Twenty Years of Complaints: Arthropods of Medical Importance in Maui County, Hawaii, from 2000 to 2019

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Abstract. A primary function of the Vector Control (VC) branch of the Hawaii Department of Health is managing invasive arthropods that endanger the health of Hawaii's residents and visitors and threaten disruption to the tourism-dependent economy. To partly accomplish this task, VC inspectors and entomologists ameliorate issues of vector nuisance raised through public complaints. In this study I assessed trends in public complaints received by the Maui VC office between the years 2000 and 2019, by year, month, island region, and pest type. Mosquitoes were the most complained-about pest across all island regions, but complaints varied little by year and month. Hymenopteran (primarily bee and yellowjacket) complaints were second-most common and were more frequent at high elevation areas on the slopes of Haleakala (= "Upcountry"). Hymenopteran complaints followed an annual unimodal trend with a peak in August and a trough in January. Altogether, complaints of outdoor pests (e.g., Hymenopterans, nuisance flies) have decreased over the past 20 years, while complaints of indoor pests (e.g., cockroaches, bed bugs) have increased. Future management of vector pests in Maui County should be carried out with consideration of these long-term trends.

Key words: Vector control, insects, mosquitoes, cockroaches, bed bugs

The Vector Control branch of the Hawaii Department of Health was created in 1970 when pre-existing Mosquito Control and Rodent Control programs were combined. The primary responsibility of the Vector Control (VC) branch is to maintain rapid-response capabilities to contain and eradicate outbreaks of vectored diseases (e.g., bubonic plague, murine typhus, leptospirosis, dengue fever, rabies) that endanger Hawaii's residents and visitors (Lew et al. 2018, Edwards 1962). Such actions are necessary after natural disaster events (Chowell et al. 2019, Kouadio et al. 2012) or when a new invasive species or arbovirus outbreak is detected (Lew et al. 2018, Hayes et al. 2006). Most recently the collaborative work of VC groups across the state led to the successful eradication of dengue fever from Hawaii island after 264 people were sickened from 2015 to 2016 (Lew et al. 2018). These events, while rare, may become more frequent as tourism and immigration to Hawaii are expected to increase over the next 25 years (HI DBEDT 2018), which increases the likelihood of vector and vectored disease incursion (LaPointe 2007).

In the absence of emergency situations, routine day-to-day operations involve monitoring for pest incursions, treating pest outbreaks on public lands, providing public outreach, and investigating and resolving public complaints of vector nuisance. Each county in Hawaii employs a team of VC workers, inspectors, and an entomologist (or, on Oahu, two entomologists) to meet these responsibilities for their respective island (i.e., Oahu, Hawaii, and Kauai) or group of islands (i.e., Maui County). However, the most time-consuming responsibility of VC offices across the state is responding to public complaints of vector nuisance from pestiferous arthropods. Public residents that raise complaints to their local VC office receive in-person technical advisory and/or pesticide application services from VC inspectors and entomologists. In return, VC inspectors and entomologists gain insights into the pest concerns of the general public and are provided with opportunities for early detection of new pests of medical importance in the field.

Numerous reviews and empirical studies have described trends of public complaints of vector pests on the island of Oahu (e.g., Leong and Grace 2009a, b, c, d). However, there remains a paucity of published material from the other Hawaiian Islands. The populations of the major Hawaiian Islands vary greatly, between Oahu (953,200), Hawaii island (186,700), Maui (144,400), Kauai (66,900), Molokai (7,300), Lanai (3,100), and Niihau (170) (World Population Review 2020), which likely affects the frequency of public complaints received by VC offices. Furthermore, population density may influence land-use (e.g., urban or rural landscapes) which may affect the types of complaints received. In this study I describe trends of public complaints of arthropods of medical importance received by the Maui VC office between the years 2000 and 2019.

Methods

After resolving a public complaint, Maui VC inspectors document the event in an electronic database maintained by the Maui VC office; information recorded are date, location, pest type, and any actions taken by the VC office to ameliorate the pest issue (e.g., technical advisory, pesticide application). From this database I assessed complaints temporally, spatially, and quantitatively by comparing year, month, island region, and pest type. I assessed data from a 20-year period from January 1, 2000 until December 31, 2019.

