2016-2020
Invasive & Native Species Monitoring Report

Prevention, early detection, monitoring, rapid response, & control efforts

OFFICE OF MAUNAKEA MANAGEMENT

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EXECUTIVE SUMMARY

The Office of Maunakea Management (OMKM), now the Center for Maunakea Stewardship (CMS), manages lands on Maunakea, Hawaiʻi, owned by the State of Hawaiʻi and leased to the University of Hawaiʻi (UH). The management area encompasses a total of 11,288 acres and includes the Mauna Kea Science Reserve (MKSR), the Astronomy Precinct, mid-level facilities at Halepōhaku (HP), and the Summit Access Road Corridor (see Appendix A). The 2009 Comprehensive Management Plan (CMP) is the guiding management document for these areas and provides a policy framework for UH to address measures to protect the cultural, natural, and recreational resources on UH-managed lands. The Natural Resources Management Plan (NRMP), a sub-plan of the CMP, addresses the threat and potential impacts of non-native plants, animals, and diseases to the natural resources on Maunakea. The NRMP requires an Invasive Species Management Program/Plan (ISMP) to prevent, detect, monitor, respond to, and control new and established invasive species within the UH management area. This report documents invasive species management actions (including native species monitoring) during the 5 year period from 2016 to 2020.

Sections in this report include *Prevention*, *Early Detection Monitoring*, *Native & Established Species Monitoring*, *Rapid Response,* and *Control*. During the period discussed here, a total of 618 inspections of equipment and vehicles being used on the mountain were conducted, for an average of 124 inspections each year, and these are summarized in the *Prevention* section.

The *Early Detection Monitoring* section discusses four distinct monitoring efforts all aimed at detecting the introduction or expansion of invasive species. Facility Surveys, in which around 63 insect traps were placed 4 times each year in and around facilities in the MKSR and at Halepōhaku, captured anywhere from 800 to 4,000 individuals each year of a total of 128 species in 20 orders. Annual alien invertebrate monitoring surveys, in which more than 200 insect traps of four different kinds were placed at 111 distinct sites around the summit and at the 9,200 ft. level once per year, captured specimens of 173 different species in 19 orders. The number of arthropods captured and/or observed in these surveys increased steadily year after year, from 2,234 in 2016 to 9,110 in 2019, until 2020, when the number fell to 1,700. These variances are illustrated in the tables and graphs in the section. Data from Rotating Panel Surveys, carried out concurrently with Archaeological monitoring, and from Incidental Early Detection Monitoring are also included in this section.

Native and Established Species Monitoring focuses primarily on the native wēkiu bug (*Nysius wekiuicola*) and the introduced European honey bee (*Apis mellifera*). Specific instances of invasive threats that required immediate action are discussed case by case in the section *Rapid Response*. Over the five-year period discussed here, rapid response procedures were initiated 6 times to address 3 distinct threats. Finally, the *Control* section describes efforts to bring or keep numbers of certain invasive plant and animal species that are already too well-established to eradicate to acceptable levels. In 2016-2020, 6-9 plant and 4 animal species were the focus of sustained control efforts.

NOTE

The Thirty Meter Telescope (TMT) Conservation District Use Permit (CDUP) granted in 2017 requires monitoring of invasive species at locations in the MKSR where TMT activity occurs (the TMT site, its access way, the Batch Plant parking lot, and the Halepōhaku staging area). TMT contracts the Big Island Invasive Species Committee (BIISC) to implement prevention efforts and monitoring of invasive species in accordance with the TMT permit. The BIISC conducted monitoring activities in 2018 and 2019, concurrent with resumed activity, which was paused during 2016 and 2017. Activity paused again in 2020, and once again no monitoring was required. BIISC/ TMT CDUP compliance efforts in 2018 and 2019 are not included in this report and can be obtained from BIISC.

INTRODUCTION

The Maunakea Invasive Species Management Plan (ISMP) was approved by the Maunakea Management Board in 2015. 2016, then is the first year in which all work was conducted in accordance with protocols finalized in that document, though many of these protocols were followed in previous years. Wēkiu bug (*Nysius wekiuicola*) and alien invertebrate monitoring efforts are a continuation of work done previously by the Bernice Pauahi Bishop Museum.

Sections in this report emphasize plant, vertebrate, and invertebrate threats. These threats are explained in detail in *SOP D: Maunakea Plant Threats, Identification, Collection, & Processing Guide*; *SOP B: Maunakea Vertebrate Threats, Identification, Collection, and Processing Guide*; and *SOP C: Maunakea Invertebrate Threats, Identification, Collection, & Processing Guide* documents developed as part of the ISMP.

PREVENTION

Preventative measures are the first line of defense for invasive species management on Maunakea. Prevention procedures for plants and arthropods are part of a comprehensive effort to identify and analyze the risk associated with potential invasion pathways (primarily vehicles and equipment). Prevention procedures for plants and arthropods are based on a comprehensive effort to identify and analyze the risk associated with potential invasion pathways. Preventative management actions include inspection requirements and strict sanitation procedures for contractors and staff throughout UH-managed lands. Sanitation guidelines are found in the Maunakea ISMP.

Delivery and Equipment Inspections

The main purpose of inspections is to reduce the risk of frequent "users" (observatory staff, Maunakea Observatory Support Services, and OMKM/CMS itself) introducing new invasive species on Maunakea. This section summarizes all inspections conducted from 2016 to 2020. Any rapid response activities that resulted from these inspections to ensure that any new invasive species were addressed swiftly and appropriately wherever found are described later in this report (see Native & Established Species Monitoring).

Study Area
Most inspections conducted during 2016-2020 occurred in Hilo at delivery base yards and facility warehouses. Less frequently, inspections occurred in Kona and Waimea. Examples of inspected items include aggregate materials, lumber, heavy equipment, empty dumpsters, lowboy trailers and semi-trucks, chiller units, and wooden crates containing electronic equipment.

Methods
Inspections are conducted to ensure that materials, supplies, and/or vehicle(s) coming to the mountain are clean and free of animal (including arthropod), plant, and earthen materials. Inspections are done by simple observation and, in some cases, baiting. Specific inspection methods vary depending on the item. For example, pallets and crates require a close look at corners and crevices while inspections of larger vehicles and equipment focus on dirt-collecting areas such as

wheel wells, tires, mudflaps, etc. Bait is used when a delivery item is stored outdoors for more than a week. In these cases, index cards baited with peanut butter, jelly, and spam are left out for at least 20 minutes and observed for invertebrate activity (primarily ants). After an inspection is completed, concerns are reported to the inspection requestor. Most concerns can be handled by the facility staff and require a subsequent self-inspection, but some situations require a re-inspection after remediations are completed.

Results and Discussion

A total of 618 inspections were conducted from 2016 to 2020 (for an average of 124 per year) by Department of Land and Natural Resources (DLNR) approved biological inspectors. Of these, 618 were undertaken on behalf of observatory facilities and their support services, the Maunakea Shared Services (MKSS). Below Table 1 displays the number of inspections, remediations, instances of non-compliance, and rush inspections (those with less than 24 hours' notice) for each facility during this period. For all inspections that required remediation, corrective action (pressure wash, vacuum, etc.) was taken and items passed subsequent inspection. The unusually high number of inspections for UH88 in 2017 and MKSS in 2019 correlate with large improvement projects that required heavy equipment and large amounts of material to be transported to the mountain.

Table 1**.** 2016-2020 Invasive species inspections.

Facility	Number of Inspections								
Year	**2016**	**2017**	**2018**	**2019**	**2020**	**Total**	**Remediations 2016-2020**	**Non-compliance**	**Rush Inspections**
MKSS	4	7	2	149	1	**163**	44	4	63
Gemini	13	12	10	6	0	**41**	8	0	4
IRTF	1	1	9	2	9	**22**	4	1	9
CFHT	0	3	10	0	6	**19**	1	0	6
Keck	11	15	21	50.5	28	**125.5**	11	1	39
Subaru	11	30	16	9.5	10	**76.5**	8	1	11
SMA	10	19	16	21	14	**80**	9	0	20
JCMT	0	0	0	1	0	**1**	0	1	1
UKIRT	0	0	2	5	0	**7**	1	1	0
UH88	1	56	2	8	9	**76**	10	0	11
UH24	0	0	3	0	0	**3**	0	0	1
VLBA	0	0	2	1	0	**3**	2	2	1
TMT	0	1	0	0	0	**1**	1	0	0
TOTAL	**51**	**144**	**93**	**253**	**77**	**618**	**99**	**11**	**166**

EARLY DETECTION MONITORING

The goals of the early detection program are to detect and prioritize control for new invasive plant and animal species before they become established on UH-managed lands, whether they are new to the island or encroaching from established populations at lower elevations. In the case of species new to the island, early detection also decreases the likelihood of dispersal outside of UH-managed lands. Early detection methods are dependent in large part on consistent monitoring activities. During the period outlined here, early detection efforts focused on three large taxonomic groups—invertebrates, plants, and vertebrates—and took three primary forms—*Facility Surveys, Rotating Panel Surveys,* and *Annual Alien Arthropod Surveys*.

Facility Surveys

Study Area

Since 2012, all facilities on UH-managed lands have been monitored for invasive arthropod species. In the Mauna Kea Science Reserve (MKSR), traps are placed in all in-use telescope facilities (each facility has 2 or more traps), the summit lunch room, the Batch Plant parking area, and the Thirty Meter Telescope (TMT) construction site when there is construction activity. At Halepōhaku (HP), traps are placed in the common building, kitchen, dorms, maintenance building, parking lots, Visitor Information Station (VIS), Ranger offices (moved to the common building in 2018), the VIS storage warehouse and presentation room, and the VIS management office.

Until 2018, this amounted to 63 trap locations. In 2018, one of the longhouses near the VIS, underneath which one trap had previously been placed, was removed. In 2019, the decision was made to stop placing traps at the Caltech Submillimeter (CSO) and Hōkū Keʻa (UH 24") Observatory facilities, as they were no longer in use. Consequently, from 2019 forward, traps have been placed quarterly at 59 locations, 6 of which (at key spots in the Halepōhaku area) host continuous traps.

Methods

The main purpose of facility trap surveys is to detect new invertebrate species in or around facilities, the biggest concern being ants. Facility monitoring employs indoor and outdoor baited sticky traps along with perimeter searches. OMKM (now CMS) uses HoyHoy cockroach traps that are cut in half and baited with spam (protein), jelly (carbohydrate), and peanut butter (lipid). Baited sticky traps are placed in areas such as lounge rooms, loading bays, parking lots, control rooms, and other areas with significant human activity. Any outside traps are covered with a plastic container for weather protection. Six facility traps in the HP common and kitchen areas and the VIS warehouse are continuously deployed with a monthly replacement cycle; all other traps are placed quarterly and retrieved within a week.

Perimeter surveying and removal of invasive plants occurs concurrently with facility surveys. Quarterly perimeter searches are also conducted around all HP facilities and parking lots when staff resources allow. Surveying entails hand searches, invasive weed pulls, and baiting with peanut butter, jelly, and spam vials. Finally, identifications to the lowest possible taxonomic unit are made for all arthropod specimens collected, to determine whether the species poses a threat.

Results & Discussion

Facility survey data is displayed in Figures 1-4 below by method, location, and time period. From 2016 to 2020, between 300 and 325 facility traps were deployed each year, except for 2020, during which the COVID-19 pandemic prevented the placement of quarterly traps in March. Arthropod captures, which included a total of 20 taxonomic orders, are illustrated in the charts and graphs that follow.

Below is a summary table (Table 2) representing arthropod capture abundance for the various survey efforts. A detailed list of arthropod taxa captured in facility traps during this period can be found in Appendix B.

Table 2. 2016-2020 Facility trap summary table.

Facility type and location	Arthropod Individuals Captured						Taxonomic Orders Identified				
Year	**2016**	**2017**	**2018**	**2019**	**2020**		**2016**	**2017**	**2018**	**2019**	**2020**
Inside Facilities – MKSR	52	223	778	195	109		7	11	8	7	6
Outside Facilities – MKSR	1,412	3,135	1,753	465	409		7	8	14	11	7
Inside Facilities – HP	368	92	746	153	139		12	8	13	15	16
Outside Facilities – HP	241	94	679	946	213		13	9	10	15	12
Totals	2,073	3,544	3,956	1,759	870		14	17	17	18	17

Perimeter searches conducted from 2016-2019 (searches were suspended in 2020 due to staffing and access challenges) detected few invertebrates, mostly seed bugs, lady beetles, and flies. Four threat species were observed during these searches: 1 yellowjacket (*Vespula pensylvanica*) in 2016; 1 dead wasp (Hymenoptera) and 1 European honeybee (*Apis mellifera*) in 2017; and 1 orb-weaver spider (Araneae: Araneidae) in 2018. All but the orb-weaver are known to have established populations on UH-managed lands on Maunakea; the orb-weaver was collected for further identification. Invasive vegetation recorded consisted entirely of fireweed (*Senecio madagascariensis*).

Inside Facility Capture Abundance by Taxonomical Order

The pie charts below (Figure 1 & 2) show the capture abundance by order for inside facility traps in the MKSR and at HP. The 'n' value in the lower right is the total number of individuals captured inside facilities. Most individuals captured inside MKSR facilities were true bugs (Hemiptera) and flies (Diptera). HP inside traps captured mostly cockroaches (Blattodea) and flies (Diptera). It should be noted that most (575) of the cockroaches captured at HP were captured in a single year (2018). Control measures were put in place at the time, and only a few cockroaches were captured thereafter (2 in 2019 and 2 in 2020).

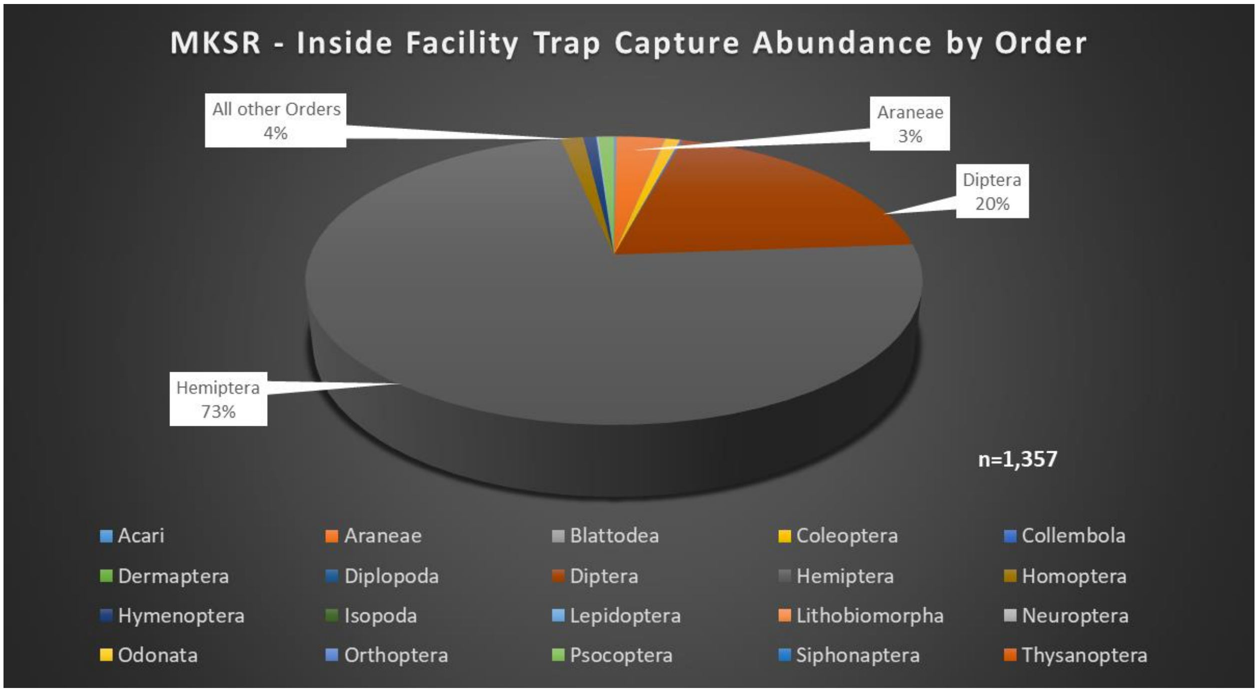

Figure 1. 2016-2020 MKSR Inside facility trap capture abundance by order.

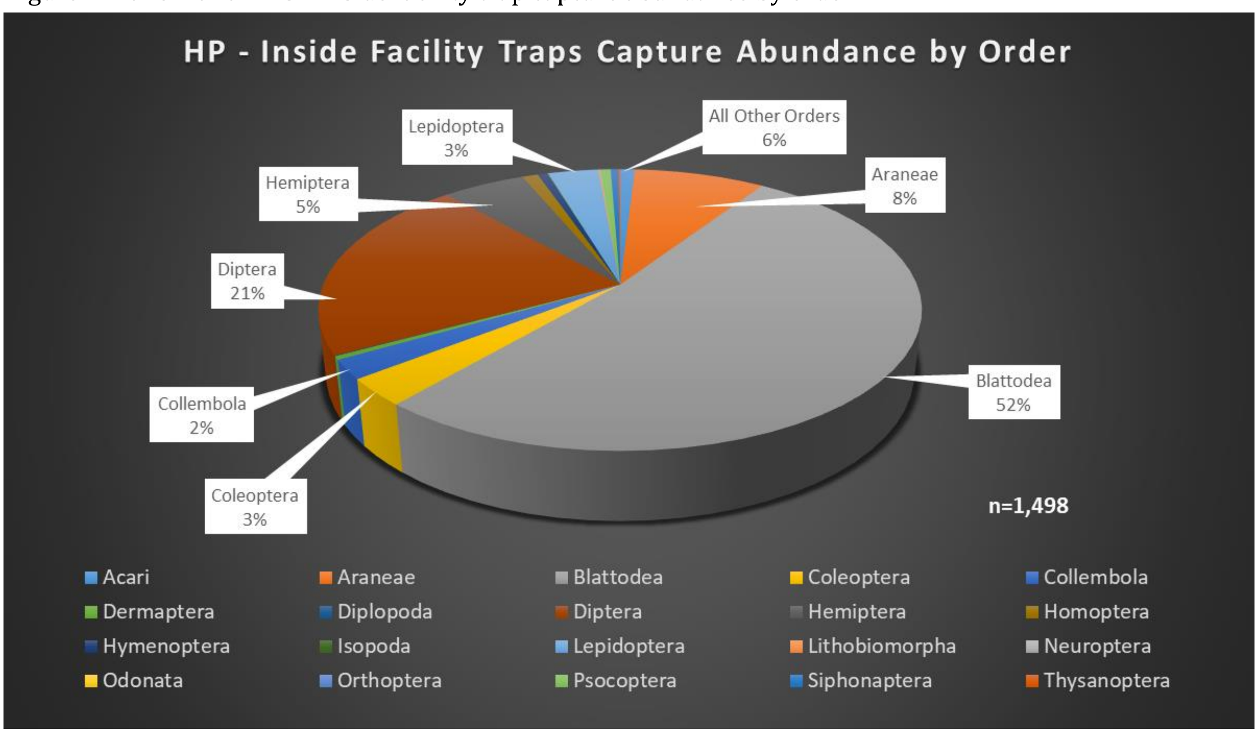

Figure 2. 2016-2020 HP Inside facility traps capture abundance by order.

Inside Facility Capture Abundance by Facility by Order

The graph below (Figure 3) shows the percentage of individuals (displayed by Order) captured inside each facility during the entire 2016-2020 period. The numbers on the top of the bars represent the total number of individuals captured in that facility during the period. By far, the majority of individuals captured inside MKSR facilities were true bugs (Hemiptera), followed by flies (Diptera). The vast majority of these (934) were *Nysius palor* (Hemiptera: Lygaeidae). At HP, cockroaches (Blattodea) made up most individuals, but as mentioned earlier, most of these (575) were captured in a single year (2018).

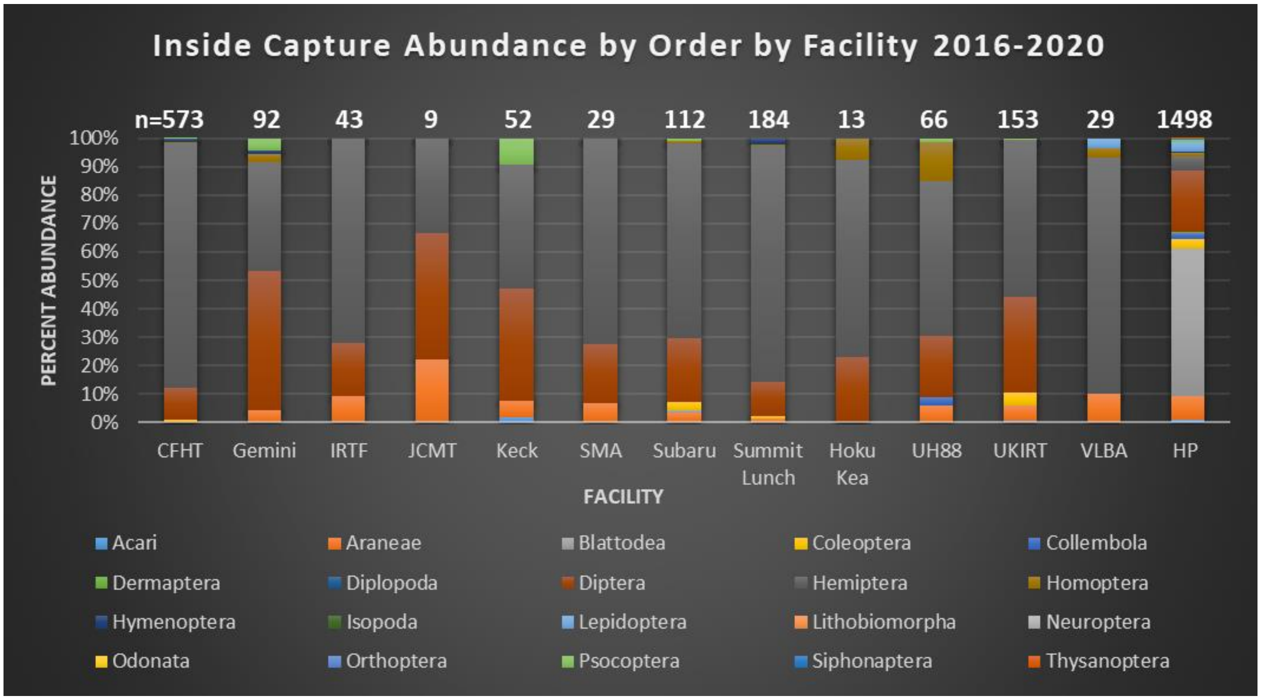

Figure 3. The percentage of individuals captured inside each facility.

Outside Facility Capture Abundance by Order

The pie charts below (Figure 4 & 5) show the capture abundance by order for outside facility traps in the MKSR and at HP during the 5-year period under review. The 'n' value in the lower left is the total number of individuals captured outside the respective facilities. The majority of individuals captured outside facilities in the MKSR were seed bugs (Hemiptera) and flies (Diptera), while traps outside HP facilities were dominated by springtails (Collembola) and mites (Acari).

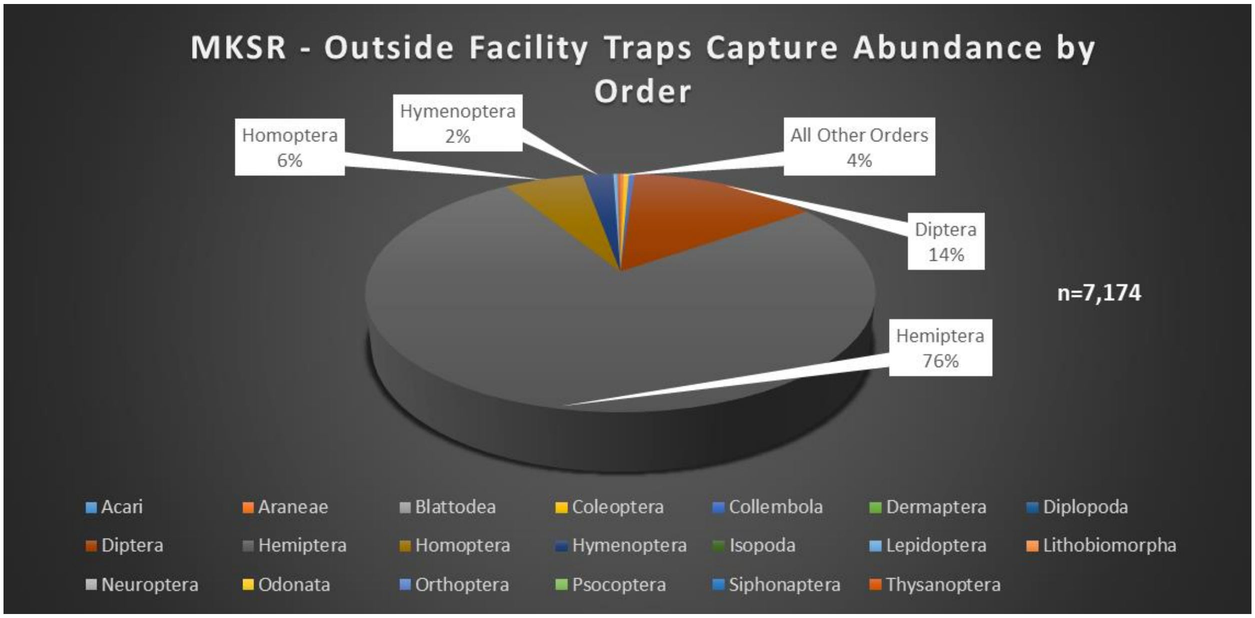

Figure 4. 2016-2020 MKSR outside facility traps capture abundance by order.

