	N/A	N/A	N/A	N/A	0	0
Kaumahina State park, Hana Hwy	0	1	1	1	0	0
Kaupo	1	0	0	1	0	0
Kealia Pond, Kihei	0	0	0	0	0	1
Keokea	1	0	0	0	0	1
Kipahulu	0	1	1	0	0	0
Kula	1	1	1	1	1	1
Lahaina	0	0	0	0	0	0
Maui Forest Bird Recovery, Makawao	0	1	1	0	0	0
Maui Invasive Species Council, Makawao	0	0	1	1	0	1
Olowalu	1	1	1	1	1	1
Waihee	1	0	0	0	0	0
Wakina, Haiku Pauwela	0	1	1	1	1	0

Table 6. Number of *Aedes albopictus* larvae hatching from samples of eggs in oviposition traps set at sites around Maui over the course of a year from April 2017 to February 2018. N/A indicates sites where traps were not set. An asterisk indicates that one of the oviposition traps went missing.

Site Name	April	June	August	October	December	February	Total (%)
Haleakala National Park	0	0	0	0	0	0	0
Haleakala Road 2	0	0*	0	0	0	0	0
Haleakala Road 1	0	0	0	0	0	0	0
Hana Health	0	0	2	0	20	0	22 (25.3%)
Hana Hwy 1	0	0	7	2	0	0	9 (10.3%)
Kahului	0	0	0	0	0	0	0
Kahului Airport	N/A	N/A	N/A	N/A	0	0	0
Kaumahina State park, Hana Hwy	0	7*	1	2	0	0	10 (11.5%)
Kaupo	2	0	0	0	0	0	2 (2.3%)
Kealia Pond, Kihei	0	0	0	0	0	0	0
Keokea	1	0	0	0	0	0	1 (1.2%)
Kipahulu	0	6	1	0	0	0	7 (8%)
Kula	0	0	0	0	0	0	0
Lahaina	0	0	0	0	0	0	0
Maui Forest Bird Recovery, Makawao	0	0	0	0	0	0	0
Maui Invasive Species Council, Makawao	0	0	2	0	0	0	2 (2.3%)
Olowalu	2	0	0	0	0*	0	2 (2.3%)
Waihee	3	0	0	0	0	0	3 (3.4%)
Wakina, Haiku Pauwela	0	2	11	1	15	0	29 (33.3%)
Total (%)	8 (9.2%)	15 (17.2%)	24 (27.6%)	5 (5.8%)	35 (40.3%)	0	87

Table 7. Number of *Aedes albopictus* collected from adult traps set at sites around Maui over the course of a year from April 2017 to February 2018.

Site	April	June	August	October	December	February	Total (%)
Hana Health	8	53	18	9	2	3	93 (31.5%)
Kahului	10	40	2	6	8	6	72 (24.4%)
Kaupo	4	0	0	10	0	0	14 (4.8%)
Kealia Pond, Kihei	0	0	0	0	0	1	1 (0.3%)
Keokea	0	0	0	0	0	2	2 (0.7%)
Kula	12	23	3	8	1	1	48 (16.3%)
Maui Forest Bird Recovery, Makawao	0	10	1	0	0		11 (3.7%)
Maui Invasive Species Council, Makawao	0	0	1	25	0	1	27 (9.2%)
Olowalu	10	1	1	1	4	10	27 (9.2%)
Total (%)	44 (14.9%)	127 (43 %)	26 (8.8%)	59 (20%)	15 (5.1%)	24 (8.1%)	295

Culex quinquefasciatus

Culex quinquefasciatus was found in many locations across Maui but not on in the southern area of the island (Figure 3) . Larvae hatched from samples collected in June, August October and December (Table 8). The majority of these came from two sites, Lahaina (74% of all *C. quinquefasciatus* larvae) and Maui Forest Bird Recovery in Makawao (29%) (Table 8). The other area of high *C. quinquefasicatus* larval hatch was Hana Health (5%) (Table 8).

Fourteen *C. quinquefasciatus* adults were collected over the course of the year at various locations and times (Table 9).

Figure 3. Distribution of *Culex quinquifasciatus* collected from adult and oviposition traps set at sites around Maui over the course of a year from April 2017 to February 2018.