Island regions. Maui was divided into seven regions, based roughly on population and environmental boundaries, which were referred to as Wailuku-Kahului, Upcountry, Kihei, Lahaina, Kahakuloa, Hana, and Kaupo (Fig. 1). During the study period there were no complaints received from Kaupo, so this region was excluded from data analysis and graphical representation.

Pest type. Pests were grouped by taxonomic and pest significance, but only seven pest groups accounted for 98.24% of all complaints; these were (1) mosquitoes, midges, and gnats (= "mosquitoes"), (2) wasps, bees, and ants (= "Hymenopterans"), (3) various nuisance flies (= "flies"), (4) various cockroaches (= "cockroaches"), (5) Siphonapterans (= "fleas"), (6) mites and ticks (= "Acarines"), and (7) *Cimex lectularius* L. (= "bed bugs") (Table 1). Data analyses tested these seven pest groups and an eighth group termed "others," which encompassed all other arthropod complaints.

Model selection and statistics. Statistical analyses were carried out using R statistical software (R core team, 2019). I initially fit a series of candidate linear models that included all possible subsets of the following fixed factors and their two-way interactions: "year," "month," "island region," and "pest type." Candidate models (N=113) were fitted using the "lme4" package (Bates et al. 2015) and the "dredge" function in the MuMIn package (Barton 2019). All candidate models were then compared using the corrected Akaike

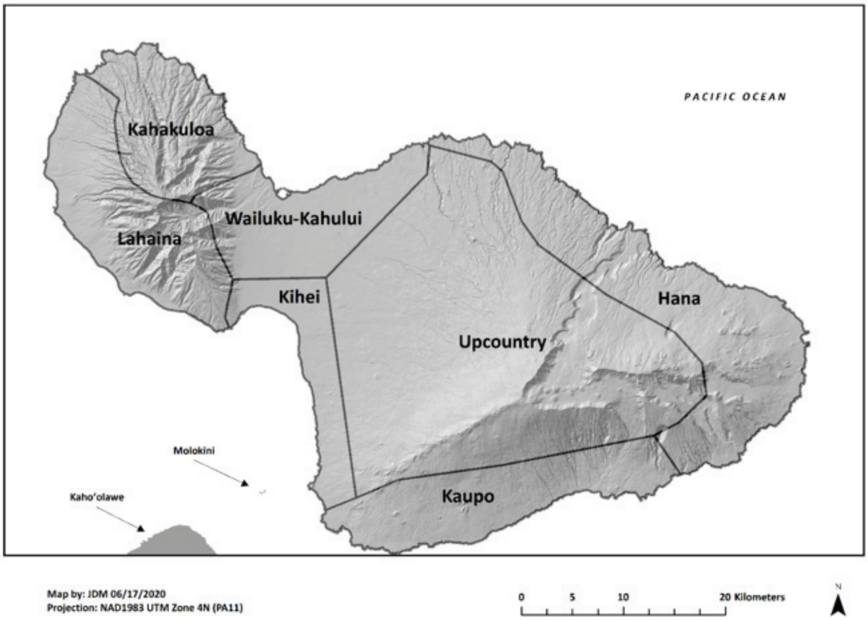

Figure 1. Maui island divided by study regions used to analyze arthropod pest complaints.

Table 1. Number of arthropod pest related complaints by pest group on Maui, Hawaii (2000–2019).

Pest group	N total complaints	% total complaints
Mosquitoes	1509	34.80
Hymenopterans	1162	26.80
Flies	746	17.20
Cockroaches	290	6.71
Fleas	275	6.34
Acarines	163	3.76
Bed bugs	114	2.63
Others	76	1.76

Information Criterion (AICc) (Akaike 1974, Hurvich and Tsai 1989), which uses information theoretical arguments to balance model fit and complexity, as

$$AICc = -2\ln(L) + 2k\left(\frac{n}{n-k-1}\right)$$

where k is the number of parameters and n is the sample size. From the candidate model pool, the single model with the lowest AICc score (AICcΔ = 0) was considered best according to this criterion and was chosen as the final model (Table 2). I found no secondary candidate models with AICcΔ ≤ 4, which could have been judged to have substantial support (Burnham et al. 2011). Residuals of all candidate models, and the final model, were normally distributed after applying a Yeo-Johnson power transformation (Yeo

Table 2. Linear model ANOVA results of the final model (AICc$\Delta = 0$), for analyses of complaints related to arthropod pest types, months, years and regions of Maui, Hawaii.