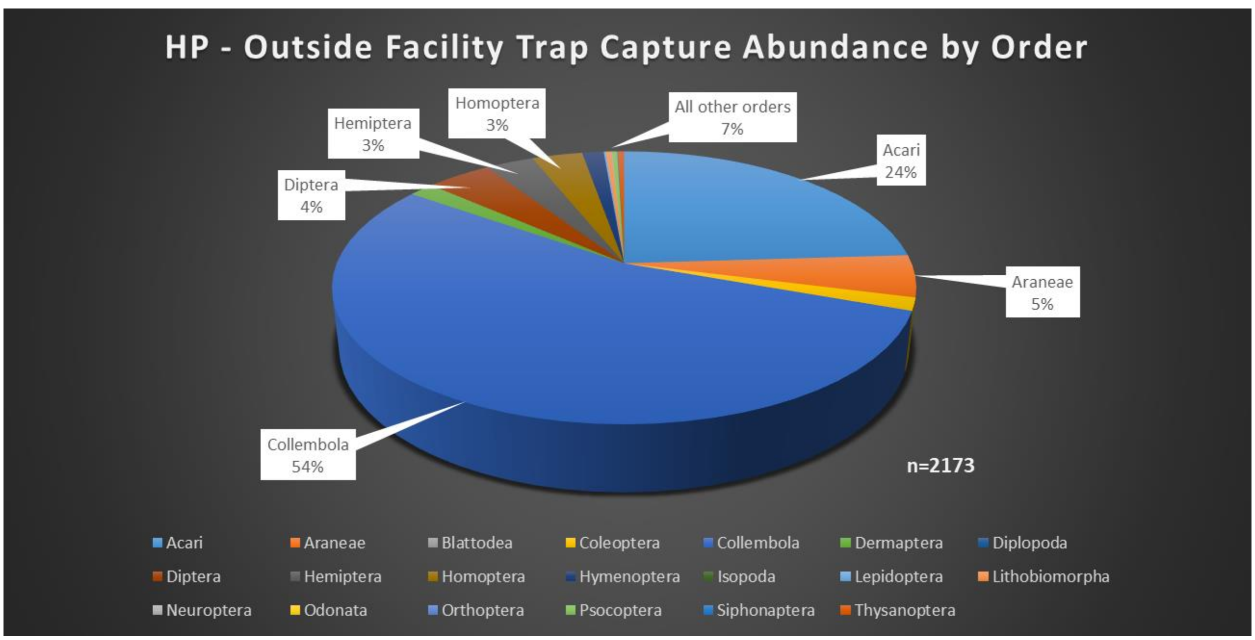

Figure 5. 2016-2020 HP outside facility traps capture abundance by order.

Outside Facility Capture Abundance by Locality

The graph below (Figure 6) shows the abundance of arthropods captured in traps outside facilities by year. The numbers on the top of the bars represent the total number of individuals captured outside the facility during the 2016-2020 period. In the upper left, "n" represents the total number of arthropods captured outside facilities during this period.

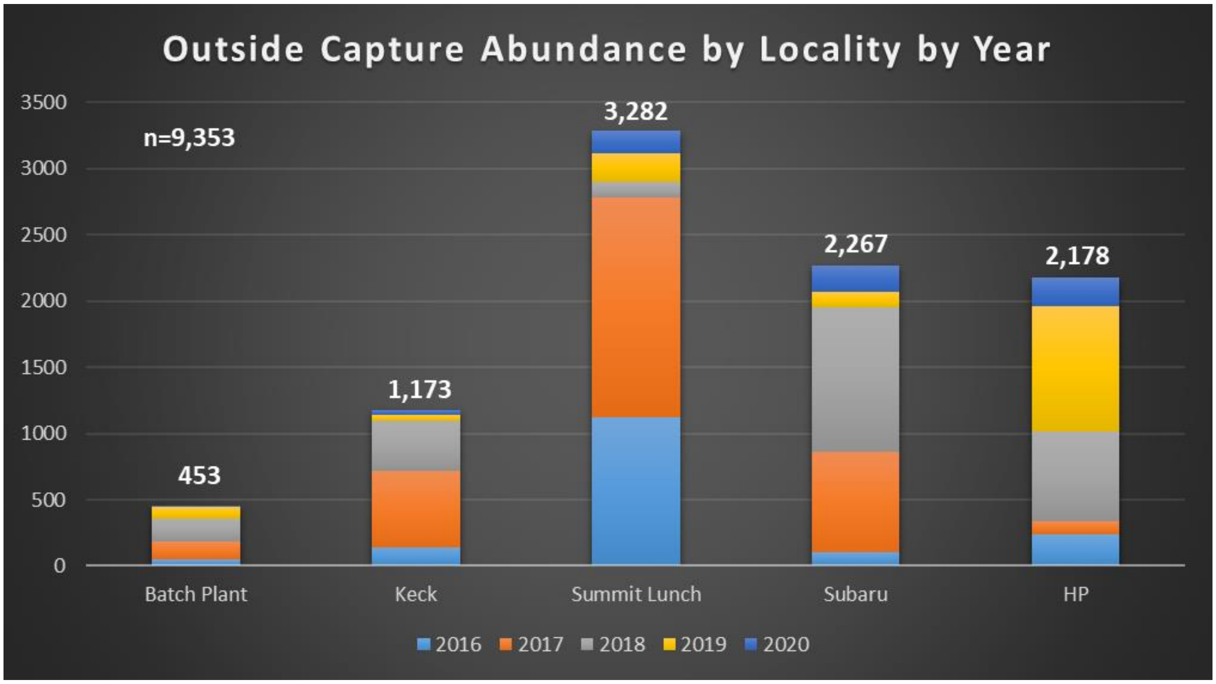

Figure 6. Outside facilities capture abundance by locality and by year.

Conclusion

From 2016-2020, inside facility traps captured a total of 2,855 invertebrate individuals (3% native, 70% non-native [2% threats], 27% undetermined[1] [6% potential threats]) consisting mainly of seed bugs, flies, and the cockroaches captured at HP in 2018. Outside facility traps captured a total of 9,347 invertebrate individuals (1% native, 64% non-native [<1% threats], 35% undetermined[1] [4% potential threats]), most being seed bugs, flies, springtails, or mites. HP displayed the widest variety (18 orders) of arthropods when compared to other facilities, while traps outside facilities in the MKSR captured the greatest abundance (largely due to high numbers of seed bugs in certain traps in certain years).

[1] All specimens are identified to the lowest taxa possible (usually to family) to determine whether the species is a threat. The term "undetermined" identifies taxons that have both native and non-native species within that taxonomic group.

Rotating Panel Surveys

Study Area

Rotating panel early detection plant and invertebrate surveys were conducted alongside State-mandated historic property monitoring in 2016-2020. However, monitoring was cut short in 2019 due to the closure of the access road, resulting in only 7 sites being visited. Rotating panel survey locations varied, based on annual, 3-year, or 5-year rotations, depending on the site. During the 2016 to 2020 period, 146 historic sites within the Mauna Kea Science Reserve (MKSR) were surveyed (shown in the Figure 7 map below). Of these, 21 were visited annually (at least 4 times in 5 years), 15 were visited 3 times, 16 twice, and 93 once.

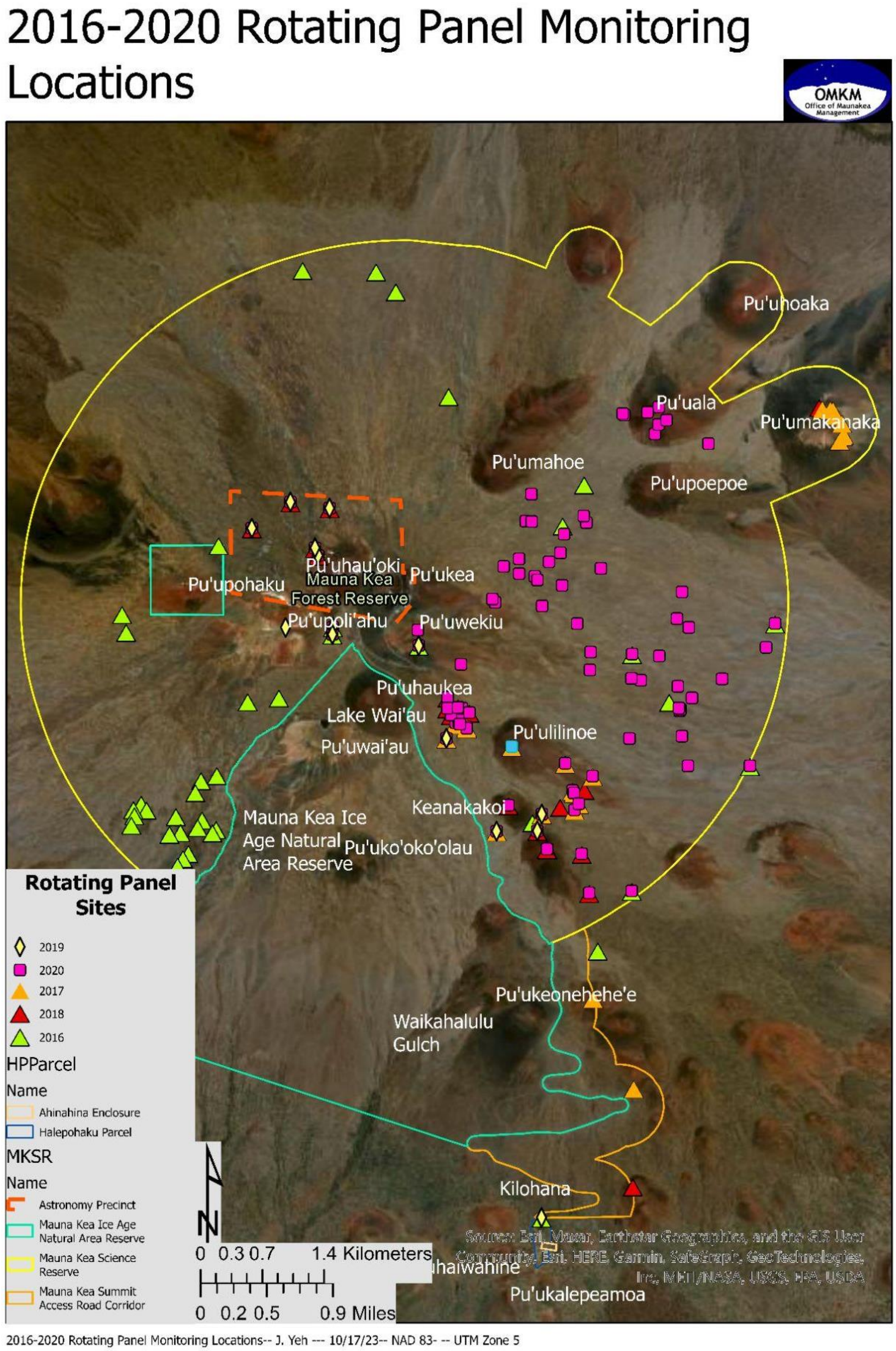

Figure 7. 2016-2020 Rotating panel monitoring locations.

Methods
The main purpose of invertebrate and plant early detection surveys is to detect, document, and monitor invasive species threats at sites across a variety of habitats within UH management jurisdiction. All collected invertebrates were identified to the lowest possible taxonomic unit necessary to determine if the species was a threat.

Invertebrates
At each site, four vials baited with spam, jelly, and peanut butter were placed in opposing cardinal directions and left out for 10-15 minutes. While waiting for the vials, a 10-minute hand search (overturning rocks and visual inspection) was conducted up to 10 m out from each site. All known observed invertebrates were recorded and unknown specimens were collected and identified in the lab.

Vegetation
Vegetation was observed within a 10 m radius of the historic properties. Native vegetation was documented; non-native vegetation was pulled, documented, and disposed of. The roots of pulled plants were carefully observed for ants and other potential invertebrate threats. All vegetation, including lichens[2] (with color description), were recorded.

Results & Discussion
Rotating panel surveys are typically conducted during September and October. During the five-year period of 2016-2020, surveys were conducted as follows (see Table 3):

Table 3. 2016-2020 Rotating panel survey data.

Year	No. of Surveys Conducted	Baited Vials Placed	No. of Specimens Observed
2016	86	469	1146*
2017	25	162	60
2018	49	324	151
2019	7	44	10
2020	88	667	191

*1000 of these were dead *N. palor* found in a single location

A comprehensive list of invertebrate observations at historic properties in the MKSR during the 2016-2020 period can be found in Appendix C.

Vegetation
Table 4 indicates the number of individuals of each plant species observed during archaeological surveys between 2016 and 2020, as well as the common name and nativity [Native (N), Non-Native (NN), Unknown (U)] of each. In most cases, non-native, invasive species are pulled and carried out for disposal. In the case of grasses identified as "*Agrostis/Trisetum*", it was not possible to determine in the field which genus individuals belonged to.

[2] Lichen colors recorded in the field were pale green, bright green, yellow, orange, white, gray and black.

Table 4**.** Plant species observed during archaeological surveys between 2016 and 2020.

Scientific Name	Common Name	Nativity	# Observed
Agrostis sandwicensis	Hawai'i Bentgrass	N	722
Agrostis / Trisetum	Native Grass	N	10
Asplenium adiantum-nigrum	ʻIwaʻiwa fern	N	147
Asplenium trichomanes	ʻOāli'i fern	N	77
Cystopteris douglasii	Douglas' Bladderfern	N	13
Fragaria chiloensis sandwicensis	ʻŌhelo papa	N	15
Heterotheca grandiflora	Telegraph Weed	NN	2
Hypochaeris radicata	Hairy Cat's Ear	NN	34
Pellaea ternifolia	Kalamoho fern	N	49
Pseudognaphalium sandwicensium	ʻEnaʻena	N	93
Senecio madagascariensis	Fireweed	NN	1277
Sophora chrysophylla	Māmane	N	6
Taraxacum officinale	Common Dandelion	NN	27
Tetramolopium humile humile	Alpine Tetramolopium	N	1 (dead)
Trisetum glomeratum	Pili Uka grass	N	147
Verbascum thapsus	Common Mullein	NN	1
Unknown	Lichen	U	151*
Unknown	Moss	U	14*

*It is not possible to count individual lichen and mosses; figures indicate the number of sites at which each was observed.

Conclusion

No new vegetation threats were observed during rotating panel monitoring during this period. A few spiders were collected for further identification but were not confirmed to be threats beyond that of established populations.

Annual Alien Invertebrate Monitoring

Introduction

From 2007 to 2012, the Bishop Museum was contracted by OMKM to conduct biological surveys to monitor native and established non-native invertebrates and detect invertebrate threats. Beginning in 2013, OMKM conducted the surveys internally using locations and methods consistent with those used by the Bishop Museum. This section includes results for all species captured during the 2016-2020 survey effort. Detailed wēkiu bug (*Nysius wekiuicola*) data and analysis can be found in the *Native & Established Species Monitoring* section further on.

Study Area

Alien invertebrate surveys are conducted concurrently with wēkiu bug monitoring surveys to reduce impacts to the environment. Alien invertebrate study areas include the Halepōhaku (HP) staff headquarters at 2,850 m (9,300 ft) elevation, the Mauna Kea Ice Age Natural Area Reserve (NAR), the road corridor, the Mauna Kea Science Reserve (MKSR), and puʻu (cinder cones) within the Astronomy Precinct that extend to the summit at 4,205 m (13,796 ft). Survey location maps are in *Appendix D: Annual Survey Location Maps*, and *Appendix E: Annual Alien Arthropod & Wēkiu Bug*

Trap Coordinates contains a table of GPS coordinates, elevation, and trap types for each survey location. Coordinate and elevation data was retrieved from GPS units in the field using the WGS 84 datum. It should be noted that most location names are not official, but rather are a means of labeling sites to easily identify specific areas of the vast summit region on Maunakea. Unless otherwise stated, puʻu names were derived from U.S. Geological Survey (USGS) geology maps and the Geographic Names Information System (GNIS).

Methods

The objectives of survey fieldwork are to document native and alien species found within UH-managed lands and neighboring lands (especially the NAR) and identify species that could be threatening to cultural sites, natural resources, and/or human health and safety. All arthropod specimens were identified by comparisons to previous catches. Collected specimens were identified to the lowest possible taxonomic unit necessary to determine if the species was a threat.

To accomplish our objectives, we sampled over a broad range of habitats at the summit including undisturbed wēkiu bug habitat and nearby disturbed habitat types that are associated with past or present human activity. Each trapping area had 1-12 sites, with each site containing at least one of four trap types (detailed below). Trap areas were defined using Natural Resources Conservation Service (NRCS) soil survey data (http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx). Exceptions were made to address potential management impacts at certain sites, for example, within the road corridor or Thirty Meter Telescope (TMT) site.

2016-2020 traps mirrored traps used since 2013 and included yellow pan traps; baited pitfall traps; un-baited wet pitfall traps; and peanut butter, jelly, and spam sticks (PBJS sticks). All traps were retrieved within 3-4 days. All specimens that were collected in traps were kept for further analysis with the exception of live wēkiu bugs, which were captured, recorded, and released.

Yellow Pan Traps

Yellow pan traps were used to capture flying insects that are attracted to the color yellow. Pan traps were placed on the substrate and filled with food-grade propylene glycol and water. Propylene glycol prevents freezing during nighttime temperatures, slows evaporation, is safe for the environment, and acts as a preservative for captured specimens.

Un-baited Wet Pitfall Traps

Un-baited wet pitfall traps were used to capture crawling arthropods. To reduce wēkiu bug mortality, un-baited wet pitfall traps were not placed in potential or known wēkiu bug habitats. To install this trap, a small hole was dug and a plastic cup was positioned in the hole such that its top was level with the surface substrate. Then, a quarter of the cup was filled with a propylene glycol-water mixture. A cap rock was placed over each trap to prevent rain or snow from filling it.

Baited Pitfall Traps

Baited pitfall traps were used to capture crawling arthropods that are attracted to putrid bait. These traps keep arthropods alive by providing them with food and water until they are retrieved. Baited pitfall traps were placed in all habitats. Two nested plastic cups with a wick between them were placed in a hole in the substrate and the rim of the top cup made level with the substrate's surface. Once the cups were set, about 1 cm of water was added to the bottom cup and the other, upper cup was inserted back into the bottom cup. This allows water from the bottom cup to move up through the wick into the top cup, providing water for captured arthropods. A few rocks were placed in the cup for shelter (no more than ½ full) and the rim and cap rock were baited with tuna. A cap rock was placed over the trap to prevent rain or snow from filling it.

Peanut Butter, Jelly, & Spam (PBJS) Sticks
PBJS sticks were used to survey primarily ants. The use of different baits allows for attraction variation across different ant species. Chopsticks were baited with peanut butter, jelly, and spam and laid on the ground, secured with a rock where needed. These were caged in large-gauge wire netting where birds and other animals were likely to steal the bait (mostly at elevations below 11,000 ft.).

Hand Search
Hand searching is practiced on the ground level and includes turning over rocks and/or brushing a hand over the substrate in search for invertebrate threats and native species. Hand searches were conducted for roughly 10 minutes throughout a 5 m radius of each site.

Vegetation Survey
The presence of native and non-native (including invasive) plants was observed within a 10 m radius of each trapping site. Non-native (including invasive) plants observed in the NAR and MKSR were removed and documented. The roots of non-native pulled plants were carefully observed for ants and other invasive arthropods. All vegetation near trapping sites within the MKSR and NAR was recorded.

Results & Discussion

OMKM alien invertebrate surveys are generally conducted from late spring to mid-summer of each year. During the five-year period of 2016-2020, surveys were conducted as follows (see table 5):

Table 5**.** Summary of the annual alien invertebrate monitoring survey for 2016-2020.

Year	No. of sites surveyed	No. of traps set	No. of Invertebrate Individuals observed*	No. of Invertebrate taxa observed	No. of Wēkiu observed
2016	104	216	2,234	82	201
2017	98	199	5,931	83	1,449
2018	111	224	7,879	106	3,798
2019	111	225	9,110	90	463
2020	111	218	1,700	86	494

*Does not include those observed during hand searches

Table 6 lists all new record captures to the Management Area. Many of these taxa had been known to be present within the management area but had never been captured in a trap and documented, or had not previously been identified to the species level. Notable among these are two native moths, *Agrotis helela* and *Agrotis kuamauna*, which were described with the help of OMKM staff in

2019. Nativity[3] can be non-native (NN), native (N), non-native & native (NN/N) within the taxonomic group, or unknown (Unk) if nativity cannot be determined. Invertebrate threats are identified here in **bold** font. With a few exceptions, non-native Araneae (spiders), Coleoptera (beetles), Muscid flies (Diptera: Muscidae), and Hymenoptera (ants, bees, and wasps) are considered threats, as they commonly predate on, parasitize, or dominate the resources of native species.

Table 6. New record captures within the Management Area.

Order	Family	*Scientific name*	Common Name	Nativity
Araneae	**Agelenidae**	***Hololena curta***	**funnel weaver spider**	**NN**
Araneae	**Corinnidae**	**unknown**	**spider**	**Unk**
Araneae	**Trachelidae**	***Meriola arcifera***	**true spider**	**Unk**
Blattodea	**Blaberidae**	***Pycnoscelus indicus***	**indian cockroach**	**NN**
Coleoptera	**Cerambycidae**	**unknown**	**long-horned beetle**	**NN/N**
Coleoptera	Coccinellidae	*Halmus chalybeus*	steelblue lady beetle	NN
Coleoptera	**Hydrophilidae**	***Cercyon laminatus***	**water scavenger beetle**	**NN**
Coleoptera	**Latridiidae**	***Aridius nodifer***	**minute brown scavenger beetle**	NN
Coleoptera	**Tenebrionidae**	**unknown**	**darkling beetle**	**NN/N**
Collembola	Hypogastruridae	unknown	pudgy springtails	NN/N
Diptera	Anthomyiidae	unknown	seedcorn maggot fly	NN
Diptera	Calliphoridae	*Eucalliphora lilaea*	common blow fly	NN
Diptera	Calliphoridae	*Lucilia unknown*	green bottle flies	NN
Diptera	Dolichopodidae	unknown	long-legged fly	NN/N
Diptera	Fanniidae	unknown	latrine fly	NN
Diptera	Lauxaniidae	unknown	lauxaniid fly	NN
Diptera	**Muscidae**	***Coenosia humilis***	**tiger fly**	**NN**
Diptera	**Nematocera**	**unknown**	**unknown fly**	**NN/N**
Diptera	Psychodidae	*Trichopsychoda insulicola*	moth fly	NN
Hemiptera	Lygaeidae	*Nysius nemorivagus*	seed bug	N
Hemiptera	Miridae	*Hyalopeplus pellucidus*	transparent-winged plant bug	Unk
Hemiptera	Miridae	*Lygus elisus*	pale legume bug	NN
Hemiptera	Miridae	*Orthotylus sophoricola*	plant bug	N
Hemiptera	Miridae	*Spanagonicus albofasciatus*	whitemarked fleahopper	NN
Hemiptera	Nabidae	*Nabis* sp.	damsel bug	NN/N
Hemiptera	Pentatomidae	unknown	stink bug	NN/N
Hemiptera	Reduviidae	unknown	assassin bug	NN/N
Hemiptera	Rhyparochromidae	*Brentiscerus australis*	dirt-colored seed bug	NN
Hemiptera	Rhyparochromidae	unknown	dirt-colored seed bug	NN
Hymenoptera	**Ichneumonidae**	***Diadegma* sp.**	**Ichneumonid wasp**	**NN**
Hymenoptera	**Mymaridae**	**unknown**	**fairy wasp**	**NN/N**
Hymenoptera	**Pompilidae**	***Anoplius toluca***	**pompilid wasp**	**NN**
Hymenoptera	**Tenthredinidae**	**unknown**	**sawfly**	**NN**
Lepidoptera	Crambidae	*Tamsica* sp.	grass moth	N
Lepidoptera	Erebidae	*Achaea janata*	croton caterpillar	NN
Lepidoptera	Gelechiidae	unknown	twirler moth	NN/N
Lepidoptera	Lycaenidae	*Lampides boeticus*	pea blue butterfly	NN
Lepidoptera	Noctuidae	*Agrotis helela*	Noctuid moth	N
Lepidoptera	Noctuidae	*Agrotis kuamauna*	Noctuid moth	N
Lepidoptera	Pterophoridae	unknown	plume moth	NN
Lepidoptera	Pyralidae	unknown	snout moth	NN/N
Neuroptera	Hemerobiidae	*Hemerobius pacificus*	brown lacewing	NN
Neuroptera	Hemerobiidae	*Unknown*	brown lacewing	NN/N

[3] Nativity was determined using various resources such as the Insects of Hawaiʻi series (The University of Hawaiʻi Press, Honolulu), the Hawaiian Terrestrial Arthropod Checklist (Nishida 2002), and the revised checklist (Matsunaga et al. 2019).

Order	Family	*Scientific name*	Common Name	Nativity
Odonata	Anisoptera	unknown	dragonfly	NN/N
Psocoptera	unknown	unknown	barklice/ booklice	NN/N
Stylommatophora	Succineidae	Succinea konaensis	amber snail	N
Stylommatophora	unknown	unknown	air-breathing land snail	NN/N
Stylommatophora	Vitrinidae	*Vitrina tenella*	Hawaiian land snail	N

A comprehensive list of all invertebrate taxa captured or observed during Annual Alien Arthropod surveys from 2016 to 2020 can be found in Appendix H.

Taxa Observed

The charts below provide an overview of the diversity of taxa observed in the various alien monitoring traps.

Capture Abundance by Order

The pie chart below (Figure 8) shows the capture percentage by order for all trap types combined (this does not include hand search[4] data). The majority of individuals captured were flies (Diptera) and true bugs (Hemiptera), mostly seed bugs (*Nysius* sp.). The 'n' value in the bottom right displays the total number of arthropods captured in all trap types.

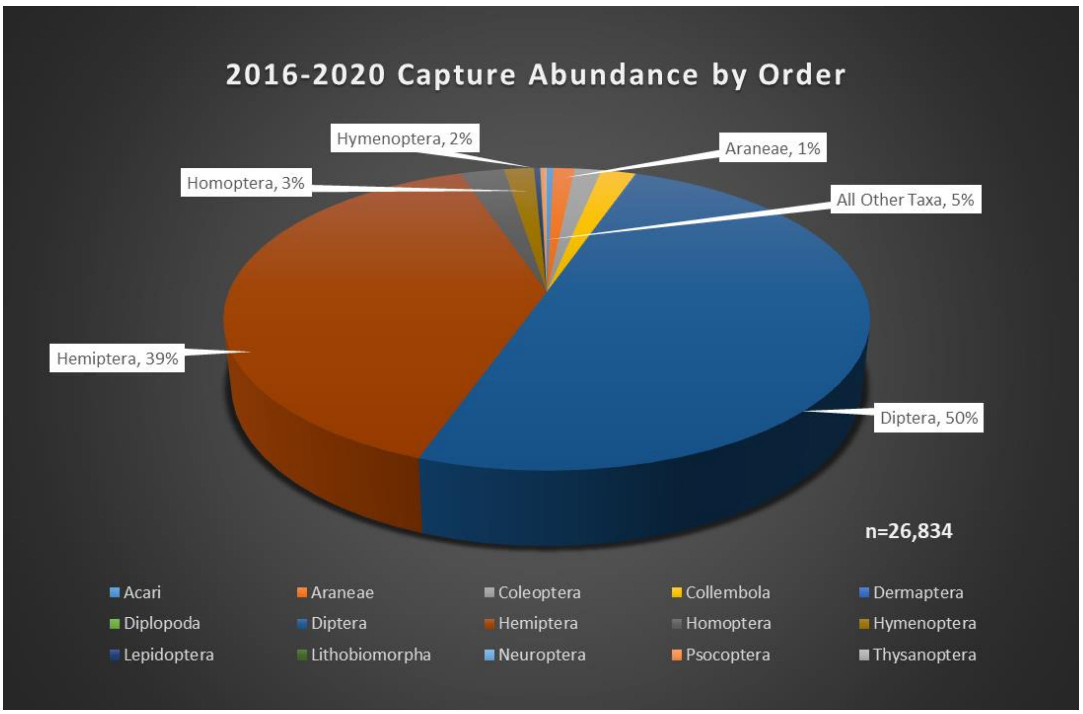

Figure 8. 2016-2020 capture abundance percentage by order for all trap types combined.