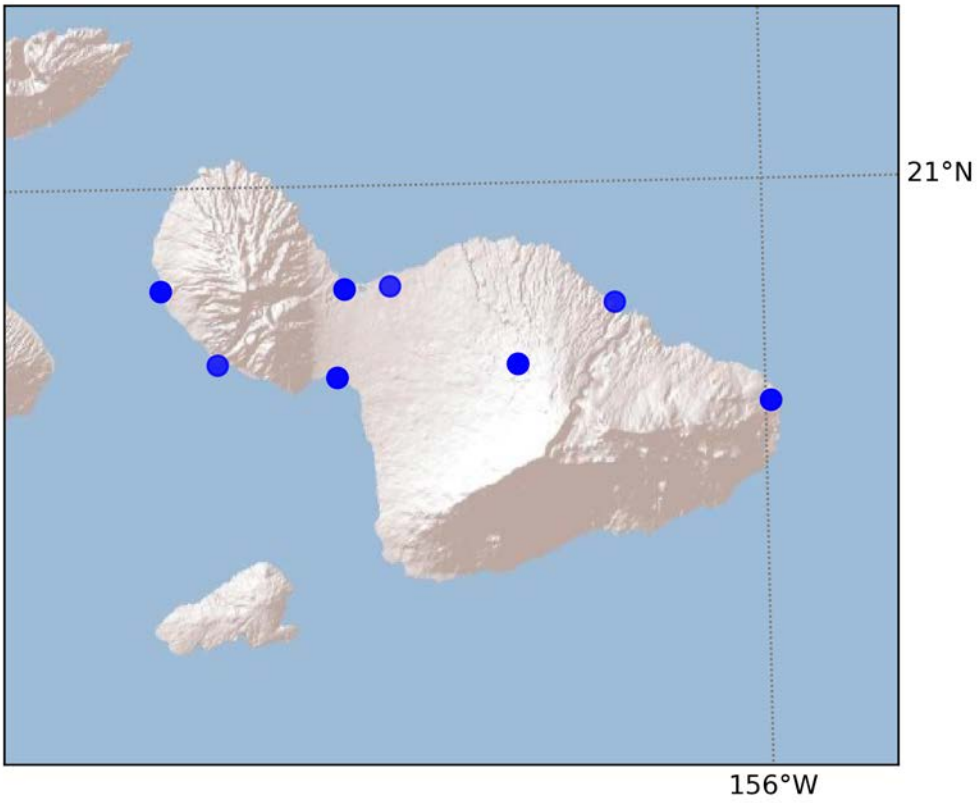


Table 8. Number of *Culex quinquefasciatus* larvae hatching from samples of eggs in oviposition traps set at sites around Maui over the course of a year from April 2017 to February 2018. N/A indicates sites where traps were not set. An asterisk indicates that one of the oviposition traps went missing.

Site	April	June	August	October	December	February	Total (%)
Haleakala National Park	0	0	0	0	0	0	0
Haleakala Road 2	0	0*	0	0	0	0	0
Haleakala Road 1	0	0	0	0	0	0	0
Hana Health	0	0	0	30	0	0	30 (4.9%)
Hana Hwy 1	0	0	0	0	0	0	0
Kahului	0	0	0	0	0	0	0
Kahului Airport	N/A	N/A	N/A	N/A	8	0	8 (1.3%)
Kaumahina State Park, Hana Hwy	0	0*	0	0	1	0	1 (0.2%)
Kaupo	0	0	0	0	0	0	0
Kealia Pond, Kihei	0	1	0	0	0	0	1 (0.2%)
Keokea	0	0	0	0	0	0	0
Kipahulu	0	0	0	0	0	0	0
Kula	0	0	0	0	0	0	0
Lahaina	0	101	350	0	0	0	451 (74.3%)
Maui Forest Bird Recovery, Makawao	0	0	109	7	0	0	116 (19.1%)
Maui Invasive Species Council, Makawao	0	0	0	0	0	0	0
Olowalu	0	0	0	0	0*	0	0
Waihee	0	0	0	0	0	0	0
Wakina, Haiku Pauwela	0	0	0	0	0	0	0
Total (%)	0	102 (16.8%)	459 (75.6%)	37 (6.1%)	9 (1.5%)	0	607

Table 9. Number of *Culex quinquefasciatus* collected from adult traps set at sites around Maui over the course of a year from April 2017 to February 2018.

Site	April	June	August	October	December	February	Total
Hana Health	0	4	0	0	0	0	4
Kahului	0	0	0	0	1	1	2
Kaupo	0	0	0	0	0	0	0
Kealia Pond, Kihei	2	0	0	0	0	0	2
Keokea	0	0	0	0	0	0	0
Kula	0	0	0	0	0	0	0
Maui Forest Bird Recovery, Makawao	4	0	0	0	0	0	4
Maui Invasive Species Council, Makawao	0	0	0	0	0	0	0
Olowalu	0	0	0	2	0	0	2
Total	6	4	0	2	1	1	14

Wyeomia mitchelli

A total of nine *W. mitchellii* adults were collected at various locations and times around Maui but none consistently (Figure 4, Table 10). No *W. mitchellii* were collected in December. No larvae hatched from any eggs collected. It may be that there were eggs laid by this species but they were among the 7% of eggs that did not hatch.

Figure 4. Distribution of *Wyeomia mitchellii* collected from adult traps set at sites around Maui over the course of a year from April 2017 to February 2018.