Factor	*F* value	DF	*P* value
Year	7.81	1, 11519	P<0.01
Month	4.23	11, 11519	P<0.0001
Region	252.47	5, 11519	P<0.0001
Pest	193.67	7, 11519	P<0.0001
Year × Pest	27.24	7, 11519	P<0.0001
Month × Pest	2.39	77, 11519	P<0.0001
Region × Pest	25.58	35, 11519	P<0.0001

and Johnson 2000) to the response variable, with $\lambda = -2$, as

$$y_i^{(\lambda)} = \frac{(y+1)^{\lambda} - 1}{\lambda}$$

All candidate models assessed in the model selection process, and the final model, reported "year" as a repeated measures variable. Factors judged to be significant ($\alpha < 0.05$) were subjected to post-hoc Tukey HSD tests using the package 'emmeans' (Lenth 2019).

Results

The number of complaints received by the Maui VC office differed significantly by the interactions of year × pest, month × pest, and region × pest (all p<0.0001) (Table 2). The frequency of mosquito complaints has increased slightly over the past 20 years, but the trend is highly variable (Fig. 2). The prevalence of Hymenopteran complaints has declined consistently and rapidly over time. Complaints regarding nuisance flies and fleas have also declined over time, while complaints of cockroaches and bed bugs have increased. Complaints of Acarines have remained constant (and low) over time. All other arthropod complaints ("others") have generally increased although their frequency is relatively low and variance between years is high.

Frequencies of complaints varied by month for mosquitoes, Hymenopterans, and flies, but did not change monthly for cockroaches, fleas, Acarines, bed bugs, or all other arthropods (Fig. 3). Comparatively fewer complaints of mosquitoes were received in August, Fall and early Winter. Complaints of Hymenopterans increased steadily from a low in January to a high in August. Complaints of flies were mostly flat throughout the year, but with a spike in June.

Frequencies of complaints varied by island region and pest type (Fig. 4). Mosquitoes were the most frequent pest complaint for all regions except Upcountry, where Hymenopterans were most frequent. Hymenopteran complaints were highest in Upcountry and Wailuku-Kahului, but relatively low everywhere else. Fly complaints were higher in Wailuku-Kahului and Kihei, while cockroach complaints were highest in Wailuku-Kahului. Flea complaints were highest in Wailuku-Kahului and Kihei. Acarine complaints were highest in Wailuku-Kahului and Upcountry, while bed bug complaints were highest in Wailuku-Kahului and Lahaina. Generally, complaints were most frequent in Wailuku-Kahului and Upcountry, followed by Kihei and Lahaina, and were less frequent in Kahakuloa and Hana.

Tabulated results. The Maui VC office responds to all vector issues within Maui County, which encompasses all of