Capture Percentage by Trap Type

The graph below (Figure 9) shows the percentage of individuals in each order captured by each trap type (does not include hand search data). The numbers on the top of each bar represent 'n', the number of individuals captured within that order. As could be expected, flies (Diptera) and wasps (Hymenoptera), many of which are known to be attracted to the color yellow, were primarily

[4] Hand search abundance data is sometimes not quantified but rather estimated.

drawn to Yellow Pan traps, which also attracted aphids and plant lice (Homoptera). Most true bugs (Hemiptera) were found in baited pitfall traps. This was also to be expected, as wēkiu bugs (*Nysius wekiuicola*) fall into this category and only this type of trap is set in known wēkiu habitat. Almost 60% of Hemiptera captured were wēkiu bugs and 93% of those were captured in baited pitfall Traps. PBJS sticks, primarily designed to attract various species of ants (Hymenoptera: Formicidae), captured mostly mites (Acari) and lady beetles (Coleoptera: Coccinellidae). Only one ant was captured in any of the traps, an individual of the species *Cardiocondyla kagutsuchi*, which was found in a baited pitfall trap near Halepōhaku, where the species is known to have a small population.

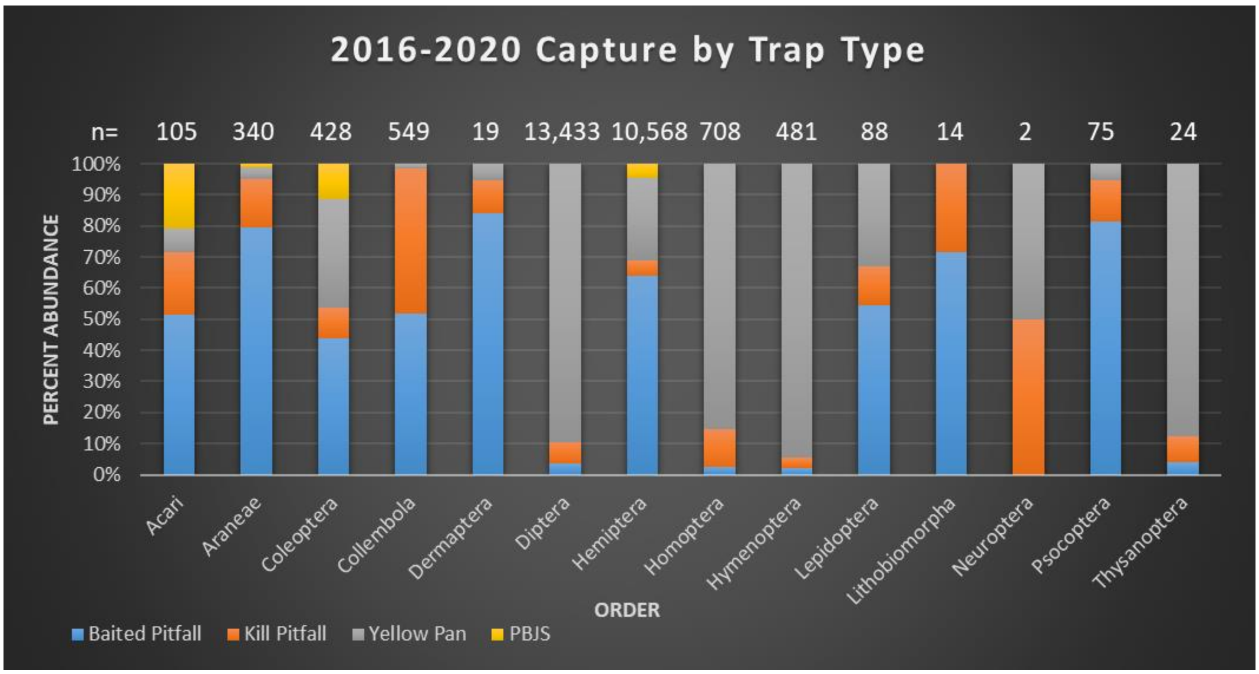

Figure 9. 2016-2020 percentage of individuals in each order captured by each trap type.

<u>Arthropod Nativity by Locality</u>

The graph below (Figure 10) shows the nativity (using abundance) of species observed by locality (including those observed in hand searches). Locations go from low elevation at left to high elevations at right, grouped as previously disturbed habitats and un-disturbed habitats. It should be noted that not all types of traps are placed at all localities, and that certain types of traps (i.e. Yellow Pan traps) are more attractive to many of the non-native species found on Maunakea.

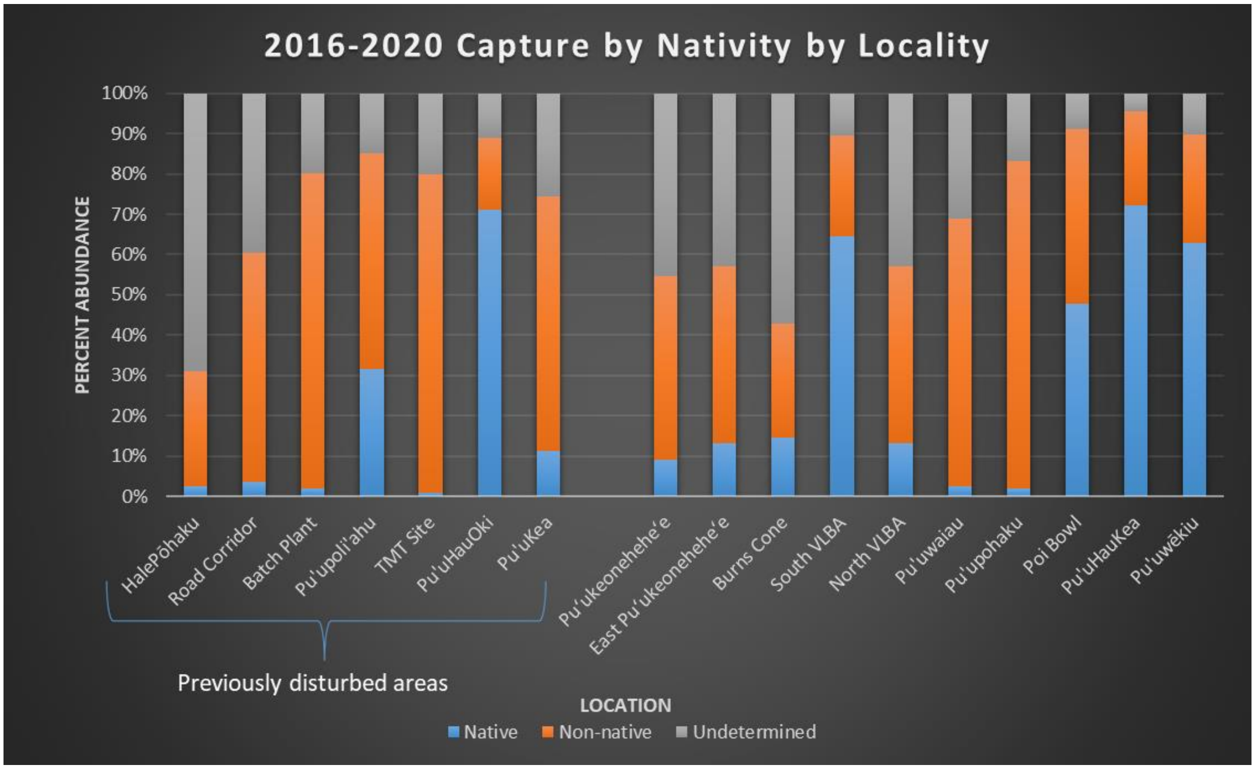

Figure 10. Arthropod nativity and percent abundance by location.

Conclusion

Most arthropods captured during this period were flies (Diptera) and seed bugs (Hemiptera), with more than half of seed bugs being endemic wēkiu bugs. See *Annual Wēkiu Bug Monitoring* section in the *Native & Established Species Monitoring* section for details on the wēkiu bug results. Of the arthropods captured in traps (excluding hand searches), 26,854 individuals were captured for an average of 5,370 each year, with 9,110 being the most captured in a single year (2019) and 1,700 being the fewest (2020). Of all arthropods captured and observed, approximately 23% were native, 57% were known to be non-native (0.02% threats), and about 20% were of undetermined nativity[5] (28% potential threats[6]). Vegetation observed at trapping sites were predominantly native grasses and lichen, though invasive fireweed was also frequently observed and pulled.

[5] All specimens are identified to the lowest taxa possible (usually to family) to determine whether the species is a threat. The term "undetermined" identifies taxon's that have both native and non-native species within that taxonomic group.

[6] This includes species that may threaten native plant species, such as aphids and thrips, which are known to be established.

Incidental Early Detection Monitoring

Introduction

Non-native vertebrates, invertebrates, and vegetation can pose major threats to native ecosystems. Therefore, timely detection and monitoring of new non-native species is key. Detection of native species is also of interest, especially if they are rarely observed by Maunakea users. Beginning in 2013, OMKM started documenting incidental observations and collections of species reported by Maunakea users, including Rangers, OMKM staff, VIS staff, observatory staff, and others. As CMS, the organization continues to collaborate with neighboring landowners and state agencies on possible biological threat issues on Maunakea, and vice versa. Incidental monitoring serves as both an early detection method and a monitoring strategy. This section includes all incidental reports of species observed within UH managed lands and adjacent lands. Species include those that 1) are not established within the management area, 2) are unique or rarely observed within the management area, or 3) are common in the habitat, but not typically encountered by Maunakea users (i.e. *Lycosa* spiders). Any non-native species not previously documented on UH managed lands is considered a threat. Early detection of threat species and their locations provides OMKM/CMS with a better understanding of trends within threat populations and can help OMKM/CMS build its knowledge of ranges of rare and unusual species.

Study Area

The study site includes all UH managed lands and neighboring lands (including Natural Area Reserves (NARS), Forest Reserves (DLNR), and Department of Hawaiian Home Lands properties (DHHL) where OMKM/CMS-related projects may occur.

Methods

Incidental reports are made through simple visual observation while conducting other activities within the Management Area. Incidental observation is a vital method for early detection, as simple awareness and active observation between field activities can allow for a much broader survey of the Management Area. These observations can be made by any Maunakea user, including CMS employees, researchers, on-mountain staff (Maunakea Rangers, Observatory staff, etc.), and neighboring landowners and managers (Maunakea Watershed Alliance, Natural Area Reserves, etc.). When an unusual or threat species is observed, the specimen (whole or part) is collected or photographed, if possible, for further identification and verification. Once verified, the incident is recorded and a report generated, if necessary. Vertebrate reports vary by vertebrate type (see below) and may entail follow-up procedures to remove the animal. Additionally, all evidence of scat is reported to CMS. If observed plant species are identified as non-native, all individuals are pulled. Detected non-native invertebrates require extensive study and planning if eradication or control tactics are necessary (see *Arthropod Control* section).

Ungulates

Ungulates including mouflon sheep (*Ovis musimon*), domesticated sheep (*Ovis aries*), goats (*Capra hircus*), cattle (*Bos taurus*), and feral pigs (*Sus scrofa*) are sparse on UH managed lands, but are occasionally observed. Maunakea users report sightings and observations of ungulate activity to CMS, and these are documented for further analysis and reported to NARS and DLNR.

Cats
Feral cats (*Felis catus*) are sparse at ~9,200 ft. and above but are occasionally observed. When cats are observed, they are reported and MKSS staff put out live traps that are checked daily for activity. Captured cats are documented and taken to the Hawaiʻi Island Humane Society.

Dogs
Feral dogs (*Canis familiaris*) are rarely observed, with no reports in recent years. Occasionally, hunting or pet dogs get lost or are abandoned. Feral dog sightings are reported to DOFAW, DHHL, and BIISC; abandoned and lost dogs are captured when possible, documented, and taken to the Hawaiʻi Island Humane Society.

Rodents
Rodents found on Maunakea include mice and rats. There are three known established rodent species on UH managed lands: the black rat (*Rattus rattus*), and two mice (*Mus musculus* & *Mus domesticus*). Rats are not very common and are rarely observed. Mice seem to be more common on UH managed lands and are observed in seasonal cycles likely related to food availability (seeds). When rodent sightings increase, MKSS staff place baited snap traps around the inside of their facility. Snap traps are checked daily; carcasses are disposed of in the rubbish can and documented. All other incidental rodent observations and captures by Maunakea users are also documented.

Mongoose
Mongoose (*Herpestes auropuntatus*) are not common at higher elevations on Maunakea and are rarely observed on UH managed lands. When mongooses are observed, they are reported to DOFAW, DHHL, and BIISC.

Rabbits
Rabbits (*Lepus curpaeums*) are rarely reported, and the few reports received have been sightings on DHHL lands. When rabbits are observed, they are reported to DOFAW, DHHL, and BIISC.

Birds
See *SOP B: Maunakea Vertebrate Threats Identification, Collection, and Processing Guide* for bird species on UH managed lands. The occasional dead bird is not typically documented, though all dead native or banded birds are collected in a Ziploc bag and reported to DOFAW. Large mortality events of non-native birds are reported to DOFAW.

Reptiles & Amphibians
Reptiles are not known to be established on Maunakea, but the occasional coqui frog, gecko, or lizard does come up on a vehicle. Reported sightings are documented.

Results and Discussion

Vertebrate Observations
From 2016 to 2020, OMKM received reports of every vertebrate type mentioned above except mongoose and rabbits. The most common sightings were of feral cats and of mice, both of which were observed around Halepōhaku and at higher elevations and were seen throughout the year. 2020 in particular saw a large number of mice at HP (more than 50 compared to only a few in

preceding years), particularly in and around the common building and the VIS facilities. Traps were set in all instances. Most of the cats observed were captured in live traps and taken to the Hawai'i Island Humane Society, which in several instances reported that the cats had microchips. Sheep were also commonly observed near UH managed lands, usually at lower elevations along the Maunakea Access Road, though in 2020 small groups (7 or 8 individuals) were seen several times in the Forest Reserve directly across from Halepōhaku.

Chukars (*Alectoris chukar*) and Erkel's Francolins (*Pternistis erckelii*) were observed frequently around Halepōhaku, often with chicks in summer months (June – August). Chukars were also seen along the road to the summit and around the Astronomy Precinct fairly often. Four instances of deceased non-native red-billed leothrix (*Leiothrix lutea*) were reported over the years at facilities near the summit. Observations of native birds were infrequent, but included several sightings of 'Apapane (*Himatione sanguinea*) and one sighting each of 'Amakihi (*Hemignathus virens* var. *virens*), 'I'iwi (*Vestiaria coccinea*), 'Iwa (*Fregata minor*) and Pueo (*Asio flammeus sandwichensis*).

It should be noted that not every vertebrate incident is reported and therefore, these results can only help in forming limited assumptions on the trends of vertebrates on Maunakea.

Invertebrate Observations

Though many invertebrates are observed on Maunakea throughout the year, only those seen less frequently or in unusual circumstances (i.e. large numbers, new elevations, etc.) are generally recorded in incidental reports and discussed here. Sightings reported from 2016 to 2020 are listed in Table 7 below, in the order in which they were reported. Additional information follows.

Table 7. Invertebrate sightings from 2016-2020.

	Order	Family	*Scientific name*	Common name	Loc.	Threat
1	Coleoptera	Chrysomelidae	*Altica troquata* (tentative)	flea beetle	HP	yes
2	Stylommatophora	Achatinellinae	*Achatinella* sp. (possible)	Hawaiian tree snail	HP	no
3	Scolopendromorpha	Scolopendridae	*Scolopendra* sp.	centipede (dead)	HP	yes
4	Diptera	Culicidae	Unknown	mosquito	HP	yes
5	Stylommatophora	Limacidae	*Limax maximus*	Leopard semi-slug	HP	yes
6	Araneae	Araneidae	unknown	unidentified spider	VLBA	yes
7	Lepidoptera	Noctuidae	*Pseudaletia unipuncta*	armyworm moth	HP	no
7	Hymenoptera	Ichneumonidae	*Ichneumon laetus*	parasitoid wasp	HP	no
8	Hymenoptera	Ichneumonidae	*Ichneumon cupitus*	ichneumonid wasp	HP	possible
9	Hemiptera	Reduviidae	unknown	assassin bug	IRTF	possible
10	Lepidoptera	Nymphalidae	*Vanessa virginiensis*	painted lady butterfly	HP	no
11	Araneae	Agelenidae	unknown	funnelweaver spider	HP	yes
12	Hymenoptera	Vespidae	*Vespula pensylvanica*	western yellowjacket	HP	yes
13	Hymenoptera	Formicidae	*Cardiocondyla kagutsuchi*	small ant	HP	yes
14	Hymenoptera	Formicidae	*Wasmannia auropunctata*	little fire ant	HP	yes
15	Hymenoptera	Apidae	*Apis mellifera*	European honey bee	HP	yes

1. *Altica troquata*

4-5 individuals were observed in a Chilean evening primrose (*Oenothera stricta*) plant. The small beetles were identified by Jesse Eiben and his lab as flea beetles, most likely *Altica troquata* (Coleoptera: Chrysomelidae). However, it was noted that they might also be *A. ambiens* or *A. Corrusca*. This beetle has been found before on Maunakea and is not a direct threat to native arthropods, though it could potentially cause damage to native plant seedlings, as it is an herbivorous agriculture pest. Nonetheless, it was not felt that rapid response procedures were needed in this case.

2. *Achatinella* sp.

A single individual was found under a mullein (*Verbascum thapsus*) during a perimeter search of the HP gravel parking area. OMKM staff suspected it may be a native Hawaiian tree snail, and the specimen was sent to Dr. Brenden Holland of the Hawaiʻi Tree Snail Conservation Lab for identification.

3. *Scolopendra* sp.

A single individual was found dead near the fueling station in the Halepōhaku utilities area. It was likely carried up on a vehicle and was already dead or died shortly after arriving on the mountain.

4. Culicidae

Mosquitos were reported at Halepōhaku by MKSS staff. OMKM staff conducted surveys to determine their source, focusing on areas with standing water (particularly the water tanks near the stone cabins). No other mosquitos were observed.

5. *Limax maximus*

Utilities staff collected a large, live semi-slug found near the road grader in the Utilities equipment parking lot. It was identified as *Limax maximus*, a Leopard slug, which is very common in Hawaiʻi. It is likely that it arrived on the mountain on a vehicle and that heavy rains provided it with adequate moisture to survive.

6. Araneidae

OMKM staff collected a small new, unknown spider on the outside wall near the door of the VLBA facility. It was identified as an Araneidae, a family which had never been observed by OMKM on Maunakea before.

7. *Pseudaletia unipuncta* and *Ichneumon laetus*

In October 2018, three noctuid pupa were found under a mullein (*V. thapsus*) plant during a volunteer weed pull. They were placed in a container with soil and brought to the OMKM office to be reared out. Approximately 3 weeks later, a non-native *Pseudaletia unipuncta* emerged from one of the pupa. This moth is known to be an agricultural pest on plants in the family Graminaceae (grain, barley, corn, millet, etc.), and not a likely threat to the native plants on Maunakea. A few days after the moth emerged, a large ichneumonid wasp emerged from another of the pupa collected. It was identified as *Ichneumon laetus*, a parasitoid of *Pseudaletia unipuncta* that matures inside the moth pupa and eventually fills it before emerging. This species had been previously recorded on UH managed lands.

8. *Ichneumon cupitus*

OMKM staff collected an ichneumonid wasp from the rim of a 4Runner in the Halepōhaku gravel parking lot. It was identified as *Ichneumon cupitus*, a species previously recorded on UH managed lands.

9. Reduviidae
IRTF staff collected a dead Reduviid and an *Neacoryphus bicrucis* (Whitecross seed bug, common on Maunakea) on a day when many insects were flying around on the summit. Though Reduviidae are not often seen, they are not unusual on the mountain.

10. *Vanessa virginiensis*
OMKM staff observed an unusual webbing on the naturally regenerating ʻenaʻena (*Pseudognaphalium sandwicensium*) near the VIS. Inside the webbing were 4 spiny caterpillars, 2 of which were collected for identification. They were identified as American painted lady (*Vanessa virginiensis*), known to utilize everlasting herbs in the genus *Pseudognaphalium*. They excrete silk to create homes in the leaves of these herbs. It is notable that this non-native species is utilizing a native *Pseudognaphalium* for habitat. It does not appear that the presence of the caterpillar adversely affects the ʻenaʻena, which continues to grow and flower.

11. Agelenidae
In early 2020, the HP manager began to receive complaints of spiders in Dorm D. A specimen was photographed and identified as a non-native funnel weaver (Family: Agelenidae). These spiders do not bite humans unless they are threatened, and their bites are essentially harmless to humans. OMKM's Natural Resource Specialist recommended that a barrier treatment like "Home Defense" be applied along the inside of Dorm entrances, as they were likely coming inside to escape the cold. This approach seemed to be effective.

12. *Vespula pensylvanica*
The fall of 2020 saw a sharp rise in the number of western yellowjackets (*Vespula pensylvanica*) present around Halepōhaku. As this species poses a threat to both humans and native arthropods, steps were taken to try to control the population, which seemed to be established in the area. Wasp-Hornet-Yellowjacket (W-H-Y) traps were set out in two areas, one near the HP common building and one in the vicinity of the VIS. From September to December of that year, more than 430 yellowjackets were captured. Detailed results of this effort can be found under Vespid Control in the Control section of this document.

13. *Cardiocondyla kagutsuchi*
During this period, ants were observed in the vicinity of Cabin 1, near and on the sidewalk leading to the VIS warehouse. The ants appeared to be nested under the sidewalk – a hole was spotted between two sections where ants were emerging and returning. Amdro bait was spread in the area. When the site was revisited several weeks later, no ants appeared to be present, nor have they been observed in the same place since. *C. kagutsuchi* has been observed in the Halepōhaku area on other occasions and is thought to have become somewhat established, despite efforts to eradicate it. It does not, however, exhibit the characteristics of tramp species, which tend to be much more invasive and a more significant threat to native ecosystems.

14. *Wasmannia auropunctata*
In December 2020, little fire ants (*Wasmannia auropunctata*) were observed by OMKM staff on the underside of an IBC watering tank donated and brought up for use at the newly constructed greenhouse. One ant was observed on the ground near the container. Raid was sprayed heavily on

the ground underneath the container and on the frame of the container, where the ants were active, and Amdro bait was spread on the ground around the container, initial steps of rapid response. The container was re-inspected the following day; though ants were still present and alive on the frame of the tank, they did not appear to have spread to the ground. The tank was again sprayed heavily with Raid and left on its side in hopes that the ants would not exit the frame and move out onto the ground. Subsequent inspections of the water tank throughout the following weeks showed no signs of any ant activity. For more information, see Appendix I.

15. *Apis Mellifera*
European honeybees are established on Maunakea. As they pose some danger to humans and compete with native *Hylaeus* bees for resources, efforts are made to control the population, though eradication is not considered a practical goal. Details of control efforts can be found under Honey Bee Monitoring in the Native & Established Species Monitoring section of this document.

Other incidental reports of arthropods during this period included 3 instances of high volumes of *Nysius* (seed bugs common on Maunakea), both dead and alive, which occurred at HP and at the summit, as well as occasional accumulations of lady beetles (Coleoptera: Coccinellidae).

Vegetation Observations
2016 to 2020 saw sightings of all invasive weeds commonly found in UH managed lands on Maunakea, including black-jack (*Bidens pilosa*), telegraph weed (*Heterotheca grandiflora*), hairy cat's ear (*Hypochaeris radicata*), evening primrose (*Oenothera stricta*), sheep's sorrel (*Rumex acetosella*), fireweed (*Senecio madagascariensis*), dandelion (*Taraxicum officinale*), and mullein (*Verbascum thapsus*). Of these, fireweed was by far the most frequently reported (6,752 individuals), likely because it is abundant, easily identified at various stages of maturity, and the subject of an organized focus for the Maunakea Rangers, who look for, pull, and report occurrences of the plant as part of their daily checks of the mountain. Mullein and hairy cat's ear were also commonly reported (50 and 33 individuals, respectively), though it should be noted that hairy cat's ear is easily confused with dandelion, and in some cases may have been misreported.

Other, less common species reported during are noted in the table below (Table 8). Among these, fountain grass (*Cenchrus setaceum*) and gorse (*Ulex europaeus*) are of the greatest concern due to their highly invasive nature. These both have come to dominate other areas of Maunakea, and steps were taken immediately by OMKM staff to remove all individuals found. The gorse noted in the table was found above the Humuʻula sheep station along the Maunakea Access Road. Though this is not UH managed land, efforts were made by OMKM staff to remove the individuals to avoid seeds being transported higher up by traffic on the road, a common vector for invasive species.

Single eucalyptus and apple trees are known to exist in a few places on UH managed lands and along the Maunakea Access Road between the VIS and the Saddle Road. Neither is native, and efforts are made to cut back individuals on UH managed land to avoid flowering and spread. Individuals are revisited from time to time and re-trimmed, as trees tend to regrow, even from stumps. The apple trees found during this period were immature and able to be pulled.

Other non-native plants on this list were reported only once or twice during the period and, whenever possible, steps were taken to remove those that might be likely to spread.

Table 8. Uncommon plant species observed between 2016-2020.

Common name	Scientific name	Location	No. observed	Pulled ?	Year
Mushrooms	2 unknown mushroom species	HP	5	N	2018
Anise hyssop	*Agastache foeniculum*	HP	1	Y	2018
Fountain grass	*Cenchrus setaceum*	HP	3	Y/N	2016 2020
Tree lucerne	*Cytisus proliferus*	HP	2	Y/N	2016
California poppy	*Eschscholzia californica*	HP	3	Y	2018
Eucalyptus	*Eucalyptus* spp.	HP	5	N	2016
Fennel	*Foeniculum vulgare*	HP	2	Y/N	2016
Indian blanket	*Gaillardia pulchella*	HP	31	Y	2018 2020
Apple	*Malus* spp.	HP	15	Y	2016
White clover	*Trifolium repens*	HP	6	Y	2016
Gorse	*Ulex europaeus*	MK Access Rd	7	Y	2018

NATIVE & ESTABLISHED SPECIES MONITORING

Monitoring of native and established species is important for understanding population and ecosystem changes through time. Native and established species monitoring goals include status documentation of established native and non-native species and tracking of invasive threats (species of threat to cultural and natural resources and/or to human health and safety) to help determine management effectiveness of both rapid response and control actions. This section includes monitoring results for wēkiu bugs, honey bees, and vegetation (all other types of monitoring can be found in the *Early Detection Monitoring* section).