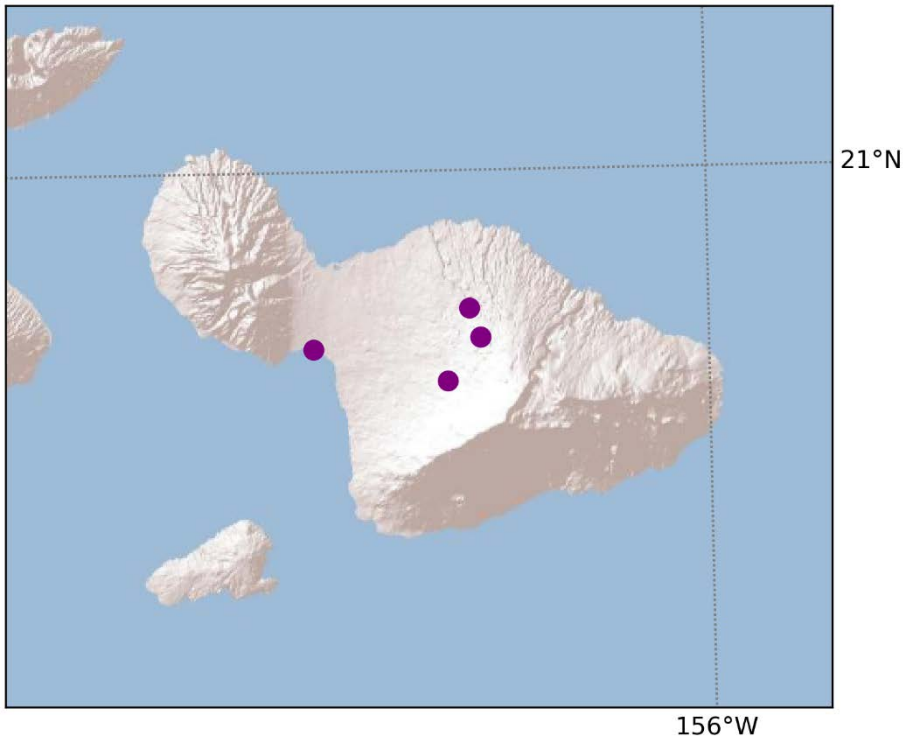


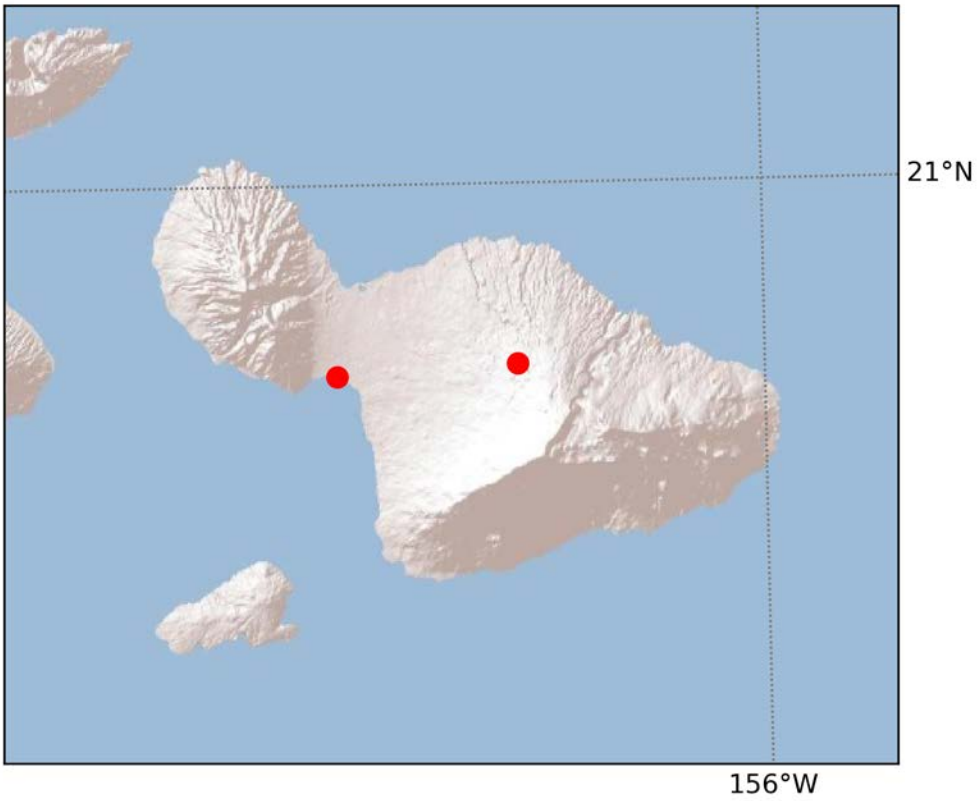
Table 10. Number of *Wyeomia mitchellii* collected from adult traps set at sites around Maui over the course of a year from April 2017 to February 2018.