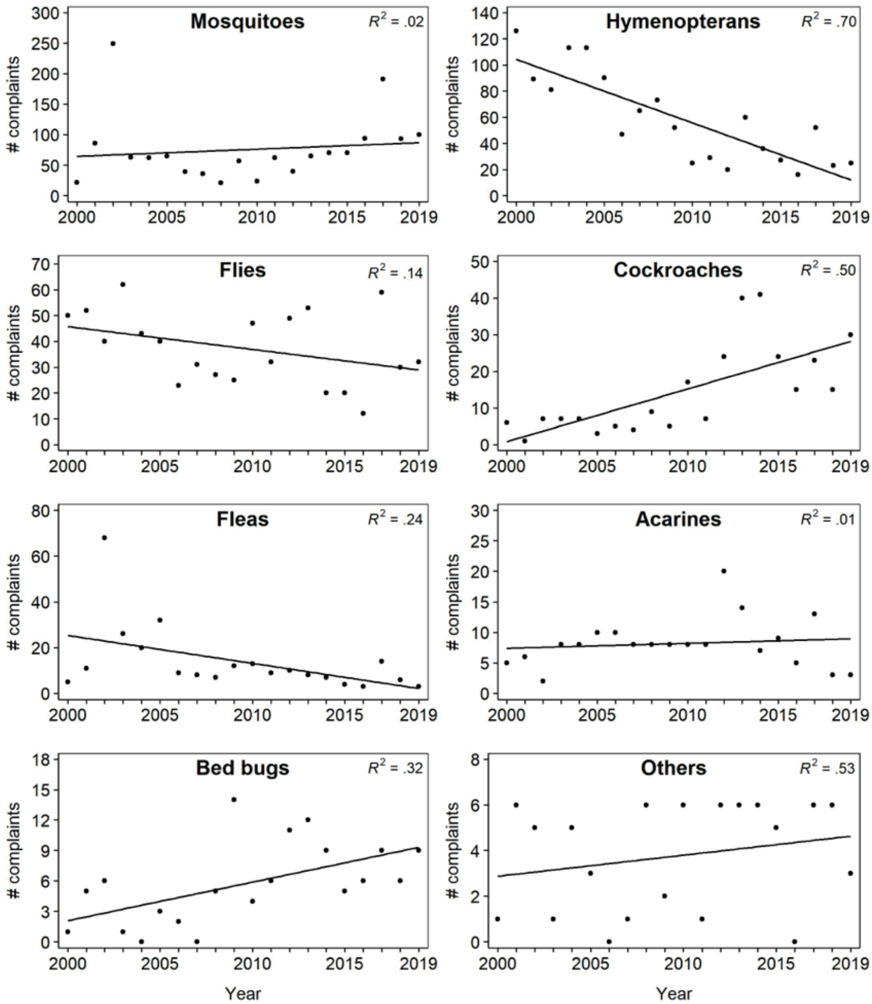

Figure 2. Total complaints received by year for various arthropod pests on Maui.

Maui Nui; all complaints received by the Maui VC office are tabulated by species in Table 3 (Maui), Table 4 (Molokai), and Table 5 (Lanai). There are no records of complaints from Kahoolawe or Molokini as those islands are not permanently inhabited. Complaints from Molokai and Lanai were excluded from statistical analysis due to limited data.

Discussion

Complaints received by the Maui VC office between 2000 and 2019 have varied considerably by year, month, region, and pest type. However, complaint frequency was best predicted by pest type. Mosquitoes were the most frequently complained-about pest on Maui, representing roughly one-third of