Annual Wēkiu Bug Monitoring

Introduction

As part of the ongoing long-term study started by Hawaiʻi Biological Survey of the Bishop Museum, the Office of Maunakea Management (OMKM)/Center for Maunakea Stewardship (CMS) continues monitoring wēkiu bug (*Nysius wekiuicola*) populations, a species endemic to the Maunakea summit area of Hawai'i Island. The objectives for the 2016-2020 field seasons were to continue to document wēkiu bug populations found within UH managed lands and neighboring lands (Natural Area Reserve [NAR]).

Study Area

Wēkiu bug surveys were done concurrently with alien invertebrate monitoring to reduce impacts to the environment. See the *Early Detection Monitoring* section above for alien species monitoring methods and results. Wēkiu bug monitoring occurs in the Alpine Stone Desert, which includes the Mauna Kea Science Reserve (MKSR) and the NAR. Monitoring begins at about 3,700 m and extends to the summit at 4,205 m, encompassing core wēkiu bug habitat. See *Appendix D* for survey locations, GPS coordinates, trap dates, and trap types associated with captured species. WGS 84 data was used for recording GPS locations and altitude.

Unless otherwise stated, pu'u names were taken from the U.S. Board on Geographic Names. Many pu'u have not yet been given official names and, when possible, these cinder cones are identified by nearby landmarks or distinctive features. These names should not be viewed as official, but instead allow us to more easily identify specific areas of the vast summit region of Maunakea.

Methods

Trapping was conducted in wēkiu bug habitats with a focus on areas of potential alien invertebrate invasion. Sampling sites ranged from undisturbed habitat to human disturbed habitat types. Each trapping area had between 1 and 12 sites, and each site contained at least one wēkiu bug trap. Trapping areas (see *Appendix D and Appendix E*) were defined using Natural Resources Conservation Service (NRCS) soil survey data.

Baited pitfall traps were used to capture wēkiu bugs (see *Baited Pitfall Trap* methods in the *Annual Alien Invertebrate Monitoring* section above) and were retrieved within 3-4 days to prevent wēkiu bug mortality. All captured wēkiu bugs were recorded and released, while all other captured specimens (bycatch) were recorded and/or collected for further analysis. All invertebrate specimens collected were identified to the lowest possible taxonomic unit necessary to determine if the species was a threat.

Results and Discussion

A total of 6,310 wēkiu bugs were captured in 405 baited pitfall traps during five 3-4 day trapping periods, one each year from 2016 to 2020 (see Table 9). Locations with the highest wēkiu bug abundances include Puʻuhaukea, Puʻuhauʻoki, Puʻupoliʻahu, and Puʻuwēkiu. See *Appendix* F*: 2016-2020 Wēkiu Bug Capture Data,* and *Appendix G: 2016-2020 Wēkiu Bug Capture Rates* for wēkiu bug captures and rates per individual trap site. All captured alien arthropod specimens from baited pitfall traps are shown in the *Early Detection Monitoring* section above and the list of all arthropods captured during annual surveys are in *Appendix H: 2016-2020 Annual Survey Arthropod Capture List*. Below is Table 9 displaying wēkiu bug captures of all trap types (not including hand searches) by location. Column “Total Traps/ yr” refers to the number of trapping sites at each location. “Trap Days/ yr” refers to the total number of days traps were set out.

Table 9. 2016-2020 Wēkiu bug captures by location.

Location	Total Traps/ yr	Trap Days/ yr	Wēkiu Captures				
			2016	2017	2018	2019	2020
Batch Plant	7	21	4	0	1	0	0
Poi Bowl	3/7*	9/21	1	16	104	45	13
Pu'uhau'oki	8†	24	20	314	785	161	272
Pu'uhaukea	14	42	105	534	1464	57	45
Pu'ukea	2	6	4	22	150	7	29
Pu'upōhaku	6	18	0	15	8	5	0
Pu'upoli'ahu	7	21	11	454	342	125	87
Pu'uwēkiu	10	30	43	45	897	29	13
Pu'uwai'au	2	6	0	0	1	2	0
TMT Site	9	27	2	8	3	9	3
N VLBA	7	21	1	0	0	2	0
S VLBA	3/6**	9/18	6	25	0	13	9
Totals	**72-85**	**216-255**	**197**	**1433**	**3755**	**455**	**470**

* 3 baited pitfall traps were set at Poi Bowl in 2016 and 2017 while 7 were set in subsequent years
** 3 baited pitfall traps were set at Poi Bowl in 2016 and 2017 while 6 were set in subsequent years
† 8 baited pitfall traps were set at Pu'uhau'oki every year except 2017 when only 2 were set

Below are two summary tables (Table 10 & 11) and a graph (Figure 11 & 12) displaying trends in wēkiu bug capture rates (bugs/trap per trap day) for Pu'uhaukea (within the Mauna Kea Ice Age Natural Area Reserve) from Bishop Museum related studies since 2001 and for the entire summit region since 2007 (when trap sites became consistent). Trapping data from 2001-2006 used a combination of glycol and shrimp baits unlike trapping efforts from 2007-2012, which only used shrimp paste. From 2013 to present, wēkiu bug traps have been baited with canned tuna.

Table 10. Pu'uhaukea wēkiu bug capture history.

Year & Month of Trapping event	Total Wēkiu bugs[7]	Number of traps	Total Trap Days	Bugs/ trap day
2001 (June) (Polhemus 2001)	473	10	40	11.8
2002 (Sept)	9	16	48	0.2
2004 (July)	0	10	90	0
2005 (May/ June)	8/11	18/16	162/144	0.05/0.08
2006 (April/May)	0/44	10/10	90/80	0/0.6
2007 (June)	274	13	66	4.2
2008 (July)	43	10	60	0.7
2009 (July)	1	10	60	0.02
2010 (June)	244	10	60	4.1
2011 (June)	207	10	60	3.5
2012 (June-July)	720	10	60	12.0
2013 (June)	788	14	42	18.8
2014 (June)	9	14	56	0.16
2015 (June-July)	128	14	42	3.05
2016 (July)	105	14	42	2.5
2017 (June)	534	14	42	12.7

[7] The total number of bugs displayed in this table slightly differs from the summary tables in the *2013 Invasive Species & Native Arthropod Report*, and previous Bishop Reports. Bug numbers were corrected based on datasheet counts and Bishop Reports. Total number of bugs do not include those observed in hand searches.

2018 (June)	1464	14	42	34.9
2019 (June)	57	14	42	1.4
2020 (June)	44	14	42	1

Table 11. Wēkiu Bug Capture History- All trap locations.[8]

Year of Trapping event	# Wēkiu Captured[9]	Number of traps	Total Trap Days	Bugs / trap day
2007	645	42	240	2.7
2008	70	30	130	0.5
2009	120	50	280	0.4
2010	2,982	50	300	9.9
2011	3,146	50	300	10.5
2012	2,536	50	300	8.5
2013	5,290	88	290	18.2
2014	52	88	292	0.2
2015	1,586	101	303	5.23
2016	190	78	234	0.8
2017	1,306	72	216	6.0
2018	3,500	85	255	13.7
2019	401	85	255	1.6
2020	459	85	255	1.8

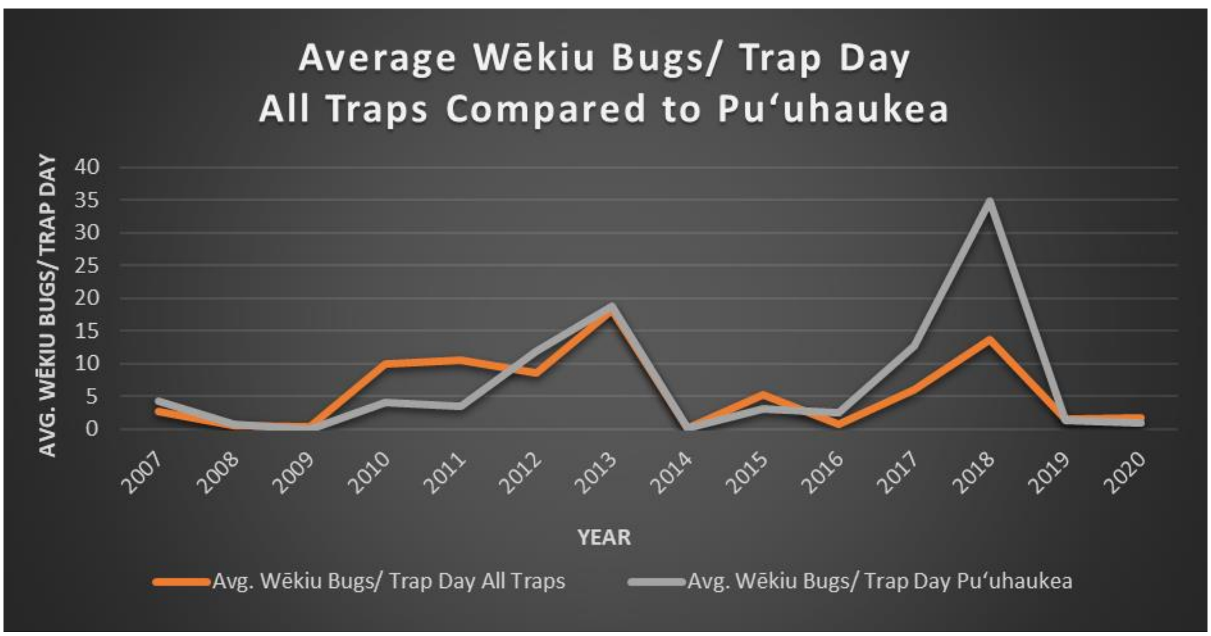

Figure 11. Trend in wēkiu bug capture rates (bugs/trap per trap day) for Pu'uhaukea.

[8] This table shows results starting from 2007, when methods and locations became consistent. These numbers reflect captures in baited traps.

[9] The number of wēkiu bugs displayed in this table slightly differs from the summary tables in the *2013 Invasive Species & Native Arthropod Report*, and previous Bishop Reports. Bug numbers were corrected based on datasheet counts and Bishop Reports.

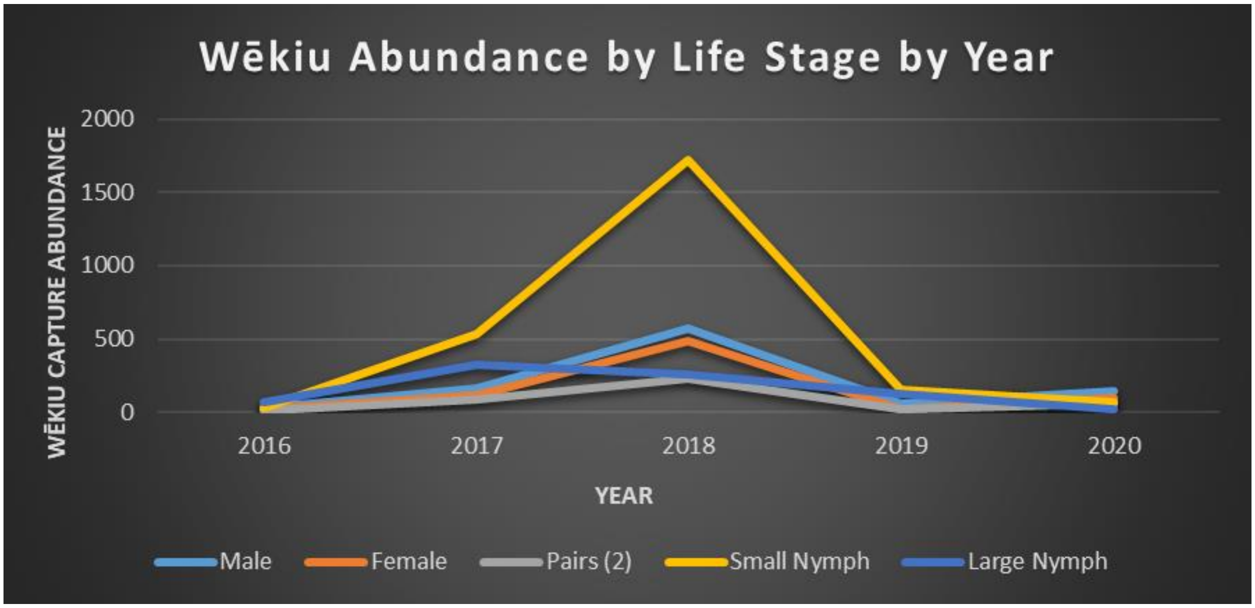

Figure 12. 2016-2020 trend in wēkiu abundance by life stage.

Conclusion

As can be seen in the charts above, wēkiu bug abundance varies widely from year to year. We hypothesize that wēkiu bug populations naturally fluctuate through time and are influenced by numerous biotic and abiotic (especially climatic) factors in their habitat. It is encouraging that all life stages are observed year after year, usually in relative proportion, indicating that the population continues to reproduce.

Honey Bee Monitoring

Introduction

Monitoring honey bee activity allows for understanding the growth and health of a population, while also keeping an eye on public safety. Honey bees in Hawaiʻi have had many threats in the past few years, including the varroa mite (*Varroa destructor*) and small hive beetle (*Aethina tumida*). The Hawaiʻi Department of Agriculture (HDOA) has a series of honey bee hives around the island to monitor threats and understand the health and growth of Hawaiʻi populations.

In May 2012, a honey bee swarm was reported inside of the Visitor Information Station facility. HDOA came up and relocated the swarm, and placed two swarm traps near the VIS. The purpose of swarm traps is to attract the honey bees away from areas of human activity. Since that time, an additional three traps have been set in the Halepōhaku area and only one trap is now maintained near the VIS. Once a swarm trap becomes populated, we allow for pupa establishment and the swarm is relocated by a representative of the Big Island Beekeepers Association.

Study Site

The study site includes four swarm traps mounted to māmane (*Sophora chrysophylla*) trees at Halepōhaku; one above the utilities building (Trap #1), one near Dorm A and the Maintenance road (Trap #3), one below the HP Commons building (Trap #4), and the other below the VIS (Trap #2).

Methods
A vial of pheromones is placed in each swarm trap to attract honey bees. Swarm traps are monitored regularly for bee activity by simple observation. All activity is documented and reported to HDOA. Other incidental observations by Maunakea users are also documented.

Results and Discussion
Overall, bee activity from 2016-2020 was fairly regular. Occupied swarm traps were removed on four occasions: November 2018, Trap #2; August 2019, Traps #1 and 3; October 2019, Trap #4; and December 2020, Trap #3. In all cases, bees were removed to a bee farm in Orchidland. None of the hives were reported to have pests, and the bees seemed healthy.

RAPID RESPONSE

Rapid response plans outline basic procedures to facilitate an efficient response to a new invasive species. While it would be impossible to anticipate every contingency, we can be prepared for new invasive species threats, and refer to established rapid response procedures. Rapid response procedures come into effect when a specimen is first identified as a threat and found on UH managed areas. The goal of a rapid response plan is to be able to quickly formulate the most effective control options (if any). This can be done by being properly prepared, identifying and understanding the invasive species, delimiting the invasions extent, generating a management plan by utilizing expert advice/literature, and organizing a reporting structure. When rapid response procedures are accomplished in a timely manner, control and eradication efforts are more effective, thereby reducing threats to cultural and natural resources. This section discusses rapid response cases for the years 2016-2020.

Three species were identified between 2016-2020 for rapid response. The first rapid response case deals with the detection of a little fire ant (*Wasmannia auropunctata*). The second rapid response case deals with the detection of a carpenter ant (*Camponotus variegatus*). And the third rapid response case deals with the detection of a big-headed ant (*Pheidole megacephala*). These species will continue to be monitored with existing methods. See appendix I, J, and K for full rapid response reports for each species.

Case 1: Little fire ant (*Wasmannia auropunctata*)
The little fire ant (LFA) (*Wasmannia auropunctata*) is a major tramp ant pest species and are native to the American Neotropical lowland forests but have since spread globally via transportation routes (Wetterer & Porter, 2003). LFA were first detected in Puna, Hawaiʻi in 1999 (Conant & Hirayama, 2000). They are known for their painful sting even though the ants are mildly aggressive (Creighton, 1950). These generalist foragers will tend honeydew-producing insects, which make them a further agricultural pest (Clark et al., 1982; Torres, 1984). LFA can feed at all times and work well together in large numbers for foraging (Meier, 1994; Clark et al., 1982). Worker ants are very aggressive towards other ant species and can dominate large areas in its non-native range (Brandao & Paiva, 1994; Way & Bolton, 1997; Delsinne et al., 2001). LFA is known to be an arboreal species in its native range, but it can also populate leaf litter, under rocks, within crevices, inside of organic materials, etc. (Motoki et al., 2013). They prefer warm, moist, and shady areas (Motoki et

al., 2013). LFA are also readily mobile to move to better or recently available nesting sites (Motoki et al., 2013).

<u>Incident 1</u>
On May 16, 2016 LFA was discovered in a Halepōhaku kitchen HoyHoy trap on Maunakea, Hawaiʻi by Office of Maunakea Management (OMKM) staff Darcy Yogi. A single *W. auropunctata* specimen was observed in a sticky HoyHoy trap that was deployed for a month in the kitchen storage room. This is the first time *W. auropunctata* has been detected within UH managed lands on Maunakea.

Control
For the incident that occurred in May 2016, control consisted of a regular heightened pest treatment regimen. After the completion of two delimiting surveys (2 weeks apart), interior baiting was done inside of the kitchen area. Consistent with label restrictions, MKSS placed bait stations with *Maxforce Complete*® in the kitchen storage room and surrounding areas. It was also recommended that an exterior barrier treatment also be employed. Consistent with label restrictions, Ortho Home Defense Max ® (liquid) was sprayed around sidewalks, foundation cracks, and other cavities within built structures (not on soil, cinder, vegetation, etc.). This barrier treatment is already used by MKSS in other areas, and it would prevent any arthropod movement for the next three months. MKSS also ensured that their Terminix exterminator knew about the detection of LFA within their kitchen and Terminix treated interior facility areas within one-week of the initial detection report. MKSS has expanded their target pest species beyond German cockroaches (*Blattella germanica*) to include the control of ants. This means expanded use of Lambda-Cyhalothrin 0.015%.

<u>Incident 2</u>
In June 2020, during invasive species monitoring of facilities, a single LFA was observed in a facility trap in the Halepōhaku Commons building under the stairs where cleaning supplies are kept. The trap was placed on June 26th and retrieved on July 15th. The trap was screened under a microscope on Monday, August 31st, and the ant was found upside down in the middle of the trap between the jelly and peanut butter bait. It looks like the ant fell into the trap while alive, as dead LFA curl up when they die. It is uncertain how the live ant got trapped upside down in the middle of a sticky trap.

Control and management recommendations
On Tuesday September 1st 2020, a survey was conducted in the Halepōhaku Commons building near the stairs and under the stairs where the ant was detected. All cleaning supplies from under the stairs were removed and inspected for ants. Ten index cards baited with peanut butter were placed under the stairs and along the inside perimeter of the floors near the stairs. Index cards were retrieved after 1 hour and 20 min. A hand search was also conducted along the inside perimeter of the commons building. No ants were observed throughout the survey effort. Additionally, no ants were captured in facility traps that were placed before and after the trapping effort that detected the ant. Facility monitoring continues in the same locations (including the location where we detected the ant), and traps are replaced monthly. Many areas in Hilo are

infested with LFA, so it's likely that this ant came up on some kind of supplies, personal equipment, or gear. Thankfully, it appears that this was an isolated incident. We will continue to monitor.

<u>Incident 3</u>

In December 2020 it was brought to the attention of conservation specialist, Jessica Kirkpatrick, that a 300-gallon IBC water container had been brought up to the greenhouse at the Halepōhaku facility without inspection. On December 3rd an inspection was conducted on site at 11:00am, at which time several live LFA were found both inside the lower frame of the container and on the ground where it had been sitting.

Control and management recommendations

On December 3rd at 11:00am Raid® was sprayed heavily around the base of the container and on the ground where it had been sitting. Amdro® ant bait was also spread on the ground in the area. At 2:30pm, a check of the container and ground revealed a pile of dead LFA on the ground and a few live ones in the frame of the container. Raid was applied liberally to the container again and the container was left on its side to discourage the ants from exiting the frame. On December 8th, 11th, 22nd, and January 5th and 13th index cards baited with peanut butter were set out around the water tank and in the area where the water tank had previously been stationed. No LFA were observed in these follow up surveys around the water tank.

Case 2: Carpenter ant (*Camponotus variegatus*)

The carpenter ant (*Camponotus variegatus*), is an infrastructure pest ant species in Hawaiʻi. This species is most likely native to Southeast Asia (Wilson & Taylor, 1967). Carpenter ants have been reported in Hawaiʻi since 1899 and are now present on all major Hawaiian Islands as well as some of the Northwestern Hawaiian Islands (Forel, 1899; Wheeler, 1934). They typically occur at lower elevation dry and mesic areas below 500 m (Reimer, 1994). Unlike most ants in Hawaiʻi, this species is nocturnal making it difficult for survey detection as they can forage until midnight or later (Jones, 2017; Reimer, 1994; Yates, 1992). This ant species produces smaller colonies, usually around 100 workers and soldiers with a single queen per colony (Kirschenbaum & Grace, 2008). Colonies tend to establish in rotting or termite-damaged wood, but it does not consume wood like termites (Yates, 1992). Indoors, carpenter ants will take advantage of hollow wooden areas such as within hollow-core doors, solid foam insulation, double walls, door and window frames, etc. (Yates, 1992; Jones, 2017). Outdoors, carpenter ant nests are associated with moisture such as tree stumps, termite-damaged wood, wood near skylights, and rotting wood (Yates, 1992; Jones, 2017). There is not much information on the ecological impacts of carpenter ants in a non-native environment, but there are no native ants to Hawaiʻi. Therefore, any ant colonization will result in competition of resources with native arthropods as well as potential native arthropod population reduction (Krushelnycky et al., 2005).

<u>Incident 1</u>

On Saturday, November 26, 2016 Visitor Information Station (VIS) staff member Kelly Whelan observed and collected a single ant specimen inside the VIS building on the sales desk during the early evening hours (between 5-7pm) of peak visitation (Figure 4). OMKM was notified the evening of Saturday, November 26th and the specimen was collected on Tuesday November 29th. On Wednesday, November 30th Hawaiʻi Ant Lab staff Michelle Montgomery identified the specimen as *Camponotus* spp., most likely *Camponotus variegatus*. The Hawaiʻi Ant Lab provided some initial information about this species identifying it as a structural pest and relatively low risk to the environment as this species would be limited to buildings, produce smaller colonies, and are not known to present a substantial ecological risk in ecosystems found at Halepōhaku or above. Additionally, no baiting or control methods were recommended by the Hawaiʻi Ant Lab at this time.

Control and management recommendations

Control recommendations consisted of a delimiting survey, interior trapping efforts, and interior baiting efforts. Consistent with label restrictions, OMKM placed six bait stations with Maxforce Complete® around the interior of the Visitor Information Station (VIS). Trapping efforts consisted of six Hoy Trap-A-Roach sticky traps baited with peanut butter, jelly, and spam. Five traps were placed inside of the VIS and one was placed outside of the front doors of the VIS. As no nest was successfully found, trapping and baiting efforts should account for night foraging of this species and potential trails that may be present within the VIS. Interior trapping and baiting efforts continued for a week. Delimiting surveys were conducted both inside and outside of the VIS using peanut butter, jelly, and spam baited vials. Long-term recommendations will be to continue quarterly facility monitoring of the VIS region.

Incident 2

On June 19th, a single carpenter ant (*Camponotus variegatus*) queen was discovered at the original entrance of the Visitor Information Station (VIS) in the Department of Transportation Right-of-Way on Maunakea, Hawaiʻi. The single queen specimen was observed around 2:30pm while replacing traffic cones after the placement of quarterly invasive species monitoring facility traps in the VIS. The ant was observed on the asphalt by Office of Maunakea Management (OMKM) intern T. Quinories and was found alive but moving slowly. After a quick hand search of the area, no other ants were found. The ant was identified as a reproductive carpenter ant queen by the Hawaiʻi Ant Lab on June 20th, and it was determined that she had detached her wings. Generally, ant queens will detach their wings after they have mated and found a suitable area to start a colony. Rapid response surveys at the time found no other individuals leading us to suspect the detection was an isolated incident. Given that this ant species was now found twice in the same relative area, we hypothesize that a small colony of carpenter ants may persist somewhere near the VIS.

Control and management recommendations

Delimiting surveys were conducted around the original VIS parking lot perimeter and entrance on June 25th, 26th, and 27th. Between 10 and 20 vials baited with peanut butter, jelly, and spam, were deployed for at least one hour during each delimiting survey and each survey also included hand searching and weed pulling of invasive plants. Surveys on the 25th were conducted from 10:45am to 11:45am by OMKM staff J. Kirkpatrick and intern T. Quinories. Surveys on the 26th were conducted from 2:30pm to 3:30pm by T. Quinories. Lastly, the survey on the 27th was conducted at 3:30pm by J. Kirkpatrick and vials were left out and checked at 5pm, 11pm, and then again at 6am on June 28th. All vials and searching efforts presented a negative result for *C. variegatus*.

Rapid Response recommendations consisted of delimiting surveys, continued facility trapping efforts, and development of site-specific control efforts if additional ants or colonies were detected. Delimiting surveys entailed baited vials, pulling of invasive weeds, and hand searches both at night and during the day. Facility trapping is a routine quarterly effort that consists of four Hoy Trap-A-Roach sticky traps baited with peanut butter, jelly, and spam that are placed inside and outside of the VIS. One trap was placed in the VIS breaker room, one was placed under the trash can outside of the front doors, another trap was placed in the janitorial closet, and the last trap was placed underneath the VIS bathrooms/ porch. *C. variegatus* was not found during our trapping and survey efforts.

Case 3: Big-headed ant (*Pheidole megacephala*)

The big-headed ant, also known as the "brown house-ant", or "coastal brown ant"*, Pheidole megacephala* is believed to be native to Ethiopia or Madagascar given the breadth of sub-species and varieties in those two regions (Wetterer, 2007). Now inhabiting almost every tropical island group, *P. megacephala* spreads through human activities and commerce. *P. megacephala* typically form "unicolonial super colonies" that have multiple queens and act as a single unified group due to the lack of colonial boundaries and intraspecific aggression (Wetterer, 2007). This predacious ant species is a well-known indoor, outdoor, and agricultural pest that can nest inside buildings, forage on nearly anything (Tenorio & Nishida, 1995) including honeydew, dead insects and plant seeds, chew through electrical wires and cables, and damage irrigation lines (Wetterer, 2007; Vanderwoude et al. 2015). Limited by rainfall, *P. megacephala* is rarely found in very wet (> 250 cm/yr) and very dry areas (<38-50cm/yr) (Reimer et al., 1990). Big-headed ants favor shaded and moist areas and although not commonly found in dry environments, they can take advantage of sheltered micro-sites (Hoffmann et al., 1999).