Site	April	June	August	October	December	February	Total
Hana Health	0	0	0	0	0	0	0
Kahului	0	0	0	0	0	0	0
Kaupo	0	0	0	0	0	0	0
Kealia Pond, Kihei	0	0	0	0	0	1	1
Keokea	0	0	0	0	0	0	0
Kula	1	0	0	0	0	0	1
Maui Forest Bird Recovery, Makawao	0	0	5	1	0	0	6
Maui Invasive Species Council, Makawao	0	0	0	0	0	1	1
Olowalu	0	0	0	0	0	0	0
Total	1	0	5	1	0	2	9

Aedes vexans

Only four adult *A. vexans* were collected over the course of the year (Figure 5): 3 at Kealia Pond in Kihe in June and one at Maui Forest Bird Recovery center in Makawao in April. No larvae hatched from any of the eggs collected.

Figure 5. Distribution of *Aedes vexans* collected from adult traps set at sites around Maui over the course of a year from April 2017 to February 2018.



Evaluation of trapping

As necessitated by travel and budgetary constraints, sampling occurred every two months across 15 sites. Adult traps were set for one day and oviposition traps were set for three days.

Despite the abundance of *A. albopictus* adults across the island, as detected by adult traps, there was not a corresponding collection of *A. albopictus* larvae from eggs deposited in oviposition traps. This may be due to the overall abundance of naturally occurring breeding sites rendering our oviposition traps less competitive or that the grass infusion used in these traps was not as attractive as the locally available sites.

Culex quinquifasciatus was detected in more sites through the oviposition traps than through the adult traps and records of larvae occurred at different times of the year than adults.

Adult traps also yielded specimens of *W. mitchellii* and *A. vexans* but larvae were not detected in any oviposition traps. It may be that the oviposition traps we used were not attractive to these mosquitoes.

There are species reported to be present on Maui that were not detected in our trapping and there were some unusual patterns in mosquito abundance that we detected and should be further resolved e.g. peak in *A. albopictus* at the MISC site in Makawao in October 2017.

Recommendations

The limitation in detecting trends, patterns and species diversity could be resolved with greater trapping intensity in time and space. Adult traps should be set at least monthly. Oviposition traps should be set at least monthly and be

placed for at least one week. Trapping should continue over several years to determine the patterns and increase the probability of trapping species that are uncommon or rare.

The variation in the species response to the different traps (oviposition and BG sentinel) suggests that a variety of traps be used to assess mosquito diversity.

Future trapping, ideally, should be conducted by someone on the island who can regularly service the traps.

This baseline provides some valuable data for future work. Such baselines ought to be collected on Kauai, Molokai, Lanai and Kahoolawe.

For biosecurity purposes and to increase the probability of detecting new incursions, trapping intensity should be highest (trap number and trapping events) in and around Kahului, Hana, Olowalu, Kula and Makawao, and Kihei. These areas have an ideal environment to support an abundance of mosquitoes and from our data have relatively consistent presence of mosquitoes year-round. Makawao and Kihei have the greatest diversity of mosquitoes suggesting that there are many favorable microhabitats in these areas.

Project expenditures

The funds from this project were used to support a graduate research assistant for one year. A PhD student, Priscilla Seabourn, was hired to assist with the work.

This project provided support for seven trips (one to scout sites and 6 sampling trips) to Maui paying for the accommodation, rental car and airfare expenses associated with this travel.

Mosquito collection and rearing equipment was purchased including: BioGents sentinel traps and lures, batteries to run the traps, materials to make and construct plastic oviposition traps, mosquito rearing cages and additional storage container and supplies.

Acknowledgements

We are grateful for the assistance of Dr. James Leary for his assistance in scouting sites, facilitating our visits to Maui and to the staff at Kula Research and Experiment Station for their support in preparation for sampling and to process the samples. The Kula Research Station also provided access to a vehicle which reduced the overall travel expenses. Mr. Gerald Crank's volunteer assistance on the field trips was invaluable. Ms. Trudy Anthony and Mr. Chris Mithen provided additional logistical support. Permits to collect mosquitoes were granted by Halekala National Park Service (HALE-2017-SCI-0003) and Kaumahina State Park near Hana (M17-006). Additional permissions to collect on-site were granted for Kealia Pond (Kihei), Maui Invasive Species Council baseyard, Maui Forest Bird Recovery site in Makawao, West Maui Mountain Watershed Partnership in Olowalu, Kula Research Station, UH Cooperative Extension Office in Kahului, Hana Health service in Hana and at Haleakala Ranch. We thank Mark Leong for mosquito identification training and confirmation of questionable specimens.