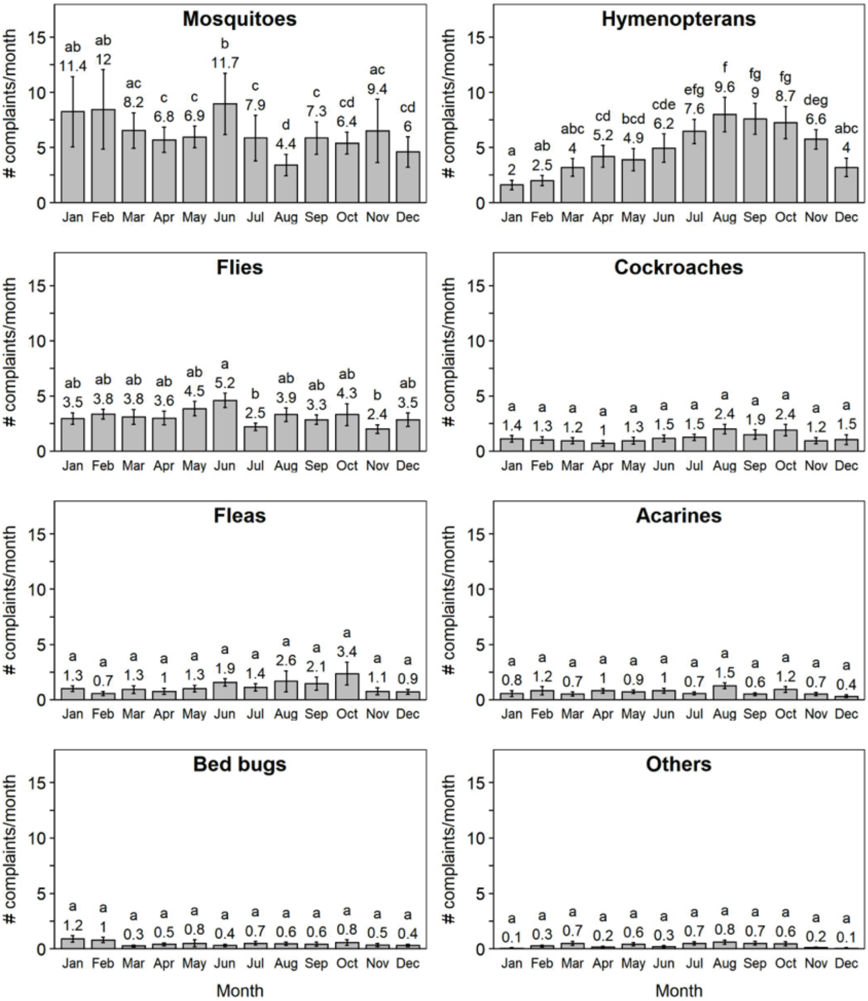

Figure 3. Mean (±SE) complaints received per month by arthropod pest type on Maui. Different letters denote statistical difference using Tukey's HSD test.

all arthropod-related complaints. Similar observations have been made on Oahu, where mosquitoes represent roughly 30% of arthropod-related complaints received by the Oahu VC office (Leong and Grace 2009d). Mosquito abundance is reportedly lower in the Fall months on Oahu (Leong and Grace 2009d), and fewer complaints were received in the Fall in the present study, although to a relatively small degree. Spikes in mosquito complaints occurred in January and February, which coincides with higher precipitation levels under normal years. However, the factors causing heightened mosquito complaints in June, and a drop-off after, are unclear. Mosquito complaints spiked in 2002 and 2017. The spike in 2002 likely resulted