Throughout the Hawaiian Islands, big-headed ants dominate the lowlands, but their distribution have also been recorded in mid-elevation forests (Perkins, 1913; LaPolla et al. 2000) and at 1,770 m elevation on Maunakea (Wetterer et al. 1998). Because this ant is most common at low elevations, there is a small probability that it could become a major pest at high elevations (Wetterer et al. 1998).

<u>Incident 1</u>

On Tuesday, October 2, 2018 OMKM staff J. Kirkpatrick detected two *Pheidole megacephala* individuals in a facility trap that was placed from September 19th through 26th in the loading bay room at the Canada France Hawaiʻi Telescope (CFHT) summit facility (Figure 5). That same day (October 2), Hawaiʻi Ant Lab staff Michelle Montgomery identified the specimens as *Pheidole megacephala*. The Hawaiʻi Ant Lab provided some initial information about this species identifying it as a high risk species given its invasive traits (i.e. aggressive behavior, multiple queens, mutualistic relationships) and ecological impacts (i.e. predation, competition) on Pacific Islands. However, they also stated that *P. megacephala* is an easy species to control.

Control and management recommendations

Delimiting surveys were conducted throughout the loading bay room and around the cement slab that is just outside of the loading bay roll up doors on October 3rd, 10th, and 24th by OMKM staff J. Kirkpatrick. Ten vials baited with peanut butter, jelly, and spam, were deployed for at least 30 minutes inside and outside of the facility on October 3rd and 10th, and both these surveys included hand searching (no weeds to pull) within the loading bay room and around the outside perimeter of the CFHT facility. Additionally, five facility traps baited with peanut butter, jelly, and spam were placed in the loading room on October 3rd and unfortunately only three of those traps were found and retrieved on October 10th; all traps retrieved had mouse damage (i.e. chew marks and mouse hair). On October 18th, four facility traps were placed inside of the loading bay room (3 traps) and in the room next to the loading room (1 trap), and only two of those traps were found and retrieved on October 24th. We assume the missing traps placed on October 3rd and 10th were taken by mice, as there were many reports of mice at the summit during this time. A hand search was not conducted on October 18th because it was overcast and temperatures were not warm enough for insects to be active. A hand search was conducted on October 24th. No ants were detected in any of the delimiting survey efforts. Rapid Response recommendations consisted of delimiting surveys, continued facility trapping efforts, and development of site-specific control efforts if additional ants or colonies were detected. Delimiting surveys entailed baited vials, facility traps, and hand searches during warm hours of the day (when insects are active).

Vespid Control

Vespid control reduces threats to Maunakea's ecosystem, maintains public safety, and allows for a greater understanding of vespid population behavior. On August 26, 2020, a single western yellowjacket (*Vespula pensylvanica*) was detected on the new walkway to the VIS. On August 28, 2020, two individuals were observed by staff in the lower VIS parking lot, and at the upper HP parking lot. As this species poses a threat to both humans and native arthropods, steps were taken to try to control the population, which seemed to be established in these areas. On September 9, 2020, staff placed one Wasp-Hornet-Yellowjacket (W-H-Y®) trap just below the VIS parking lot. On September 11, 2020 a W-H-Y trap was placed near the HP common building.

Study Area

Monitoring efforts were focused around the Halepōhaku and VIS vicinity. Two traps were deployed in an effort to control *Vespula pensylvanica*.

Methods

In September 2020, Wasp-Hornet-Yellowjacket (W-H-Y®) traps were set out in two areas, one near the HP common building and one in the vicinity of the VIS. In December 2020 the trap that was located near the VIS was relocated to the HP area, behind Dorm C, in hopes that it would capture a higher number of vespids. Traps were set for a four-month period from September to December 2020.

Results and Discussion

Vespid trapping efforts captured a total of 436 *Vespula pensylvanica* between September to December 2020. Traps also captured other arthropods; mainly plant bugs, common flies, and moths. Table 12 below displays all species captured in W•H•Y® traps. Threat species are in **bold**.

Table 12. List of arthropods captured in vespid traps.

Order	Family	Genus & species	Nativity	# of Individuals Collected
Acari	Unknown	Unknown	Non-Native & Native	6
Collembola	Unknown	Unknown	Non-Native & Native	4
Collembola	Entomobryidae	*Entomobryidae*	Non-Native & Native	2
Dermaptera	Forficulidae	*Forficula auricularia*	Non-Native	1
Diptera	Sciaridae	Unknown	Non-Native	8
Diptera	Calliphoridae	Unknown	Non-Native & Native	36
Diptera	Unknown Fly	Unknown Fly	Non-Native & Native	1
Hemiptera	Lygaeidae	*Nysius terrestris*	Native	4
Hemiptera	Miridae	*Orthotylus sophoricola*	Native	20
Hemiptera	Lygaeidae	*Nysius sp.*	Non-Native & Native	1
Hymenoptera	**Vespidae**	***Vespula pensylvanica***	**Non-Native**	**436**
Hymenoptera	**Unknown**	**Unknown**	**Non-Native & Native**	**3**
Hymenoptera	**Apidae**	***Apis mellifera***	**Non-Native**	**6**
Hymenoptera	**Encyrtidae**	***Encyrtidae***	**Non-Native & Native**	**1**
Lepidoptera	Noctuidae	*Agrotis*	Native	9
Lepidoptera	Unknown	Unknown	Non-Native & Native	4
Lepidoptera	Noctuidae	*Noctuidae*	Non-Native & Native	7
Lepidoptera	Tortricidae	*Cydia (Tortrix moth)*	Non-Native & Native	3
Psocoptera	Psocidae	Unknown	Non-Native & Native	11
Psocoptera	Psocidae	*Ptycta* sp.	Non-Native & Native	1
Thysanoptera	Thripidae	*Thripidae*	Non-Native & Native	6
Unknown	Unknown	Unknown	Unknown	1

Vespid Trap Capture Abundance

Figure 13 below shows the capture abundance for vespid trapping locations (near Halepōhaku and the VIS vicinity). The majority of individuals captured were *Vespula pensylvanica*, plant bugs, noctuid moths, and calliphorid flies. The “n” on the left of the chart represents the total number of individuals captured during vespid trapping efforts.

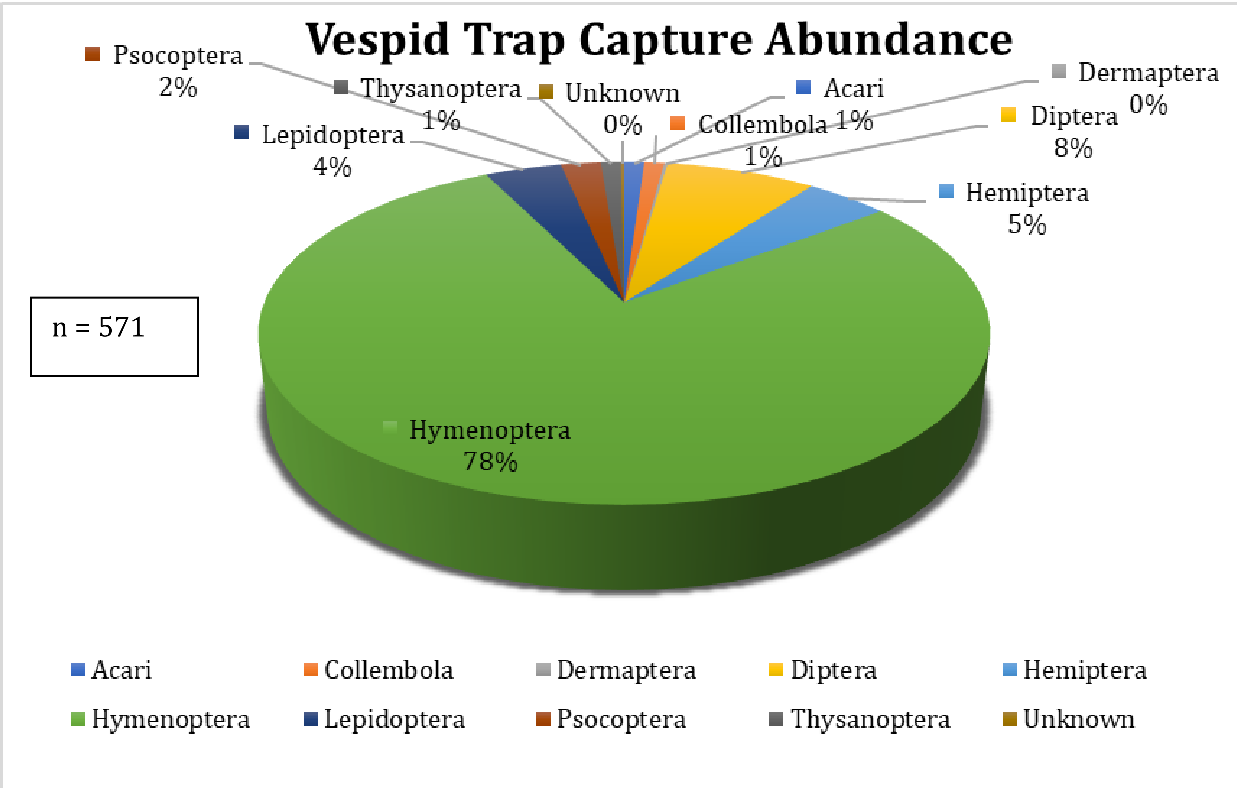

Figure 13. Percentage of individuals of each arthropod order captured in the vespid traps.

Vegetation Control

Introduction

Vegetation was removed around Halepōhaku and MKSR facilities through manual labor. Removing weeds reduces habitat for invasive arthropods (such as *Cardiocondyla kagutsuchi*), reduces the spread of invasive species on UH managed lands, and can help to detect new arthropods threats. We are investigating other control options such as herbicide application for long-term management and control.

Study Area

Vegetation control focused on human pathways and traffic areas. Sites included parking areas around Halepōhaku and the Visitor Information Station (VIS), areas along the Maunakea Access Road, and around the perimeter of facilities in the MKSR and Astronomy Precinct.

Methods

Vegetation control was achieved monthly through physical removal by volunteers, OMKM staff, and Maunakea rangers. Hand removal served two purposes; the removal of invasive vegetation (reduces seed spread & habitat for arthropod threats) and the detection of invasive arthropods associated with the roots of removed vegetation. The most effective way to observe ants is by simply pulling weeds because ants use invasive vegetation for habitat.

Volunteers were given vegetation removal instructions that included invasive plant identification, proper removal and disposal methods, and identification and reporting of ant detections if observed. OMKM staff supervised volunteer activities. Hand tools such as hand trowels, picks, and weeders were used to remove vegetation and their roots. Removed vegetation was observed for ants, the excess dirt was shaken off, and vegetation was placed in trash bags and taken to the South Hilo Sanitary Landfill. When volunteers reported ants, the location was flagged, and documented for future survey locations, and arthropod control (if applicable).

Additionally, OMKM Rangers observe and remove invasive weeds in the MKSR and Astronomy precinct throughout each year (2016-2020). When invasive weeds are observed the species, the number of individuals, and their locations are recorded, and the weeds are removed. The rangers record invasive weed observations and removals in a ranger report that is sent daily to OMKM staff. Staff then review, and document invasive species observations.

Results and Discussion

In 2016 the volunteer program engaged 200 volunteers, working 1,500 hours, removing about 300 bags of invasive weeds. In 2017 the volunteer program engaged 165 volunteers, working 1,238 hours, removing about 271 bags of invasive weeds. In 2018 the volunteer program engaged 200 volunteers, working 1,080 hours, removing about 323 bags of invasive weeds. In 2019 the volunteer program engaged 44 volunteers, working 308 hours, removing about 75 bags of invasive weeds. In 2020 the volunteer program engaged 23 volunteers, working 58 hours, removing about 43 bags of invasive weeds. Invasive weed species that were pulled are shown in Table 13 below.

Invasive Weed Species Pulled by Volunteers

Table 13. List of the targeted invasive weeds.

Family	Genus & Species	Common Name
Asteraceae	*Heterotheca grandiflora*	Telegraph weed
Asteraceae	*Hypochaeris radicata*	Hairy cat's ear
Asteraceae	*Senecio madagascariensis*	Fireweed
Asteraceae	*Taraxacum officinale*	Common dandelion
Geraniaceae	*Erodium cicutarium*	Pin clover, Alfilaria
Onagraceae	*Oenothera stricta*	Chilean evening primrose
Polygonaceae	*Rumex acetosella*	Sheep's sorrel
Scrophulariaceae	*Verbascum thapsus*	Common mullein
Scrophulariaceae	*Verbascum virgatum*	Wand mullein

Invasive Weed Species Pulled by Maunakea Rangers

Maunakea Rangers observed and pulled invasive weed species in the MKSR including fireweed (*Senecio madagascariensis*), common mullein *(Verbascum thapsus)*, hairy cat's ear (*Hypochaeris radicata*), sheep's sorrel (*Rumex acetosella*), and common dandelion (*Taraxacum officinale*). See Table 14 below for the number of days each year spent removing invasive species and the number of individual species removed per year from 2016-2020. Fireweed was the most abundant species removed by rangers, the average number of fireweeds removed per day and days spent removing fireweed is included in the figure below (Figure 14).

Table 14. Data log of invasive species removed each year.

Year	Days per year	Average Fireweed Removed Per Day	Fireweed	Mullein	Cat's Ear	Sheep's Sorrel	Dandelion
2016	218	26.6	5629	30	4	5	0
2017	39	2.8	94	6	7	0	2
2018	51	6.0	259	7	6	0	1
2019	65	9.2	568	4	0	0	3
2020	52	4.2	197	3	16	0	0

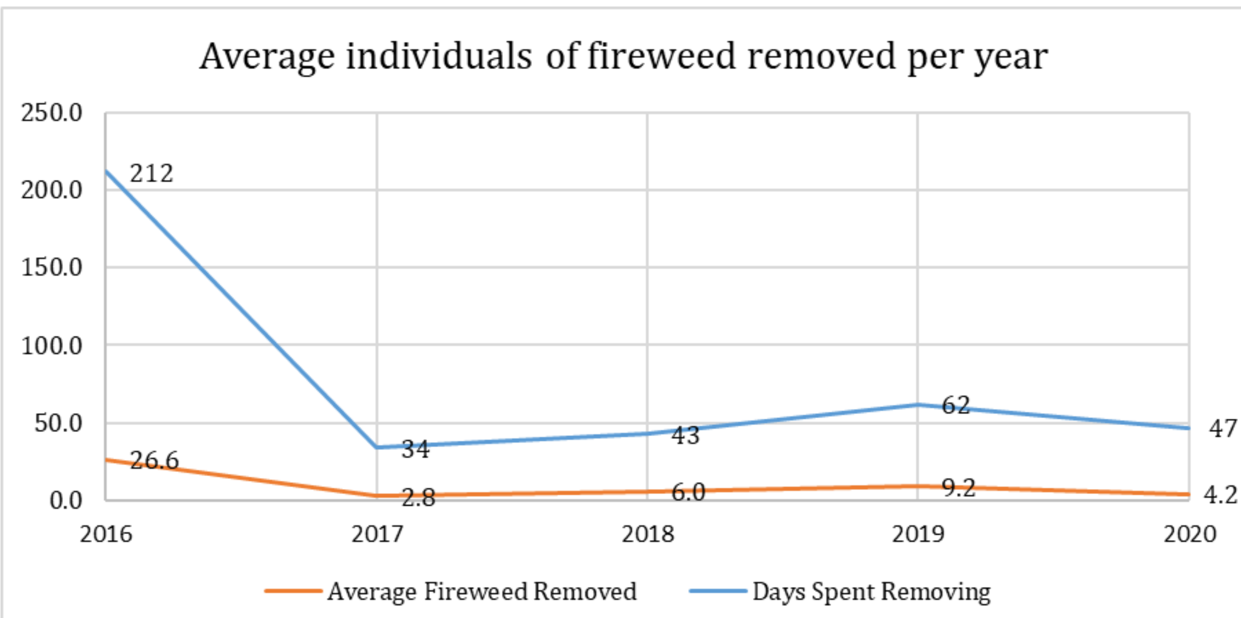

Figure 14. The average number of fireweed individuals removed by rangers.

Conclusion

Volunteers and Maunakea Rangers serve as effective vegetation control and early detection agents on UH managed lands. These efforts are essential for long-term control of invasive species on Maunakea. Vegetation control along with occasional spot treatment for ants around Halepōhaku and VIS facilities have been effective. Invasive weed pulls reduce the risk of seed dispersal by Maunakea users and eliminate ant habitat for at least a few months until more weeds sprout up again. Continued vegetation control can allow for possible restoration of native plant species, a management goal for Halepōhaku.

Arthropod Control

Introduction

As explained in the introduction paragraph of this section, arthropods are difficult to control, and available options are few. In 2016-2020, we continued control of three ant species: *Cardiocondyla kagutsuchi* (a common ant), *Tapinoma melanocephalum*, and *Ochetellus glaber*. Control for these species is feasible because the ants were confined to disturbed areas. We used *Talstar Professional* insecticide, a liquid formulation with Bifenthrin as the active ingredient, as a spot treatment control method. All applications were recorded in a detailed pesticide log and all applicators were pesticide certified by HDOA. Please see *Appendix L* for pesticide log and use records.

Study Area

Control efforts focused in the upper, lower, and gravel HP parking lots, the HP Commons building main entrance, HP firehose corner near kitchen, and retaining wall between longhouse buildings. The VIS parking area 1 and the vegetated area below the VIS storage warehouse and presentation room (Lower longhouse building). *C. kagutsuchi* continues to persist in these areas.

Methods

Ant Surveys

Intense surveys were conducted throughout HP, along roadways, parking lots and facility perimeters in search for ants. When ants were observed, we conducted micro-surveys in the detection area to determine the species range and to identify the amount of area we need to cover for accurate and effective pesticide formulations and applications.

Vials were baited with peanut butter, spam, and jelly, and placed throughout survey areas (roads, parking lot, facility, and staging area perimeters), and observed within 15 minutes for any signs of ant activity. While vials were being placed, invasive weeds were also pulled and observed for ants. This particular species of ant *C. kagutsuchi* is not always attracted to the bait. Pulling weeds is our most effective method for detecting this species of ant. Ants tend or farm aphids and mealybugs that are found on the roots of invasive weeds. In many cases we found ants entirely by pulling weeds, even when vials were less than a foot away. Areas where ants were found were flagged off for later treatment.

Control

Ant areas were spot treated with *Talstar Professional* insecticide. Insecticide dilution and application followed all label requirements.

Results & Discussion

Monitoring and control for *Cardiocondyla kagutsuchi* (a common ant), *Tapinoma melanocephalum* and *Ochetellus glaber* continues.

ACKNOWLEDGEMENTS

We thank the Bishop Museum for their years of effort monitoring both invasive species and wēkiu bugs on Maunakea. We appreciate all the hard work that was put into their research, making the monitoring surveys much easier for us. We thank C. King for collecting the permits necessary for this work, J. Eiben for his field assistance and arthropod identifications, and field assistants A. Stillman, M. Sheffield, J. Yoshina, H. Stever, and S. Van Kralingen. Mahalo to Pacific Internship Programs for Exploring Science (PIPES) and Hawaii Community College Forest TEAM interns K. Kiyuna, S. Kirkpatrick, S. Kahiapo, S. Wells, T. Quinories, T. Piʻilani-Pelanca and T. Medina for assisting in field/monitoring surveys and/or conducting research at Maunakea. We would also like to thank L. Shizuma, J. Parker, J. Zarders, M. Vinent, D. Koon, K. Akima, K. Mossman, and S. Merrick for their assistance with field work and arthropod surveys. We also thank C. Vanderwoude and S. Kaye for their efforts towards writing and executing the Maunakea Invasive Species Management Plan. Lastly, mahalo to the Maunakea Rangers for keeping us safe and joining in our efforts to protect the natural resources of Maunakea. Mahalo nui!

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APPENDICES

Appendix A: UH Management Areas on Maunakea

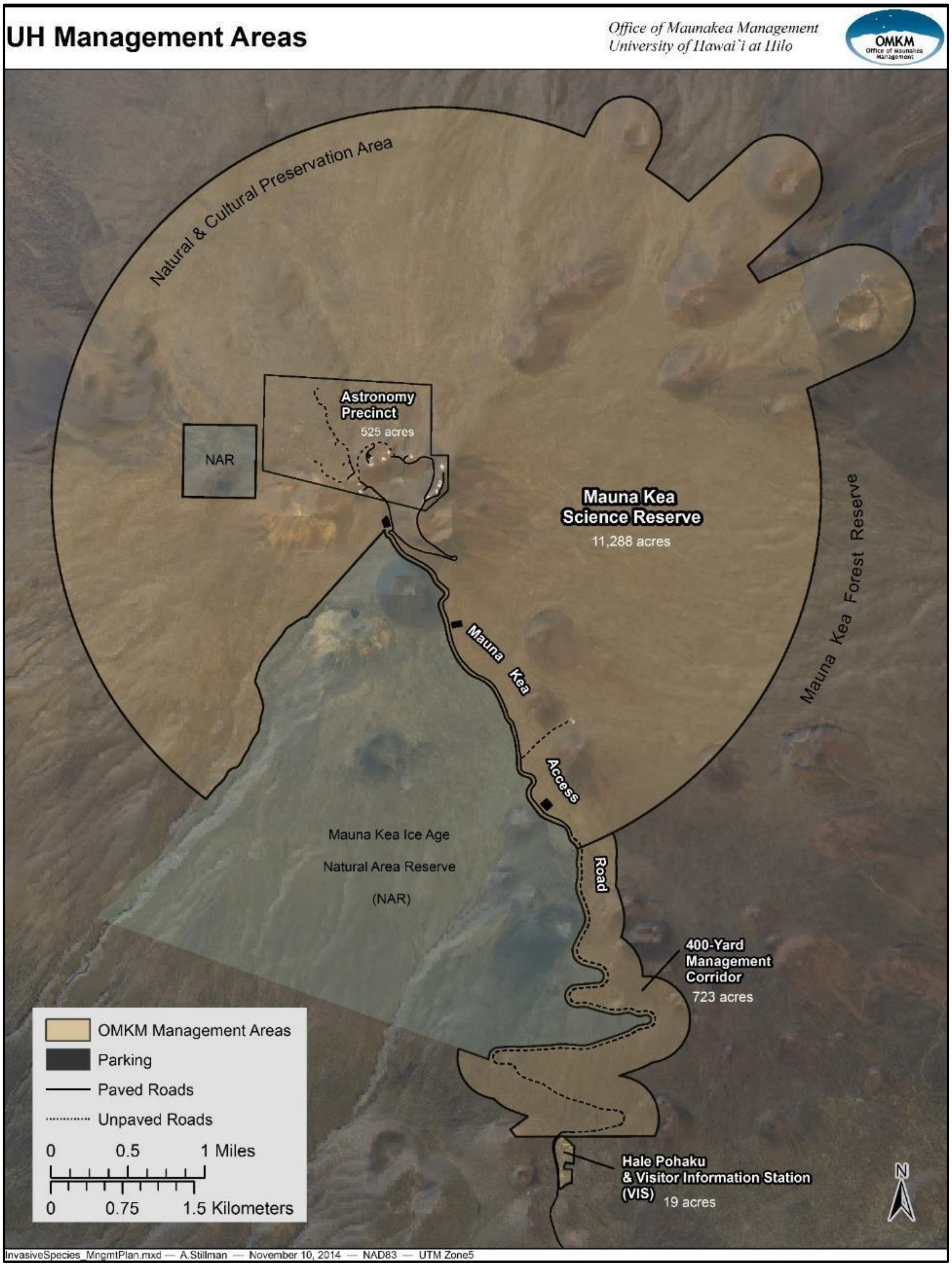

Figure 15. Map of the OMKM management areas on Maunakea, HI.

Appendix B: 2016-2020 Facility Survey Arthropod Capture List

All arthropods captured during the 2016-2020 Facility Survey are listed alphabetically by taxa. Arthropod threats are identified in **bold** font and shaded rows identify new species records to the management area. New record threats are shown in **bold** font with shaded rows. Nativity[10] is either non-native, native, non-native & native within that taxonomic group, or unknown. Notable non-arthropod captures are included at the end of Table 15.

Taxa	Order	Family	Genus & species	Nativity
2	**Araneae**	**Agelenidae**	***Hololena curta***	**Non-Native**
3	**Araneae**	**Agelenidae**	***Hololena unknown***	**Non-Native**
4	**Araneae**	**Agelenidae**	**Unknown**	**Non-Native**
5				
6	**Araneae**	**Corinnidae**	**Unknown**	**Unknown**
7	**Araneae**	**Gnaphosidae**	**Unknown**	**Non-Native**
8	**Araneae**	**Linyphiidae**	***Erigone autumnalis***	**Unknown**
9	**Araneae**	**Linyphiidae**	***Lepthyphantes tenuis***	**Non-Native**
10	**Araneae**	**Linyphiidae**	***Unknown***	**Non-Native & Native**
11	Araneae	Lycosidae	*Lycosa hawaiiensis*	Native
12				
13				
14	**Araneae**	**Trachelidae**	**Unknown**	**Non-Native & Native**
15	**Araneae**	**Unknown**	**Unknown**	**Non-Native & Native**
16				
17	Blattodea	Blattidae	*Supella longipalpa*	Non-Native
18	**Coleoptera**	**Carabidae**	***Laemostenus complanatus***	**Non-Native**
19	**Coleoptera**	**Carabidae**	***Trechus obtusus***	**Non-Native**
20	**Coleoptera**	**Chrysomelidae**	**Unknown**	**Non-Native**
21	Coleoptera	Coccinellidae	*Coccinella septempunctata*	Non-Native
22	Coleoptera	Coccinellidae	*Harmonia conformis*	Non-Native
23				
24	Coleoptera	Coccinellidae	*Rhyzobius lophanthae*	Non-Native
25	Coleoptera	Coccinellidae	Unknown	Non-Native
26	Coleoptera	Curculionidae	*Oodemas unknown*	Native
27	**Coleoptera**	**Dermestidae**	**Unknown**	**Non-Native & Native**
28				
29				
30				
31	**Coleoptera**	**Tenebrionidae**	**Unknown**	**Non-Native & Native**
32				
33				
34	Collembola	Neanuridae	Unknown	Unknown
35	Collembola	Unknown	Unknown	Non-Native & Native
36	Dermaptera	Forficulidae	*Forficula auricularia*	Non-Native
37	Diplopoda	Unknown	Unknown	Non-Native
38	Diptera	Agromyzidae	Unknown	Non-Native & Native

[10] Nativity was determined using various resources such as the Insects of Hawaiʻi series (The University of Hawaiʻi Press, Honolulu), the Hawaiian Terrestrial Arthropod Checklist (Nishida 2002), and the revised checklist (Matsunaga et al. 2019).

39	Diptera	Anthomyiidae	Unknown	Non-Native
40	Diptera	Calliphoridae	*Calliphora vomitoria*	Non-Native
41	Diptera	Calliphoridae	Unknown	Non-Native & Native
42	Diptera	Cecidomyiidae	Unknown	Non-Native & Native
43	Diptera	Chironomidae	Unknown	Non-Native & Native
44	Diptera	Chloropidae	Unknown	Non-Native
45	Diptera	Drosophilidae	*Drosophila suzukii*	Non-Native
46	Diptera	Drosophilidae	*Drosophila unknown*	Non-Native & Native
47	Diptera	Drosophilidae	Unknown	Non-Native & Native
48	Diptera	Ephydridae	Unknown	Non-Native & Native
49	**Diptera**	**Muscidae**	***Atherigona orientalis***	**Non-Native**
50	**Diptera**	**Muscidae**	***Unknown***	**Non-Native & Native**
51	Diptera	Mycetophilidae	*Leia unknown*	Native
52	Diptera	Mycetophilidae	Unknown	Non-Native & Native
53	Diptera	Phoridae	Unknown	Non-Native & Native
54	Diptera	Psychodidae	*Psychoda unknown*	Non-Native & Native
55	Diptera	Psychodidae	Unknown	Non-Native & Native
56	Diptera	Sarcophagidae	Unknown	Non-Native & Native
57	Diptera	Sciaridae	Unknown	Non-Native
58	Diptera	Sepsidae	Unknown	Non-Native
59	Diptera	Sphaeroceridae	Unknown	Non-Native & Native
60	Diptera	Syrphidae	Unknown	Non-Native
61	Diptera	Tachinidae	Unknown	Non-Native
62	Diptera	Tipulidae	Unknown	Non-Native & Native
63	Diptera	Unknown	Unknown	Non-Native & Native
64	Hemiptera	Anthocoridae	Unknown	Non-Native & Native
65	Hemiptera	Geocoridae	*Geocoris pallens*	Non-Native
66	Hemiptera	Geocoridae	*Geocoris unknown*	Non-Native
67	Hemiptera	Lygaeidae	*Neacoryphus bicrucis*	Non-Native
68	Hemiptera	Lygaeidae	*Nysius palor*	Non-Native
69	Hemiptera	Lygaeidae	*Nysius terrestris*	Native
70	Hemiptera	Lygaeidae	*Nysius unknown*	Non-Native & Native
71	Hemiptera	Lygaeidae	*Nysius wekiuicola*	Native
72				
73				
74				
75	Hemiptera	Miridae	*Orthotylus sophoricola*	Native
76	Hemiptera	Miridae	Unknown	Non-Native & Native
77				
78				
79	Hemiptera	Rhyparochromidae	*Pachybrachius pacificus*	Non-Native
80				
81	Hemiptera	Rhyparochromidae	*Pseudopachybrachius vinctus*	Non-Native
82	Hemiptera	Unknown	Unknown	Non-Native & Native
83	Homoptera	Aphididae	Unknown	Non-Native
84	Homoptera	Cicadellidae	Unknown	Non-Native & Native
85	Homoptera	Pseudococcidae	Unknown	Non-Native & Native
86	Homoptera	Psyllidae	Unknown	Non-Native & Native
87	**Hymenoptera**	**Aphelinidae**	**Unknown**	**Non-Native**
88	**Hymenoptera**	**Bethylidae**	**Unknown**	**Non-Native & Native**
89	**Hymenoptera**	**Braconidae**	***Aphidius gifuensis***	**Unknown**
90	**Hymenoptera**	**Braconidae**	**Unknown**	**Non-Native & Native**
91	**Hymenoptera**	**Encyrtidae**	**Unknown**	**Non-Native & Native**

92	**Hymenoptera**	**Eulophidae**	**Unknown**	**Non-Native & Native**
93	**Hymenoptera**	**Formicidae**	***Pheidole megacephalum***	**Non-Native**
94	**Hymenoptera**	**Formicidae**	***Wasmannia auropunctata***	**Non-Native**
95				
96	**Hymenoptera**	**Mymaridae**	**Unknown**	**Non-Native & Native**
97	**Hymenoptera**	**Pteromalidae**	**Unknown**	**Non-Native & Native**
98	**Hymenoptera**	**Scelionidae**	**Unknown**	**Non-Native & Native**
99	**Hymenoptera**	**Unknown**	**Unknown**	**Non-Native & Native**
100	**Hymenoptera**	**Vespidae**	***Vespula pensylvanica***	**Non-Native**
101				
102				
103				
104	Lepidoptera	Noctuidae	*Agrotis kuamauna*	Native
105				
106	Lepidoptera	Noctuidae	*Pseudaletia unipuncta*	Non-Native
107	Lepidoptera	Noctuidae	Unknown	Non-Native & Native
108	Lepidoptera	Oecophoridae	*Endrosis sarcitrella*	Non-Native
109	Lepidoptera	Oecophoridae	Unknown	Non-Native & Native
110				
111	Lepidoptera	Pyralidae	Unknown	Non-Native & Native
112	Lepidoptera	Tineidae	Unknown	Non-Native
113	Lepidoptera	Tortricidae	*Cydia plicata*	Native
114	Lepidoptera	Unknown	Unknown	Non-Native & Native
115	Lithobiomorpha	Lithobiidae	*Lithobius unknown*	Non-Native & Native
116				
117	Neuroptera	Hemerobiidae	*Hemerobius pacificus*	Non-Native
118	Neuroptera	Hemerobiidae	Unknown	Non-Native & Native
119	Odonata	Unknown	Unknown	Non-Native & Native
120	Orthoptera	Gryllidae	*Trigonidomorpha sjostedti*	Non-Native
121	Orthoptera	Gryllidae	Unknown	Non-Native & Native
122	Psocodea	Psocidae	*Ptycta unknown*	Native
123	Psocodea	Psocidae	Unknown	Non-Native & Native
124				
125				
126	Siphonaptera	Pulicidae	Unknown	Non-Native
127	Thysanoptera	Thripidae	Unknown	Non-Native & Native
		Non-arthropod taxa		

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Appendix C: Rotating Panel Surveys Arthropod Capture List

All arthropods captured during the 2016-2020 Rotating Panel surveys are listed alphabetically by taxa. Arthropod threats are identified in **bold** font and shaded rows identify new species records to the management area. New record threats are shown in **bold** font with shaded rows. Nativity[11] is either non-native, native, non-native & native within that taxonomic group, or unknown.

Taxa	Order	Family	Genus & species	Nativity
2	**Araneae**	**Linyphiidae**	**Unknown**	**Non-Native & Native**
3	Araneae	Lycosidae	*Lycosa hawaiiensis*	Native
4	**Araneae**	**Salticidae**	**Unknown**	**Non-Native & Native**
5	**Araneae**	**Theridiidae**	**Unknown**	**Non-Native & Native**
6	**Araneae**	**Unknown**	**Unknown**	**Non-Native & Native**
7	Coleoptera	Coccinellidae	*Coccinella septempunctata*	Non-Native
8	Coleoptera	Coccinellidae	*Harmonia conformis*	Non-Native
9	Coleoptera	Coccinellidae	*Hippodamia convergens*	Non-Native
10	Coleoptera	Coccinellidae	Unknown	Non-Native
11	**Coleoptera**	**Scarabaeidae**	***Onthophagus nigriventris***	**Non-Native**
12	**Coleoptera**	**Unknown**	**Unknown**	**Non-Native & Native**
13	Collembola	Entomobryidae	Unknown	Non-Native & Native
14	Diptera	Calliphoridae	Unknown	Non-Native & Native
15	Diptera	Chironomidae	Unknown	Non-Native & Native
16	Diptera	Drosophilidae	*Drosophila unknown*	Non-Native & Native
17	Diptera	Eulophidae	Unknown	Non-Native & Native
18	**Diptera**	**Muscidae**	**Unknown**	**Non-Native & Native**
19	Diptera	Oestridae	*Hypoderma bovis*	Non-Native
20	Diptera	Phoridae	Unknown	Non-Native & Native
21	Diptera	Sarcophagidae	Unknown	Non-Native
22	Diptera	Sarcophagidae	Unknown	Non-Native
23	Diptera	Sciaridae	Unknown	Non-Native & Native
24	Diptera	Sepsidae	Unknown	Non-Native
25	Diptera	Syrphidae	Unknown	Non-Native
26	Diptera	Unknown	Unknown	Non-Native & Native
27	Hemiptera	Anthocoridae	Unknown	Non-Native
28	Hemiptera	Geocoridae	*Geocoris pallens*	Non-Native
29	Hemiptera	Lygaeidae	*Neacoryphus bicrucis*	Non-Native
30	Hemiptera	Lygaeidae	*Nysius palor*	Non-Native
31	Hemiptera	Lygaeidae	*Nysius terrestris*	Native
32	Hemiptera	Lygaeidae	*Nysius unknown*	Non-Native & Native
33	[illegible]	[illegible]	[illegible]	[illegible]
34	[illegible]	[illegible]	[illegible]	[illegible]
35	Hemiptera	Miridae	*Orthotylus sophoricola*	Native
36	Hemiptera	Miridae	Unknown	Non-Native & Native
37	Hemiptera	Pentatomidae	Unknown	Non-Native & Native
38	Hemiptera	Unknown	Unknown	Non-Native & Native
39	Homoptera	Aphididae	Unknown	Non-Native

[11] Nativity was determined using various resources such as the Insects of Hawaiʻi series (The University of Hawaiʻi Press, Honolulu), the Hawaiian Terrestrial Arthropod Checklist (Nishida 2002), and the revised checklist (Matsunaga et al. 2019).

40	Homoptera	Cicadellidae	Unknown	Non-Native & Native
41	Homoptera	Psyllidae	Unknown	Non-Native & Native
42	**Hymenoptera**	**Apidae**	***Apis mellifera***	**Non-Native**
43	**Hymenoptera**	**Braconidae**	**Unknown**	**Non-Native & Native**
44	**Hymenoptera**	**Eulophidae**	**Unknown**	**Non-Native & Native**
45	**Hymenoptera**	**Ichneumonidae**	**Unknown**	**Non-Native & Native**
46	**Hymenoptera**	**Pteromalidae**	**Unknown**	**Non-Native & Native**
47	[illegible]	[illegible]	[illegible]	[illegible]
48	[illegible]	[illegible]	[illegible]	[illegible]
49	Lepidoptera	Noctuidae	*Agrotis kuamauna*	Native
50	Lepidoptera	Noctuidae	*Agrotis unknown*	Non-Native & Native
51	Lepidoptera	Noctuidae	Unknown	Non-Native & Native
52	Lepidoptera	Pieridae	*Pieris rapae*	Non-Native
53	Lepidoptera	Pterophoridae	Unknown	Non-Native
54	Lepidoptera	Tortricidae	Cydia plicata	Native
55	Lepidoptera	Tortricidae	Cydia unknown	Non-Native & Native
56	Lepidoptera	Unknown	Unknown	Native
57	Lithobiomorpha	Lithobiidae	Lithobius unknown	Non-Native & Native
58	Psocodea	Psocidae	Unknown	Non-Native & Native

References

Matsunaga, J. N., Howarth, F. G., & Kumashiro, B. R. (2019). New state records and additions to the alien terrestrial arthropod fauna in the Hawaiian Islands. *Proceedings of the Hawaiian Entomological Society*, 51, 1-71.

Nishida, G. M. (2002). Hawaiian terrestrial arthropod checklist 4th ed. *Honolulu, Hawaii: Hawaii Biological Survey (Bishop Museum) Technical Report, 22.*

Appendix D: 2016-2020 Annual Survey Location Maps

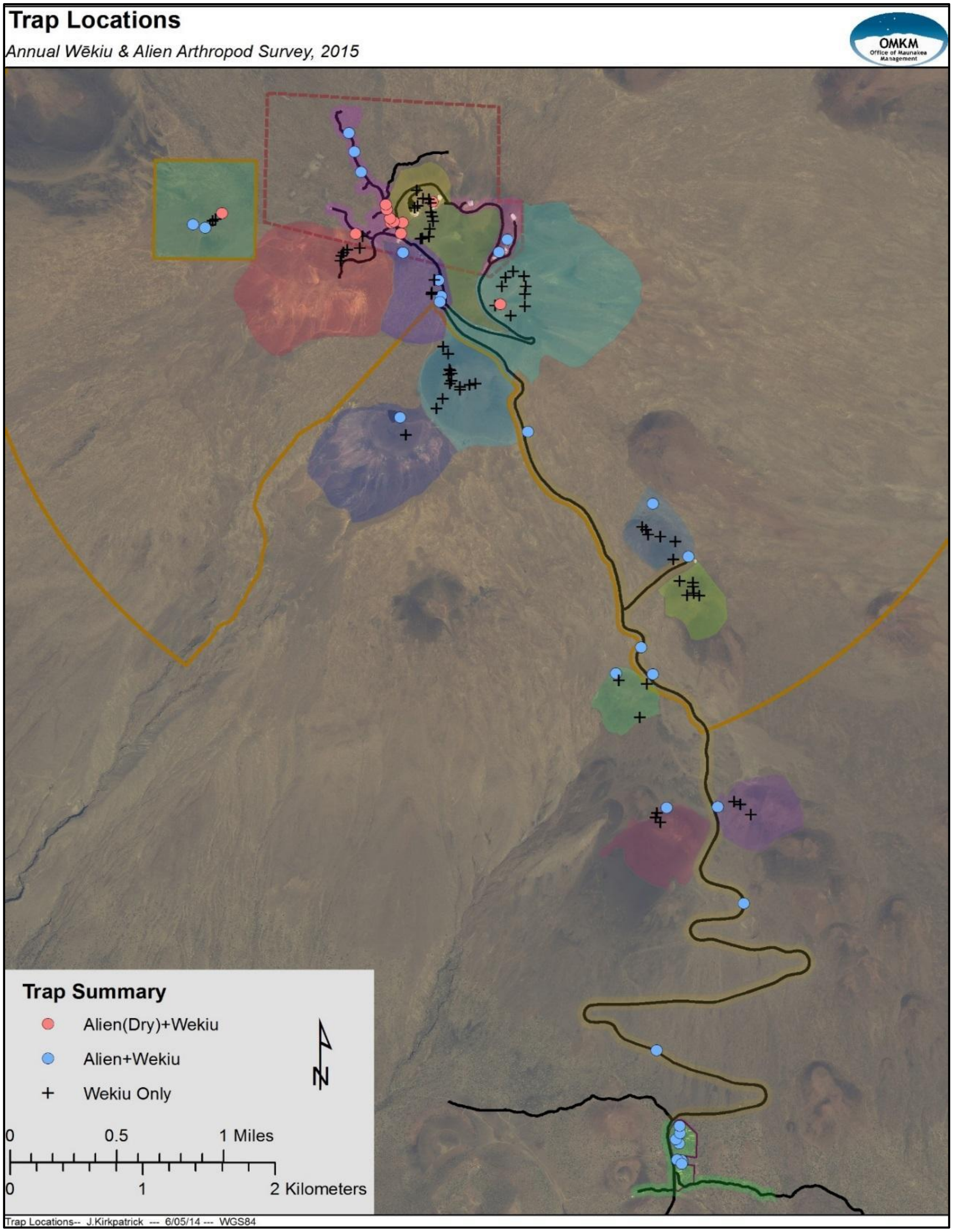

Figure 16. 2016-2020 Annual Alien Invertebrate Monitoring survey locations.

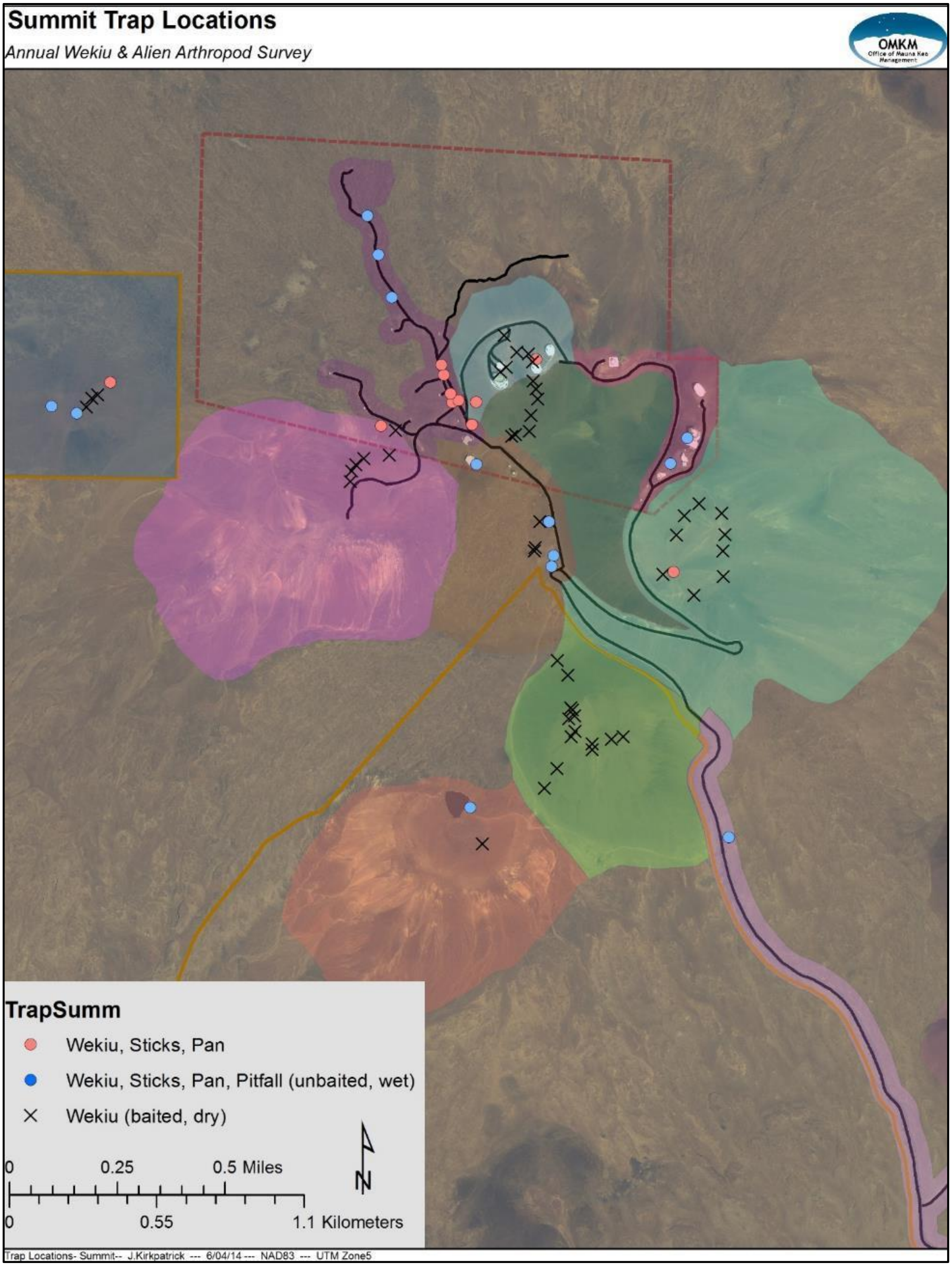

Figure 17. 2016-2020 Annual Alien Invertebrate Monitoring survey locations at the Summit area.

Figure 18. 2016-2020 Annual Alien Invertebrate Monitoring survey locations at Halepōhaku.

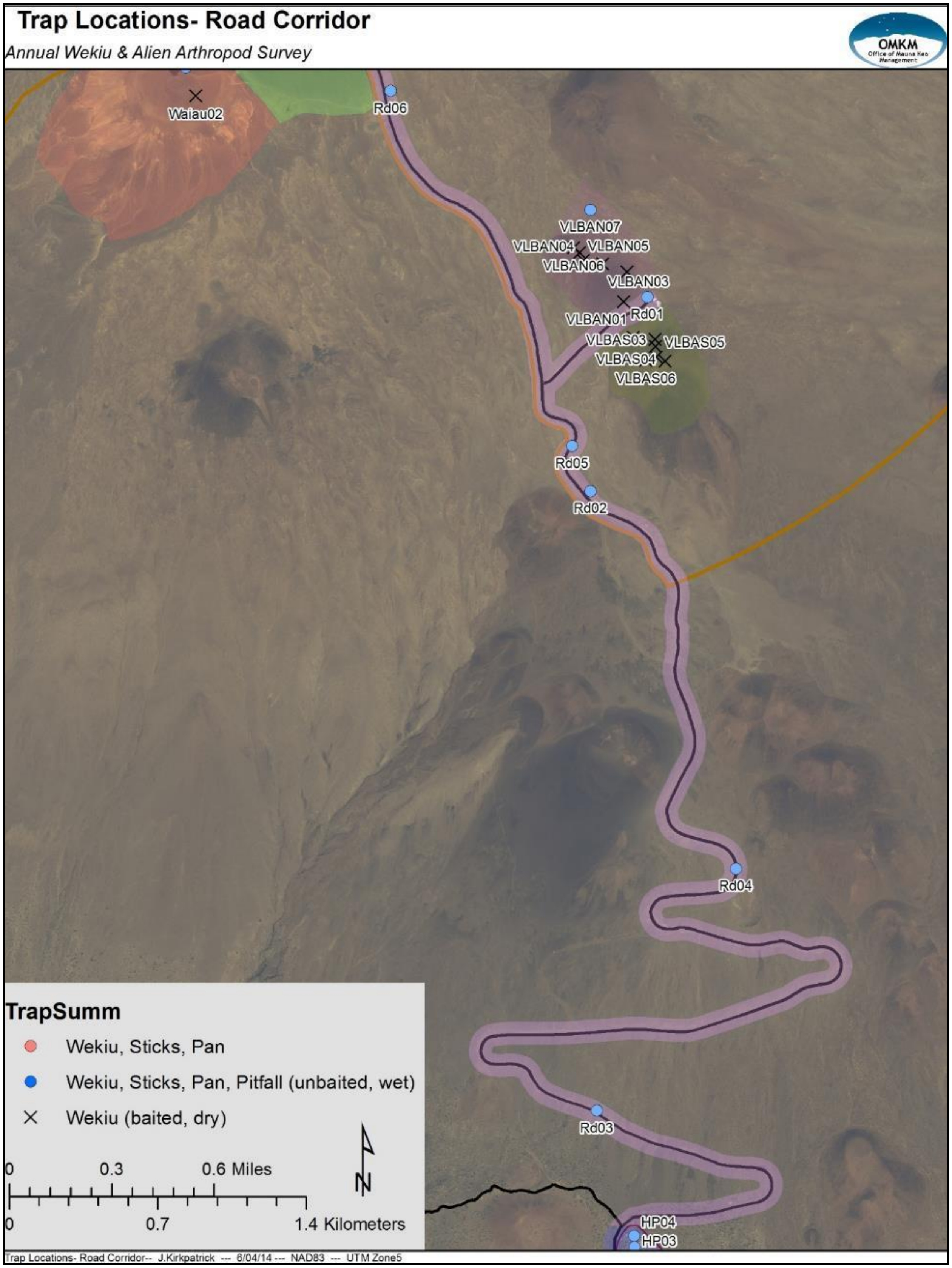

Figure 19. Annual Alien Invertebrate Monitoring survey locations on the Road Corridor.

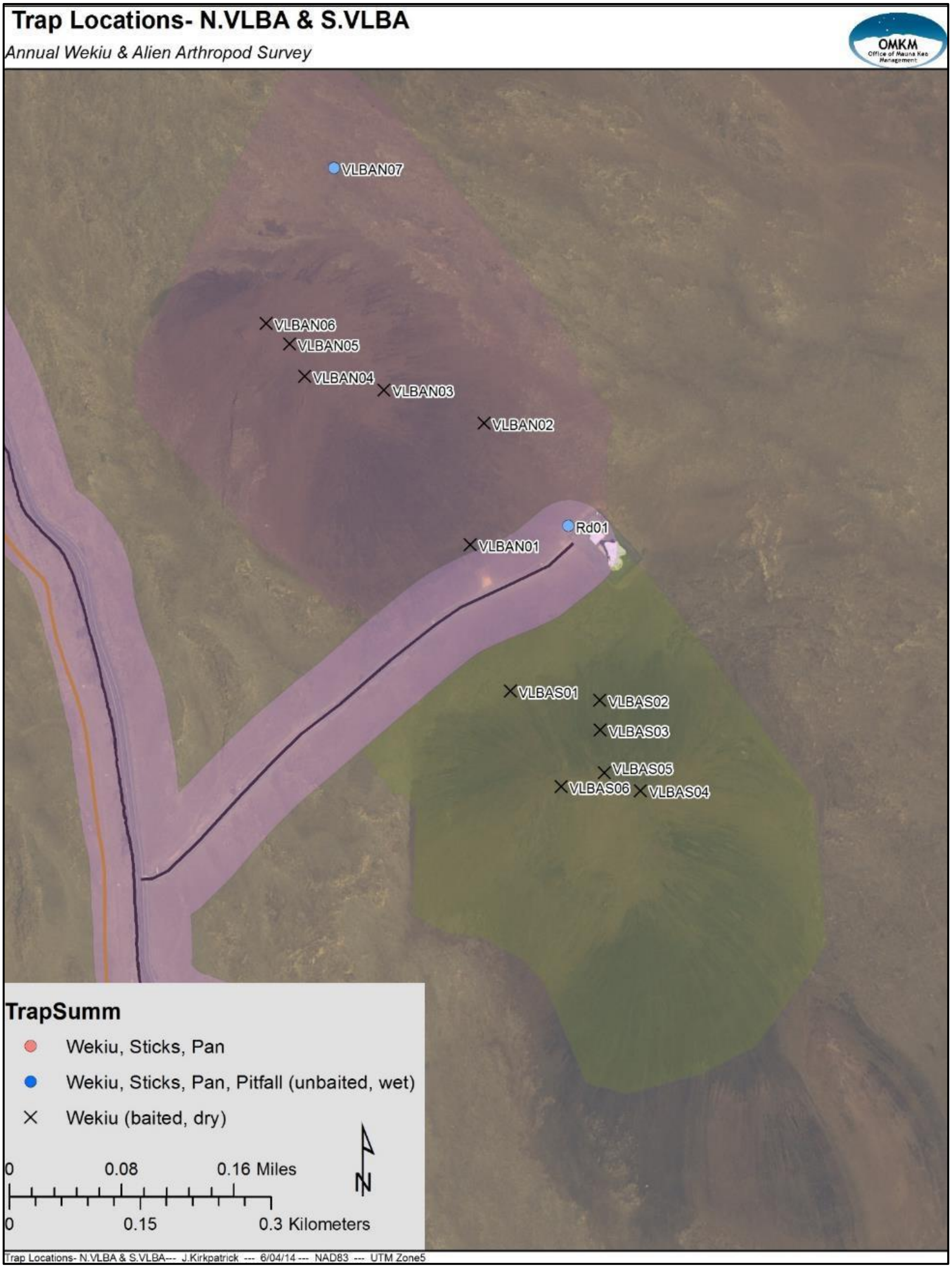

Figure 20. Annual Alien Invertebrate Monitoring survey locations on North and South VLBA.