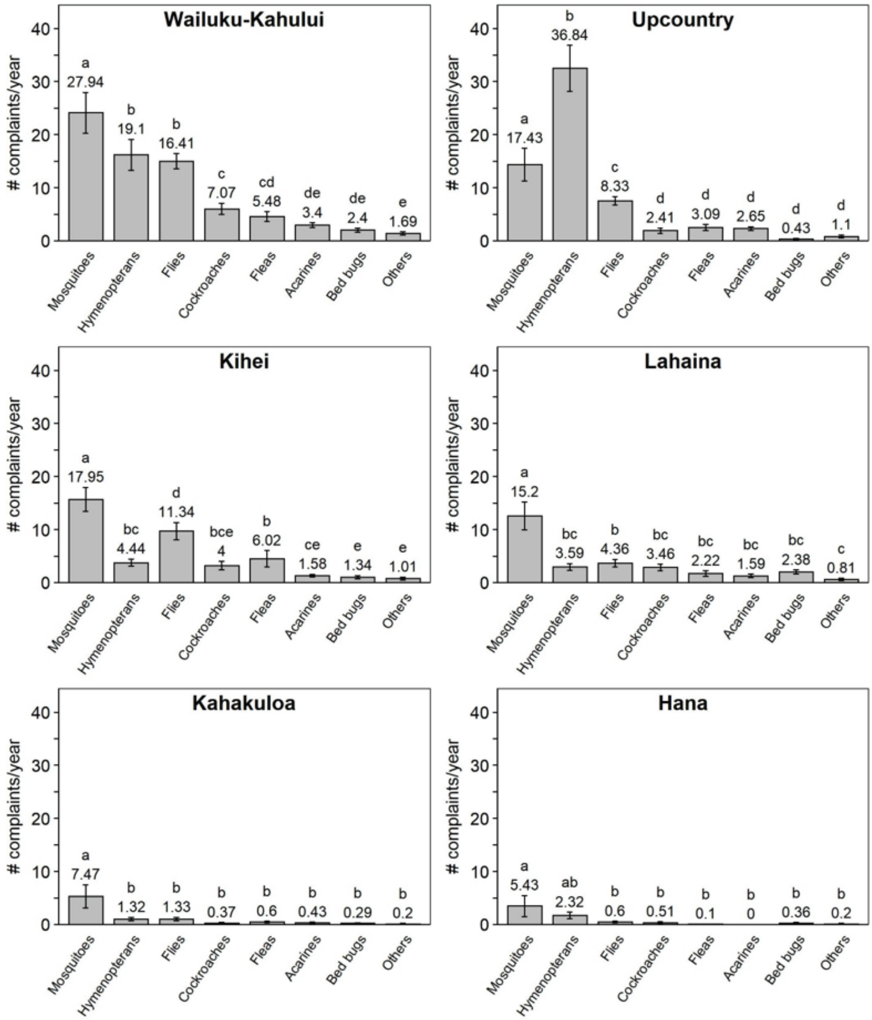

Figure 4. Mean (±SE) complaints received per year by arthropod pest type and region on Maui. Different letters denote statistical difference using Tukey's HSD test.

from an unprecedented outbreak of dengue fever from late-2001 through 2002 that sickened 92 people on Maui (Effler et al. 2005). The spike in 2017 likely resulted from considerably high precipitation levels (especially in January and April) during that year (WRCC 2020) that caused numerous island-wide floods. A multi-year mosquito trapping survey on Maui also reported higher than normal mosquito counts in 2017 (Spafford 2019). Furthermore, contributing to heightened mosquito complaints in 2017 may have been a Maui-wide public education campaign following a dengue fever outbreak on the Big Island (Johnston et al. 2020) and global outbreaks of the Zika virus (Zhang et al. 2017), and the detection of an *Aedes aegypti* L. indi-

Table 3. Public complaints of arthropod pests received by the Maui VC office from Maui island from 2000 to 2019. When only common names were provided in the database, these are given in parentheses

Order	Common name	Pest	2000–'04	2005–'09	2010–'14	2015–'19	N total	% total
Acari	Mites	Acari sp. (=mites)	10	20	30	14	74	1.71
		Ornithonyssus sp. (=bird mites)	5	10	18	12	45	1.04
		Sarcoptes scabiei (=scabies)	0	0	1	0	1	0.02
	Ticks	Ixodida sp. (=ticks)	14	14	8	7	43	0.99
Amphipoda	Amphipods	Amphipoda sp.	0	1	0	0	1	0.02
Annelida	Ringed worms	Annelida sp. (=worms)	1	0	0	0	1	0.02
Araneae	Spiders	Araneae sp. (=spiders)	9	2	16	7	35	0.81
Blattodea	Cockroaches	*Balta* sp. (=Balta cockroach)	1	2	0	2	5	0.12
		Blattella germanica (=German cockroach)	7	9	65	60	142	3.27
		Neostylopyga rhombifolla (=Harlequin cockroach)	1	0	0	0	1	0.02
		Periplaneta americana (=American cockroach)	15	13	58	44	130	3.00
		Pycnoscelus surinamensis (=Surinam cockroach)	0	0	0	1	1	0.02
		Supella longipalpa (=brown banded cockroach)	2	0	2	1	5	0.12
		Blattodea sp. (=cockroach)	1	2	4	0	7	0.16
Collembola	Springtails	Collembola sp. (=springtails)	0	1	0	0	1	0.02
Coleoptera	Beetles	*Lasioderma serricorne* (=cigarette beetle)	0	0	2	0	2	0.05
		Oedemeridae sp. (=false blister beetle)	0	1	0	0	1	0.02
		Coleoptera sp. (=beetles)	1	2	2	2	7	0.16
		Urophorus humeralis (=pineapple beetle)	0	0	1	0	1	0.02
	Weevils	*Sitophilus oryzae* (=rice weevil)	0	0	1	0	1	0.02
Diptera	Mosquitoes	*Aedes albopictus*	348	130	181	405	1064	24.54
		Culex quinquefasciatus	122	84	66	139	411	9.48
		Culicidae sp. (=mosquito)	5	0	0	0	5	0.12
		Toxorhynchites rutilus	1	0	0	0	1	0.02
		Wyeomyia mitchellii	0	0	0	1	1	0.02
	Flies	Calliphoridae sp. (=blow fly)	119	84	99	71	373	8.60
		Chrysomya sp.	23	1	1	10	35	0.81