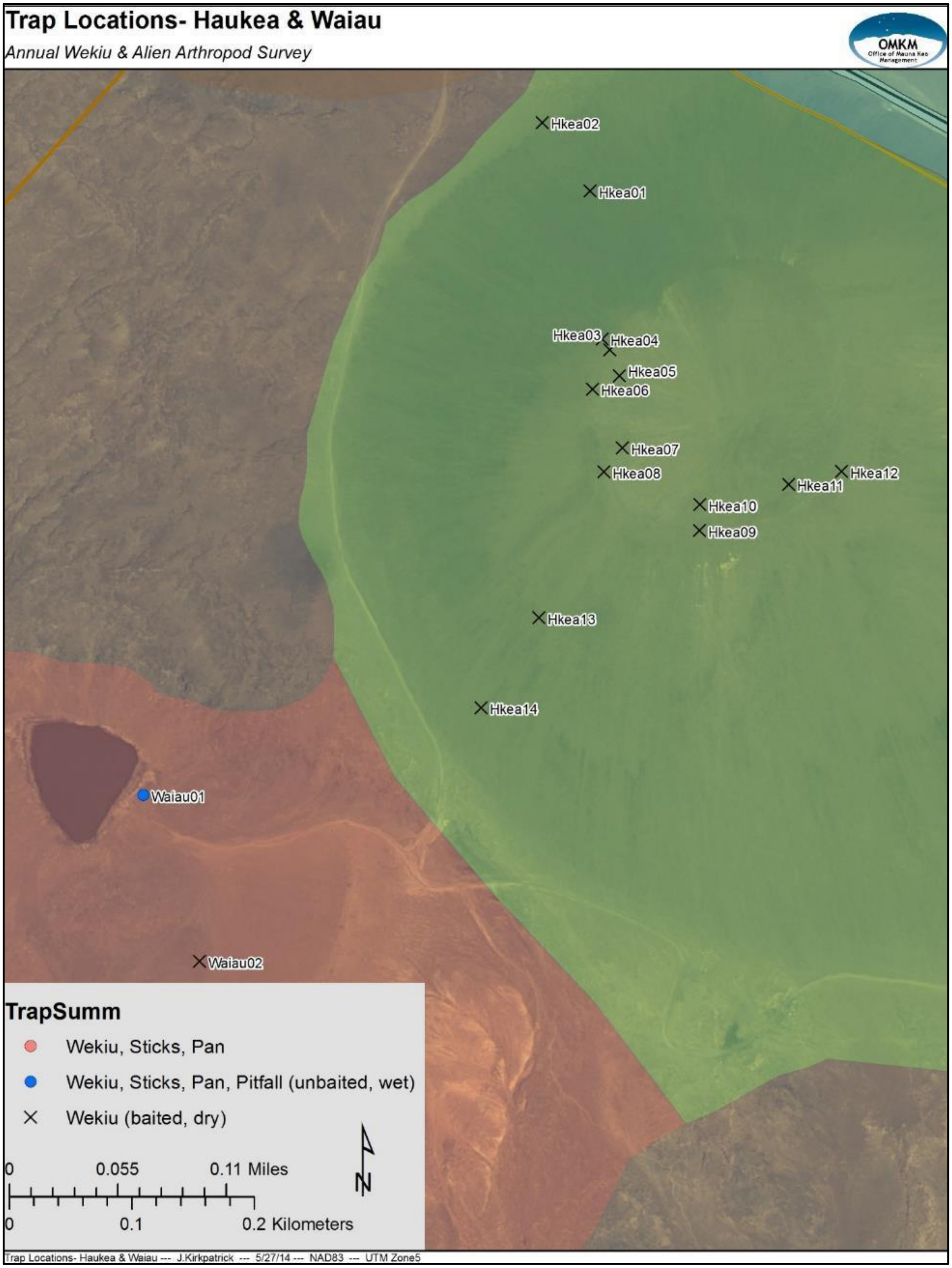

Figure 21. Annual Alien Invertebrate Monitoring survey locations on Puʻuhaukea and Puʻuwaiau.

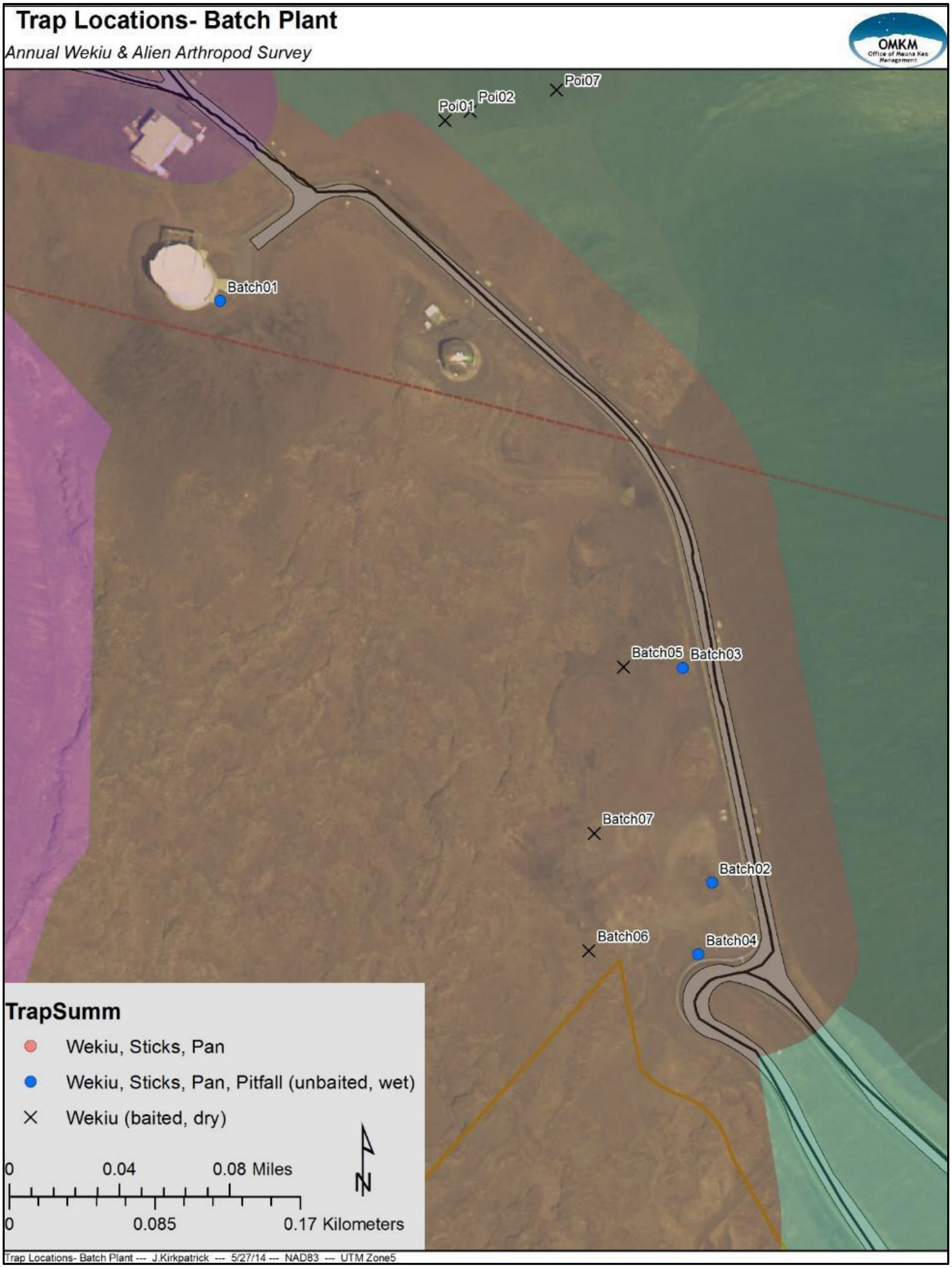

Figure 22. Annual Alien Invertebrate Monitoring survey locations at Batch Plant.

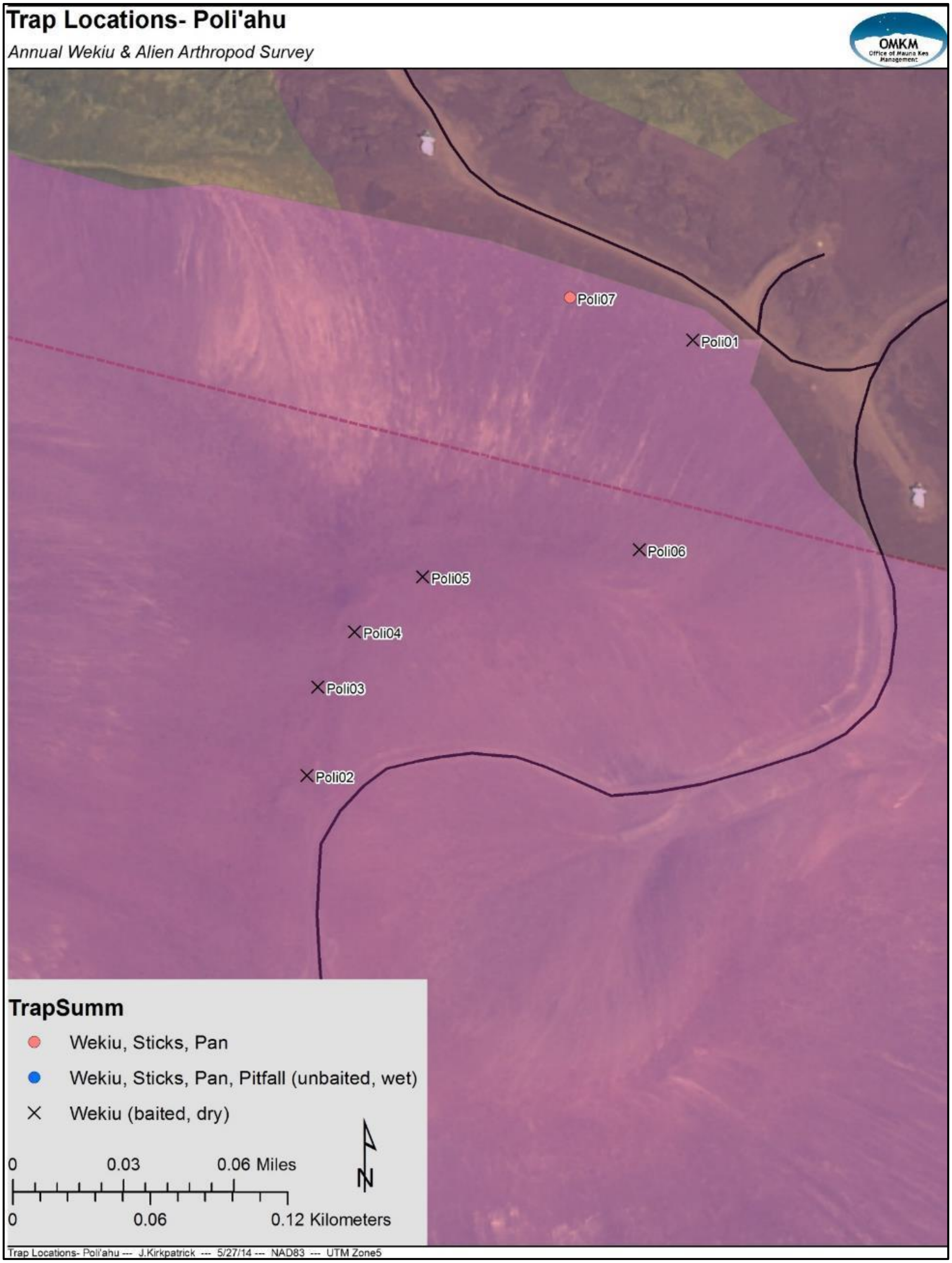

Figure 23. Annual Alien Invertebrate Monitoring survey locations at Puʻupoliahu.

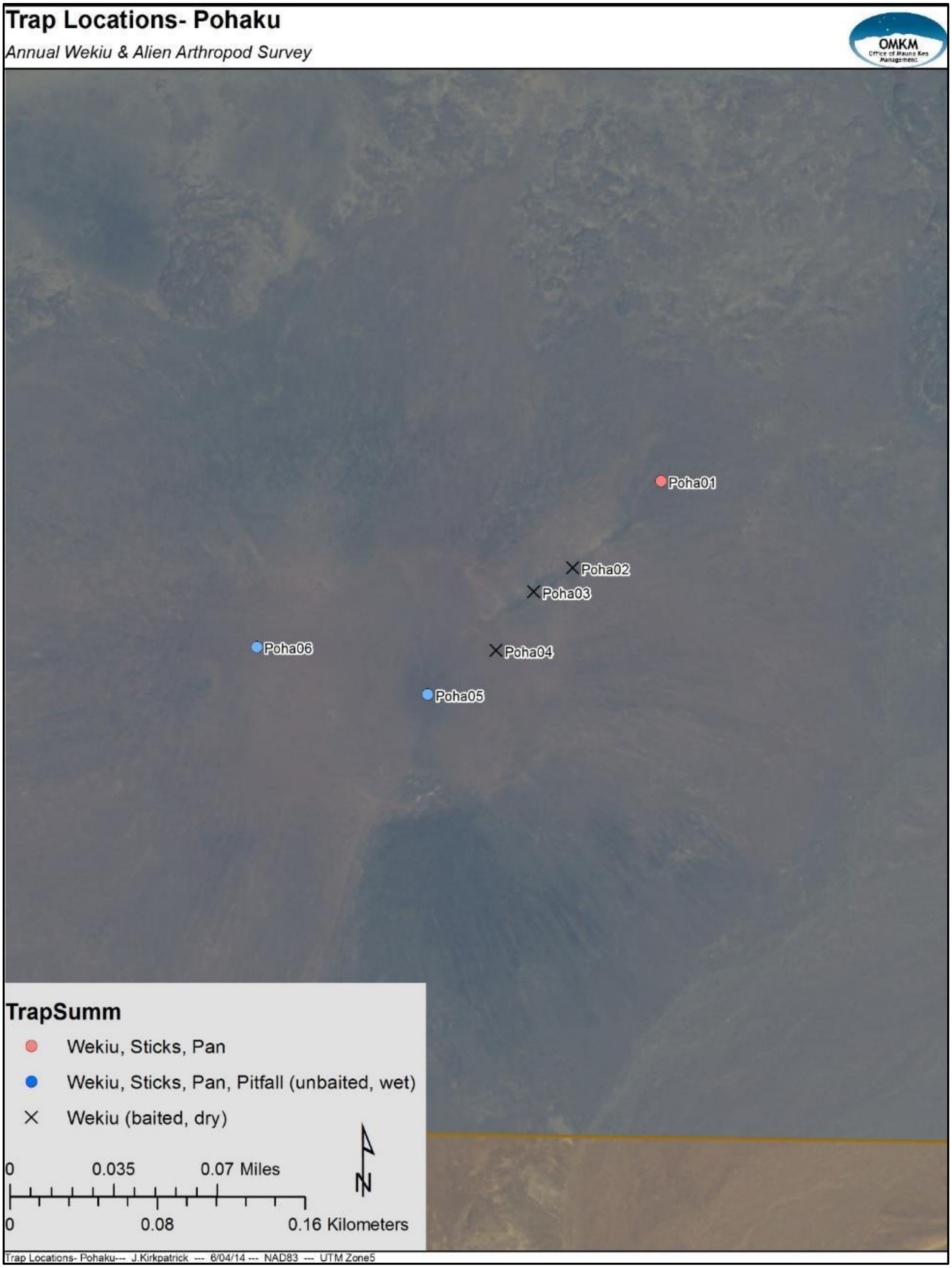

Figure 24. Annual Alien Invertebrate Monitoring survey locations at Puʻupōhaku.

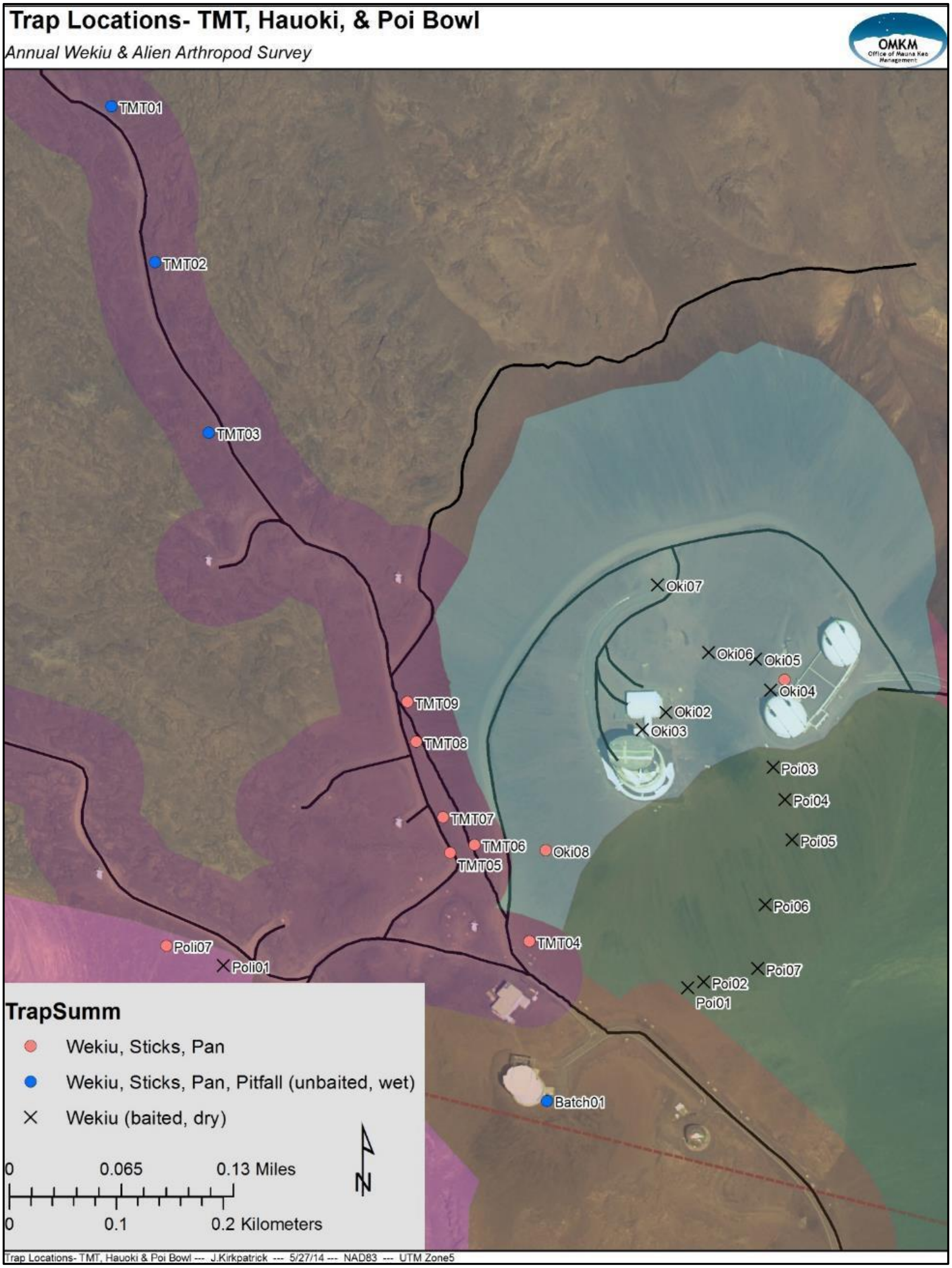

Figure 25. Annual Alien Invertebrate Monitoring survey locations at TMT, Puʻuhauʻoki, and Poi Bowl.

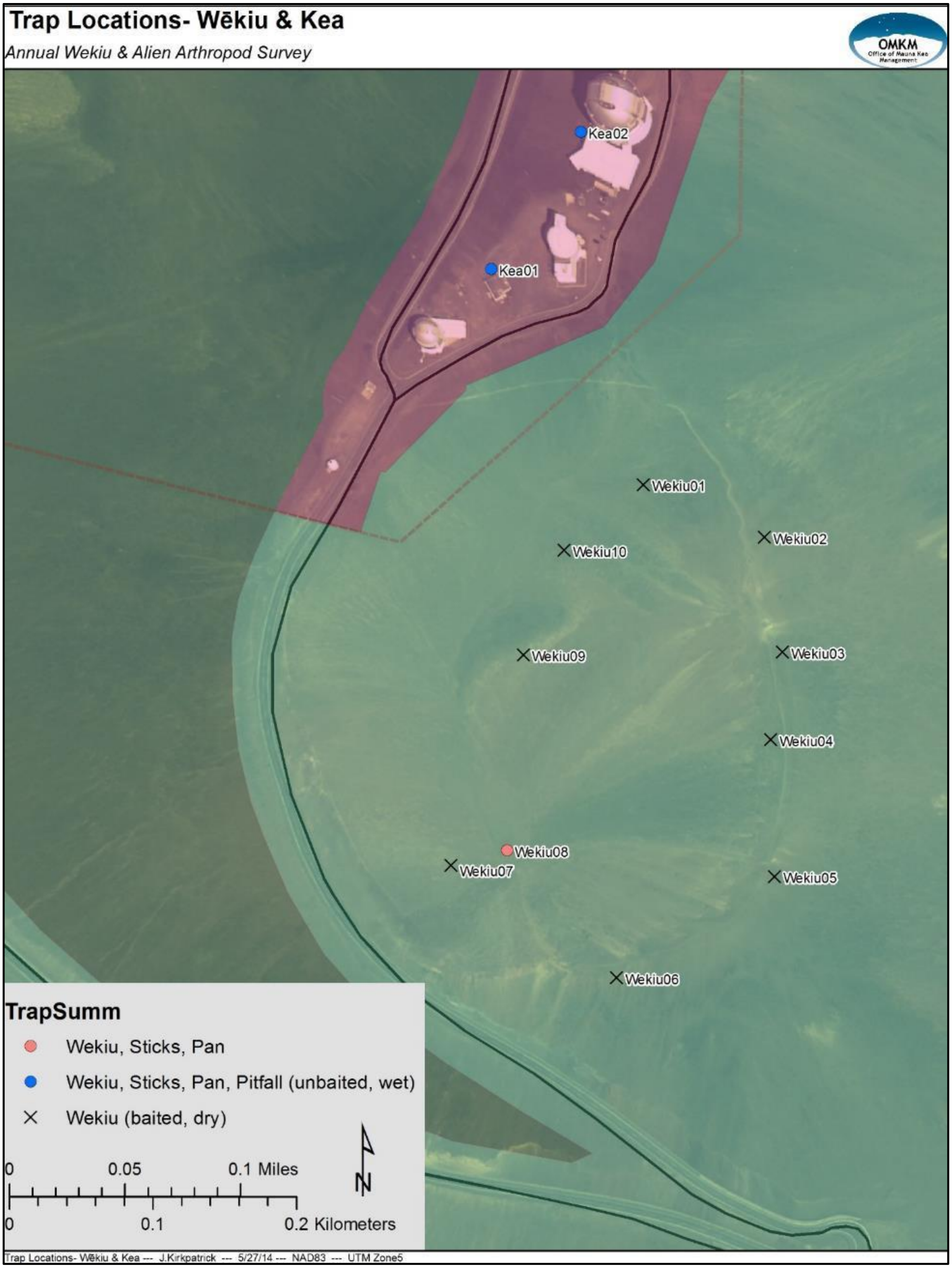

Figure 26. Annual Alien Invertebrate Monitoring survey locations at Pu'uwēkiu and Pu'ukea.

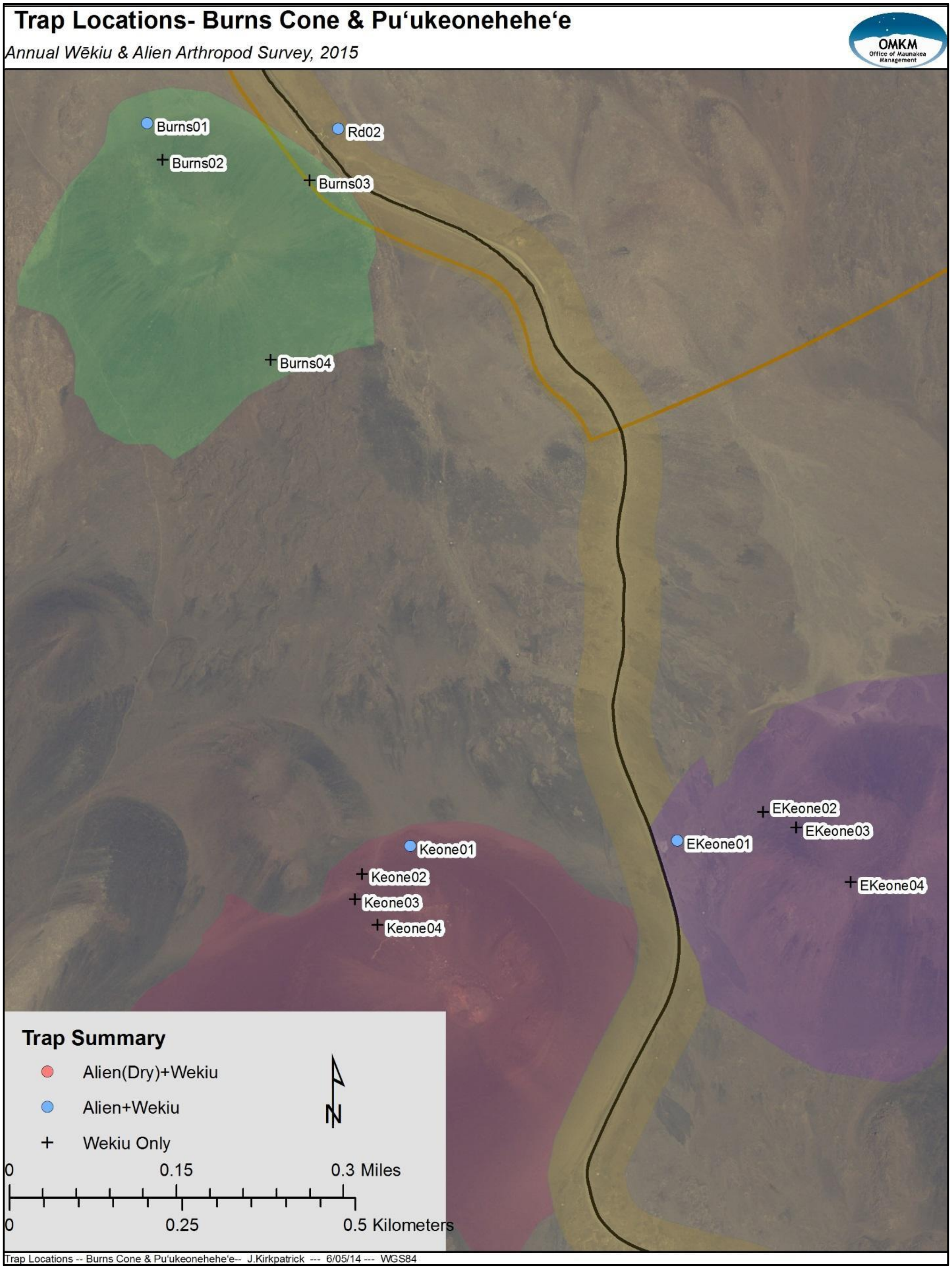

Figure 27. Annual Alien Invertebrate Monitoring survey locations at Burns Cone and Puʻukeonehēheʻe.