Order	Common name	Pest	2000–'04	2005–'09	2010–'14	2015–'19	N total	% total
		Diptera sp. (=flies)	0	0	4	0	4	0.09
		Drosophila sp. (=vinegar flies)	2	4	14	9	29	0.67
		Hydrotaea aenescens	3	2	0	0	5	0.12
		Lucilia cuprina	0	0	0	1	1	0.02
		Musca domestica	25	18	29	11	83	1.91
		Musca sorbens	71	36	49	48	204	4.70
		Phoridae sp.	0	0	1	0	1	0.02
		Sarcophagidae sp. (=flesh fly)	1	1	3	3	8	0.18
		Sepsidae sp. (=black scavenger fly)	1	0	0	0	1	0.02
		Stomoxys calcitrans	1	0	0	0	1	0.02
		Syrphidae sp. (=syrphid fly)	0	0	1	0	1	0.02
	Midges	*Nematocera* sp. (=midges)	1	2	4	0	7	0.16
		Chironomidae sp.	0	0	0	1	1	0.02
	Gnats	Sciaridae sp. (=gnats)	5	2	10	2	19	0.44
Gastropoda	Slugs	Gastropoda sp. (=slugs)	0	0	1	11	12	0.28
Hemiptera	Bugs	Aleyrodidae sp. (=whitefly)	0	1	0	0	1	0.02
		Cimex lectularius (=bed bug)	13	24	42	35	114	2.63
		Corixidae sp. (=water boatmen)	0	1	0	0	1	0.02
		Reduviidae sp. (=assassin bugs)	1	0	0	0	1	0.02
Hymenoptera	Wasps	Hymenoptera sp. (=wasps)	15	3	8	18	44	1.01
		Sceliphron caementarium	1	0	0	1	2	0.05
		Vespula pensylvanica	134	88	94	63	379	8.74
	Bees	*Apis melifera*	333	213	22	39	607	14.00
	Ants	Formicidae sp. (=ants)	39	23	46	22	130	3.00
Mantodea	Mantids	Mantodea sp. (=praying mantis)	0	1	0	0	1	0.02
Scorpiones	Scorpions	*Isometrus maculatus*	5	2	1	0	8	0.18
Siphonaptera	Fleas	Siphonaptera sp. (=fleas)	130	68	47	30	275	6.34
Zygentoma	Silverfish	*Lepisma saccharina*	1	0	1	0	2	0.05
Total			1467	865	932	1070	4336	100.0

Table 4. Public complaints of arthropod pests received by the Maui VC office from Molokai from 2000 to 2019. When only common names were provided in the database, these are given in parentheses.

Order	Common name	Pest	2000–'05	2005–'10	2010–'15	2015–'19	N total	% total
Acari	Mites	Acari sp. (=mites)	0	1	0	1	2	1.04
		Ornithonyssus sp. (=bird mites)	3	1	0	1	5	2.59
Araneae	Spiders	Araneae sp. (=spiders)	3	0	0	0	3	1.55
Blattodea	Cockroaches	*Blatella germanica* (=German cockroach)	1	0	0	5	6	3.11
		Periplaneta americana (=American cockroach)	1	0	0	2	3	1.55
Diptera	Mosquitoes	*Aedes albopictus*	33	1	1	4	39	20.20
		Culex quinquefasciatus	10	1	1	3	15	7.77
		Culicidae sp. (=mosquito)	1	0	0	0	1	0.52
	Flies	Calliphoridae sp. (=blow fly)	4	8	1	1	14	7.25
		Chrysomya sp.	2	0	0	0	2	1.04
		Musca domestica	1	0	1	0	2	1.04
		Musca sorbens	2	5	0	0	7	3.63
		Sarcophagidae sp. (=flesh fly)	0	2	0	0	2	1.04
		Stomoxys calcitrans	0	1	0	0	1	0.52
	Gnats	Sciaridae sp. (=gnats)	1	0	0	0	1	0.52
Hemiptera	Bugs	Notonectidae sp. (=back swimmers)	2	0	0	0	2	1.04
Hymenoptera	Wasps	Hymenoptera sp. (=wasps)	6	0	0	7	13	6.74
	Bees	*Apis melifera*	33	14	0	0	47	24.35
	Ants	Formicidae sp. (=ants)	6	0	0	3	9	4.66
Siphonaptera	Fleas	Siphonaptera sp. (=fleas)	6	9	1	3	19	9.84
Total			115	43	5	30	193	100.0

Table 5. Public complaints of arthropod pests received by the Maui VC office from Lanai from 2000 to 2019. When only common names were provided in the database, these are given in parentheses.

Order	Common name	Pest	2000–'05	2005–'10	2010–'15	2015–'19	N total	% total
Acari	Mites	*Ornithonyssus* sp. (=bird mites)	0	1	0	0	1	6.25
Diptera	Mosquitoes	*Aedes albopictus*	4	1	1	0	6	37.50
		Culex quinquefasciatus	2	1	0	0	3	18.75
	Flies	Calliphoridae sp. (=blow fly)	0	1	0	0	1	6.25
Siphonaptera	Fleas	Siphonaptera sp. (=fleas)	4	1	0	0	5	31.25
Total			10	5	1	0	16	100.0

vidual at Kahului Airport in December 2017 (Spafford 2019).

Complaints of Hymenopterans were primarily caused by yellowjacket nests (*Vespula pensylvanica* Saussure) and honeybee swarms (*Apis melifera* L.). These complaints followed a unimodal trend with a peak in August and trough in January, which coincides closely with previous reports of monthly abundance of *V. pensylvanica* workers trapped at Haleakala National Park (Gambino and Loope 1992, Gambino 1991) and a report that *A. melifera* swarms are less frequent in winter on Oahu (Leong and Grace 2009a). Complaints of Hymenopterans were most prevalent in Upcountry, which was expected as these insects prefer cooler Hawaiian habitats at high elevation (Gambino et al. 1990). Of notable importance, I observed a roughly five-fold decline in the number of Hymenoptera complaints received over the past 20 years. Long-term trends in Hymenopteran abundance on Maui have not been described in the available literature, so it is unknown if a decline in received complaints corresponds to reduced abundance of pestiferous Hymenopterans over time.

Complaints regarding nuisance flies have decreased over time but with little variance between months. By region, nuisance flies are a greater issue in the Wailuku-Kahului and Kihei regions, which may be due to high population densities in these areas. Nuisance flies generally breed on trash and populations can increase rapidly under high temperature conditions (Lole 2005; Thomas and Skoda 1993) which are also present in the urban environments around Wailuku-Kahului and Kihei.

Fleas were the fifth-most common pest group, and complaints of these pests decreased over time. Flea complaints spiked in 2002, which coincided with a major outbreak of murine typhus (a disease vectored by fleas) on Maui (CDC 2003) resulting from one of the largest rodent outbreaks on record in the Kihei and Wailuku-Kahului regions in that year (Inskeep et al., unpublished data). Flea complaints were most common in Kihei, which coincides with the highest levels of rodent occurrence on Maui (Inskeep et al., unpublished data).

Overall, I expected to observe an increase in all pest complaints due to the rapid development of Maui over recent decades (HI DBEDT 2018). Therefore, the decrease of some pests (mentioned above) over the past 20 was unexpected. Two explanations for these declines may be offered; first, homeowners may be seeking pest management solutions from sources other than the Maui VC office, such as research through online search engines, by contacting other local pest management experts (e.g., Master Gardeners associations, Hawaii Department of Agriculture, private industry), or by following advice transcribed on pest management flyers released by VC offices. Second, fewer calls may indicate reduced presence of these pests due to changing conditions (e.g., climate, cultural) that are precluding their proliferation. Future studies may investigate both possibilities. However, since 2000 there has been a steep increase in complaints among indoor pests (e.g., cockroaches and bed bugs). This is likely from a 33.8% annual increase in the resident population of Maui island and a 28.8% annual increase in tourist arrivals over the past 20 years (HI DBEDT 2018).

Management of arthropods of medical importance on Maui should take note of the long-term trends described here. There appears to be a shift in received complaints, whereby outdoor pests are decreasing while indoor pests are increasing. Vector control work on Maui may therefore plan for continued increase in cockroach and bed bug issues. However, mosquitoes remain the most common vector nuisance for Maui residents.

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