Appendix E: 2016-2020 Annual Alien Arthropod & Wēkiu Bug Trap Coordinates

Table 17. Annual Alien Invertebrate Monitoring trap location surveyed from 2016-2020 (including altitude in meters, geographic coordinates, and trap type).

Location*	Site ID	Altitude (meters)	Latitude	Longitude	Trap Type**
Batch Plant	Batch01	4106	19.822789950	-155.476869920	Alien
Batch Plant	Batch02	4056	19.819759980	-155.474079920	Alien
Batch Plant	Batch03	4082	19.820889940	-155.474259960	Alien
Batch Plant	Batch04	4064	19.819379940	-155.474150000	Alien
Batch Plant	Batch05	4080	19.820890000	-155.474590000	Wēkiu
Batch Plant	Batch06	4067	19.819900000	-155.474760000	Wēkiu
Batch Plant	Batch07	4063	19.820010000	-155.474740000	Wēkiu
Burns Cone	Burns01	TBD	19.793485000	-155.461087000	Alien
Burns Cone	Burns02	TBD	19.793012000	-155.460865000	Wēkiu
Burns Cone	Burns03	TBD	19.792773000	-155.458835000	Wēkiu
Burns Cone	Burns04	TBD	19.790424000	-155.459337000	Wēkiu
East Puʻukeoneheʻeheʻe	EKeone01	TBD	19.784230000	-155.453634000	Alien
East Puʻukeoneheʻeheʻe	EKeone02	TBD	19.784621000	-155.452456000	Wēkiu
East Puʻukeoneheʻeheʻe	EKeone03	TBD	19.784424000	-155.451997000	Wēkiu
East Puʻukeoneheʻeheʻe	EKeone04	TBD	19.783725000	-155.451233000	Wēkiu
Halepōhaku	HP01	2851	19.760589940	-155.456039970	Alien
Halepōhaku	HP02	2853	19.760859920	-155.456269970	Alien
Halepōhaku	HP03	2865	19.761309950	-155.455979960	Alien
Halepōhaku	HP04	2868	19.761799960	-155.456009960	Alien
Halepōhaku	HP05	2832	19.759329980	-155.455759930	Alien
Halepōhaku	HP06	2833	19.759409940	-155.455869990	Alien
Halepōhaku	HP07	2833	19.759439950	-155.456160000	Alien
Halepōhaku	HP08	2831	19.759149930	-155.455839980	Alien
Puʻuhaukea	Hkea01	TBD	19.815719444	-155.473500000	Wēkiu
Puʻuhaukea	Hkea02	TBD	19.816219444	-155.473880556	Wēkiu
Puʻuhaukea	Hkea03	4124	19.814549960	-155.473329990	Wēkiu
Puʻuhaukea	Hkea04	4120	19.814629920	-155.473389920	Wēkiu
Puʻuhaukea	Hkea05	4116	19.814359940	-155.473249950	Wēkiu
Puʻuhaukea	Hkea06	4125	19.814259940	-155.473460000	Wēkiu
Puʻuhaukea	Hkea07	4118	19.813829950	-155.473219940	Wēkiu
Puʻuhaukea	Hkea08	4128	19.813649990	-155.473359920	Wēkiu
Puʻuhaukea	Hkea09	4124	19.813229970	-155.472609990	Wēkiu
Puʻuhaukea	Hkea10	4115	19.813419990	-155.472609990	Wēkiu
Puʻuhaukea	Hkea11	4116	19.813579920	-155.471919990	Wēkiu
Puʻuhaukea	Hkea12	4126	19.813680000	-155.471509950	Wēkiu
Puʻuhaukea	Hkea13	4070	19.812570000	-155.473850000	Wēkiu
Puʻuhaukea	Hkea14	4042	19.811900000	-155.474290000	Wēkiu
Puʻuhauʻoki	Oki01	4174	19.826369950	-155.474809990	Alien(Dry)
Puʻuhauʻoki	Oki02	4151	19.826079930	-155.475859990	Wēkiu
Puʻuhauʻoki	Oki03	4164	19.825929980	-155.476069950	Wēkiu
Puʻuhauʻoki	Oki04	4171	19.826279930	-155.474929930	Wēkiu
Puʻuhauʻoki	Oki05	4162	19.826539930	-155.475069990	Wēkiu
Puʻuhauʻoki	Oki06	TBD	19.826589970	-155.475489930	Wēkiu
Puʻuhauʻoki	Oki07	TBD	19.827152780	-155.475952778	Wēkiu
Puʻuhauʻoki	Oki08	TBD	19.824900000	-155.476916667	Alien(Dry)
Puʻukea	Kea01	4223	19.822919960	-155.469959960	Alien
Puʻukea	Kea02	4213	19.823790000	-155.469379940	Alien
Puʻupōhaku	Poha01	4001	19.825379960	-155.489939990	Alien(Dry)
Puʻupōhaku	Poha02	4026	19.824949970	-155.490389930	Wēkiu
Puʻupōhaku	Poha03	4035	19.824829940	-155.490589920	Wēkiu
Puʻupōhaku	Poha04	4036	19.824539930	-155.490779940	Wēkiu
Puʻupōhaku	Poha05	4033	19.824319980	-155.491129970	Alien
Puʻupōhaku	Poha06	4044	19.824539930	-155.492019960	Wēkiu

Poi Bowl	Poi01	TBD	19.823760000	-155.475630000	Wēkiu
Poi Bowl	Poi02	TBD	19.823810000	-155.475490000	Wēkiu
Poi Bowl	Poi03	4168	19.825629990	-155.474899920	Wēkiu
Poi Bowl	Poi04	4153	19.825359930	-155.474789950	Wēkiu
Poi Bowl	Poi05	4144	19.825019960	-155.474719960	Wēkiu
Poi Bowl	Poi06	4123	19.824469940	-155.474949960	Wēkiu
Poi Bowl	Poi07	4105	19.823929970	-155.475009980	Wēkiu
Puʻupoliʻahu	Poli01	TBD	19.823890000	-155.479770000	Wēkiu
Puʻupoliʻahu	Poli02	4150	19.822149990	-155.481349970	Wēkiu
Puʻupoliʻahu	Poli03	4152	19.822499940	-155.481309980	Wēkiu
Puʻupoliʻahu	Poli04	4162	19.822719960	-155.481159950	Wēkiu
Puʻupoliʻahu	Poli05	4160	19.822939990	-155.480879990	Wēkiu
Puʻupoliʻahu	Poli06	4139	19.823059930	-155.479979940	Wēkiu
Puʻupoliʻahu	Poli07	TBD	19.824050000	-155.480283333	Alien(Dry)
Puʻukeoneheʻeheʻe	Keone01	TBD	19.784108000	-155.457314000	Alien
Puʻukeoneheʻeheʻe	Keone02	TBD	19.783737000	-155.457974000	Wēkiu
Puʻukeoneheʻeheʻe	Keone03	TBD	19.783407000	-155.458068000	Wēkiu
Puʻukeoneheʻeheʻe	Keone04	TBD	19.783075000	-155.457750000	Wēkiu
Road Corridor	Rd01	3753	19.801739980	-155.456009960	Alien
Road Corridor	Rd02	3667	19.793449940	-155.458449940	Alien
Road Corridor	Rd03	3032	19.767099920	-155.457749960	Alien
Road Corridor	Rd04	3390	19.777479980	-155.451659920	Alien
Road Corridor	Rd05	3658	19.795349950	-155.459299940	Alien
Road Corridor	Rd06	3932	19.810339980	-155.467699950	Alien
TMT/SMA	TMT01	4044	19.831119970	-155.480879990	Alien
TMT/SMA	TMT02	4058	19.829809960	-155.480469950	Alien
TMT/SMA	TMT03	4068	19.828379930	-155.479969970	Alien
TMT/SMA	TMT04	TBD	19.824133333	-155.477050000	Alien(Dry)
TMT/SMA	TMT05	TBD	19.824866667	-155.477766667	Alien(Dry)
TMT/SMA	TMT06	4106	19.824940000	-155.477550000	Alien(Dry)
TMT/SMA	TMT07	TBD	19.825166667	-155.477833333	Alien(Dry)
TMT/SMA	TMT08	TBD	19.825800000	-155.478083333	Alien(Dry)
TMT/SMA	TMT09	TBD	19.826133333	-155.478166667	Alien(Dry)
VLBA, N. Puʻu	VLBAN01	TBD	19.801530000	-155.457080000	Wēkiu
VLBA, N. Puʻu	VLBAN02	3776	19.802789980	-155.456949990	Wēkiu
VLBA, N. Puʻu	VLBAN03	3819	19.803119970	-155.458049950	Wēkiu
VLBA, N. Puʻu	VLBAN04	3860	19.803249980	-155.458919990	Wēkiu
VLBA, N. Puʻu	VLBAN05	3858	19.803579970	-155.459089980	Wēkiu
VLBA, N. Puʻu	VLBAN06	3864	19.803789940	-155.459349980	Wēkiu
VLBA, N. Puʻu	VLBAN07	3824	19.805409990	-155.458629980	Alien
VLBA, S. Puʻu	VLBAS01	TBD	19.800020000	-155.456620000	Wēkiu
VLBA, S. Puʻu	VLBAS02	3770	19.799939960	-155.455639990	Wēkiu
VLBA, S. Puʻu	VLBAS03	3786	19.799630000	-155.455629930	Wēkiu
VLBA, S. Puʻu	VLBAS04	3811	19.799009990	-155.455179990	Wēkiu
VLBA, S. Puʻu	VLBAS05	3809	19.799189950	-155.455579970	Wēkiu
VLBA, S. Puʻu	VLBAS06	3806	19.799040000	-155.456049940	Wēkiu
Puʻuwaiʻau	Waiau01	3990	19.811219990	-155.476909990	Alien
Puʻuwaiʻau	Waiau02	TBD	19.809999000	-155.476454000	Wēkiu
Puʻuwēkiu	Wekiu01	4196	19.821579940	-155.468930000	Wēkiu
Puʻuwēkiu	Wekiu02	4214	19.821259920	-155.468119970	Wēkiu
Puʻuwēkiu	Wekiu03	4225	19.820540000	-155.467989970	Wēkiu
Puʻuwēkiu	Wekiu04	4215	19.819989980	-155.468059960	Wēkiu
Puʻuwēkiu	Wekiu05	4207	19.819129990	-155.468019970	Wēkiu

*Most trap locations were derived from Bishop Museum Monitoring Surveys.

**Alien trap types include all traps: PBJS Sticks, Yellow Pan, Un-baited wet pitfall, and Baited Pitfall. Alien(Dry) trap types include 3 traps: PBJS Sticks, Yellow Pan, and Baited Pitfall. Wēkiu trap types include only Baited Pitfalls.

Appendix F: 2016-2020 Wēkiu Bug Capture Data

The number of Wēkiu bug individuals captured at each site over the 2016-2020 Annual Wēkiu Bug Monitoring and Annual Alien Invertebrate Monitoring survey period (including altitude in meters, geographic coordinates, and trap type) are listed below. Alien trap types include all traps: PBJS Sticks, Yellow Pan, Un-baited wet pitfall, and Baited Pitfall. Alien(Dry) trap types include 3 traps: PBJS Sticks, Yellow Pan, and Baited Pitfall. Wēkiu trap types include only Baited Pitfalls. Most trap locations were derived from Bishop Museum Monitoring Surveys.

Table 18. Annual Wēkiu Bug Monitoring trap locations surveyed from 2016-2020.

Location	Site ID	Altitude (meters)	Latitude	Longitude	# of Wēkiu	Trap Type
Batch Plant	Batch01	4106	19.822789950	-155.476869920	6	Alien
Batch Plant	Batch02	4056	19.819759980	-155.474079920	1	Alien
Batch Plant	Batch03	4082	19.820889940	-155.474259960	0	Alien
Batch Plant	Batch04	4064	19.819379940	-155.474150000	0	Alien
Batch Plant	Batch05	4080	19.820890000	-155.474590000	0	Wēkiu
Batch Plant	Batch06	4067	19.819900000	-155.474760000	0	Wēkiu
Batch Plant	Batch07	4063	19.820010000	-155.474740000	0	Wēkiu
Burns Cone	Burns01	TBD	19.793485000	-155.461087000	0	Alien
Burns Cone	Burns02	TBD	19.793012000	-155.460865000	0	Wēkiu
Burns Cone	Burns03	TBD	19.792773000	-155.458835000	0	Wēkiu
Burns Cone	Burns04	TBD	19.790424000	-155.459337000	0	Wēkiu
E. Puʻukeonehehe'e	EKeone01	TBD	19.784230000	-155.453634000	0	Alien
E. Puʻukeonehehe'e	EKeone02	TBD	19.784621000	-155.452456000	0	Wēkiu
E. Puʻukeonehehe'e	EKeone03	TBD	19.784424000	-155.451997000	0	Wēkiu
E. Puʻukeonehehe'e	EKeone04	TBD	19.783725000	-155.451233000	0	Wēkiu
Halepōhaku	HP01	2851	19.760589940	-155.456039970	0	Alien
Halepōhaku	HP02	2853	19.760859920	-155.456269970	0	Alien
Halepōhaku	HP03	2865	19.761309950	-155.455979960	0	Alien
Halepōhaku	HP04	2868	19.761799960	-155.456009960	0	Alien
Halepōhaku	HP05	2832	19.759329980	-155.455759930	0	Alien
Halepōhaku	HP06	2833	19.759409940	-155.455869990	0	Alien
Halepōhaku	HP07	2833	19.759439950	-155.456160000	0	Alien
Halepōhaku	HP08	2831	19.759149930	-155.455839980	0	Alien
Puʻuhaukea	Hkea01	TBD	19.815719444	-155.473500000	678	Wēkiu
Puʻuhaukea	Hkea02	TBD	19.816219444	-155.473880556	338	Wēkiu
Puʻuhaukea	Hkea03	4124	19.814549960	-155.473329990	152	Wēkiu
Puʻuhaukea	Hkea04	4120	19.814629920	-155.473389920	104	Wēkiu
Puʻuhaukea	Hkea05	4116	19.814359940	-155.473249950	112	Wēkiu
Puʻuhaukea	Hkea06	4125	19.814259940	-155.473460000	60	Wēkiu
Puʻuhaukea	Hkea07	4118	19.813829950	-155.473219940	359	Wēkiu
Puʻuhaukea	Hkea08	4128	19.813649990	-155.473359920	29	Wēkiu
Puʻuhaukea	Hkea09	4124	19.813229970	-155.472609990	60	Wēkiu
Puʻuhaukea	Hkea10	4115	19.813419990	-155.472609990	183	Wēkiu
Puʻuhaukea	Hkea11	4116	19.813579920	-155.471919990	116	Wēkiu
Puʻuhaukea	Hkea12	4126	19.813680000	-155.471509950	45	Wēkiu
Puʻuhaukea	Hkea13	4070	19.812570000	-155.473850000	12	Wēkiu
Puʻuhaukea	Hkea14	4042	19.811900000	-155.474290000	8	Wēkiu
Puʻuhauʻoki	Oki01	4174	19.826369950	-155.474809990	287	Alien(Dry)
Puʻuhauʻoki	Oki02	4151	19.826079930	-155.475859990	91	Wēkiu
Puʻuhauʻoki	Oki03	4164	19.825929980	-155.476069950	48	Wēkiu
Puʻuhauʻoki	Oki04	4171	19.826279930	-155.474929930	252	Wēkiu
Puʻuhauʻoki	Oki05	4162	19.826539930	-155.475069990	454	Wēkiu
Puʻuhauʻoki	Oki06	TBD	19.826589970	-155.475489930	359	Wēkiu
Puʻuhauʻoki	Oki07	TBD	19.827152780	-155.475952778	59	Wēkiu
Puʻuhauʻoki	Oki08	TBD	19.824900000	-155.476916667	13	Alien(Dry)
Puʻukea	Kea01	4223	19.822919960	-155.469959960	19	Alien

Puʻukea	Kea02	4213	19.823790000	-155.469379940	202	Alien
Puʻupōhaku	Poha01	4001	19.825379960	-155.489939990	3	Alien(Dry)
Puʻupōhaku	Poha02	4026	19.824949970	-155.490389930	9	Wēkiu
Puʻupōhaku	Poha03	4035	19.824829940	-155.490589920	4	Wēkiu
Puʻupōhaku	Poha04	4036	19.824539930	-155.490779940	1	Wēkiu
Puʻupōhaku	Poha05	4033	19.824319980	-155.491129970	13	Alien
Puʻupōhaku	Poha06	4044	19.824539930	-155.492019960	0	Wēkiu
Poi Bowl	Poi01	TBD	19.823760000	-155.475630000	14	Wēkiu
Poi Bowl	Poi02	TBD	19.823810000	-155.475490000	17	Wēkiu
Poi Bowl	Poi03	4168	19.825629990	-155.474899920	37	Wēkiu
Poi Bowl	Poi04	4153	19.825359930	-155.474789950	47	Wēkiu
Poi Bowl	Poi05	4144	19.825019960	-155.474719960	21	Wēkiu
Poi Bowl	Poi06	4123	19.824469940	-155.474949960	44	Wēkiu
Poi Bowl	Poi07	4105	19.823929970	-155.475009980	6	Wēkiu
Puʻupoliʻahu	Poli01	TBD	19.823890000	-155.479770000	406	Wēkiu
Puʻupoliʻahu	Poli02	4150	19.822149990	-155.481349970	0	Wēkiu
Puʻupoliʻahu	Poli03	4152	19.822499940	-155.481309980	0	Wēkiu
Puʻupoliʻahu	Poli04	4162	19.822719960	-155.481159950	1	Wēkiu
Puʻupoliʻahu	Poli05	4160	19.822939990	-155.480879990	1	Wēkiu
Puʻupoliʻahu	Poli06	4139	19.823059930	-155.479979940	44	Wēkiu
Puʻupoliʻahu	Poli07	TBD	19.824050000	-155.480283333	0	Alien(Dry)
E. Puʻukeonehēheʻe	Keone01	TBD	19.784108000	-155.457314000	1	Alien
E. Puʻukeonehēheʻe	Keone02	TBD	19.783737000	-155.457974000	1	Wēkiu
E. Puʻukeonehēheʻe	Keone03	TBD	19.783407000	-155.458068000	44	Wēkiu
E. Puʻukeonehēheʻe	Keone04	TBD	19.783075000	-155.457750000	578	Wēkiu
Road Corridor	Rd01	3753	19.801739980	-155.456009960	0	Alien
Road Corridor	Rd02	3667	19.793449940	-155.458449940	0	Alien
Road Corridor	Rd03	3032	19.767099920	-155.457749960	0	Alien
Road Corridor	Rd04	3390	19.777479980	-155.451659920	0	Alien
Road Corridor	Rd05	3658	19.795349950	-155.459299940	0	Alien
Road Corridor	Rd06	3932	19.810339980	-155.467699950	0	Alien
TMT/SMA	TMT01	4044	19.831119970	-155.480879990	0	Alien
TMT/SMA	TMT02	4058	19.829809960	-155.480469950	1	Alien
TMT/SMA	TMT03	4068	19.828379930	-155.479969970	0	Alien
TMT/SMA	TMT04	TBD	19.824133333	-155.477050000	4	Alien(Dry)
TMT/SMA	TMT05	TBD	19.824866667	-155.477766667	3	Alien(Dry)
TMT/SMA	TMT06	4106	19.824940000	-155.477550000	5	Alien(Dry)
TMT/SMA	TMT07	TBD	19.825166667	-155.477833333	7	Alien(Dry)
TMT/SMA	TMT08	TBD	19.825800000	-155.478083333	6	Alien(Dry)
TMT/SMA	TMT09	TBD	19.826133333	-155.478166667	6	Alien(Dry)
VLBA, N. Puʻu	VLBAN01	TBD	19.801530000	-155.457080000	1	Wēkiu
VLBA, N. Puʻu	VLBAN02	3776	19.802789980	-155.456949990	0	Wēkiu
VLBA, N. Puʻu	VLBAN03	3819	19.803119970	-155.458049950	0	Wēkiu
VLBA, N. Puʻu	VLBAN04	3860	19.803249980	-155.458919990	0	Wēkiu
VLBA, N. Puʻu	VLBAN05	3858	19.803579970	-155.459089980	2	Wēkiu
VLBA, N. Puʻu	VLBAN06	3864	19.803789940	-155.459349980	0	Wēkiu
VLBA, N. Puʻu	VLBAN07	3824	19.805409990	-155.458629980	0	Alien
VLBA, S. Puʻu	VLBAS01	TBD	19.800020000	-155.456620000	0	Wēkiu
VLBA, S. Puʻu	VLBAS02	3770	19.799939960	-155.455639990	32	Wēkiu
VLBA, S. Puʻu	VLBAS03	3786	19.799630000	-155.455629930	18	Wēkiu
VLBA, S. Puʻu	VLBAS04	3811	19.799009990	-155.455179990	2	Wēkiu
VLBA, S. Puʻu	VLBAS05	3809	19.799189950	-155.455579970	0	Wēkiu
VLBA, S. Puʻu	VLBAS06	3806	19.799040000	-155.456049940	0	Wēkiu
Puʻuwaiʻau	Waiau01	3990	19.811219990	-155.476909990	0	Alien
Puʻuwaiʻau	Waiau02	TBD	19.809999000	-155.476454000	4	Wēkiu
Puʻuwēkiu	Wekiu01	4196	19.821579940	-155.468930000	12	Wēkiu
Puʻuwēkiu	Wekiu02	4214	19.821259920	-155.468119970	81	Wēkiu
Puʻuwēkiu	Wekiu03	4225	19.820540000	-155.467989970	9	Wēkiu
Puʻuwēkiu	Wekiu04	4215	19.819989980	-155.468059960	14	Wēkiu
Puʻuwēkiu	Wekiu05	4207	19.819129990	-155.468019970	1	Wēkiu
Puʻuwēkiu	Wekiu06	4186	19.818479980	-155.469059920	12	Wēkiu

Puʻuwēkiu	Wekiu07	4159	19.819169980	-155.470169930	553	Wēkiu
Puʻuwēkiu	Wekiu08	4148	19.819269970	-155.469799950	351	Alien(Dry)
Puʻuwēkiu	Wekiu09	4178	19.820499930	-155.469709930	1	Wēkiu
Puʻuwēkiu	Wekiu10	4183	19.821159920	-155.469449930	0	Wēkiu

Appendix G: Wēkiu Bug Abundance and Capture Rate Maps

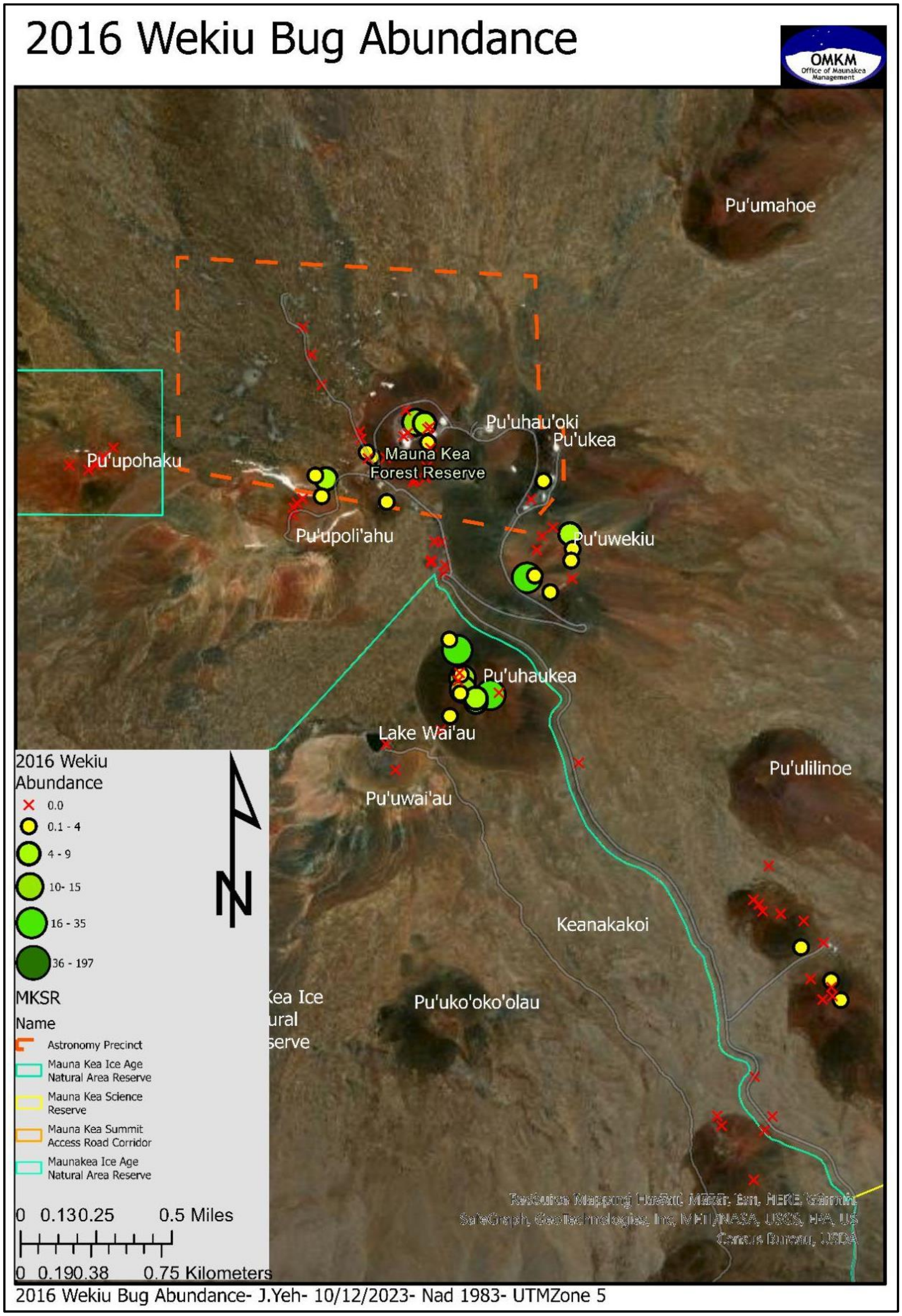

Figure 28. Map of the number of wēkiu bugs captured at each location during the Annual Wēkiu and Alien Invertebrate Monitoring surveys in 2016.

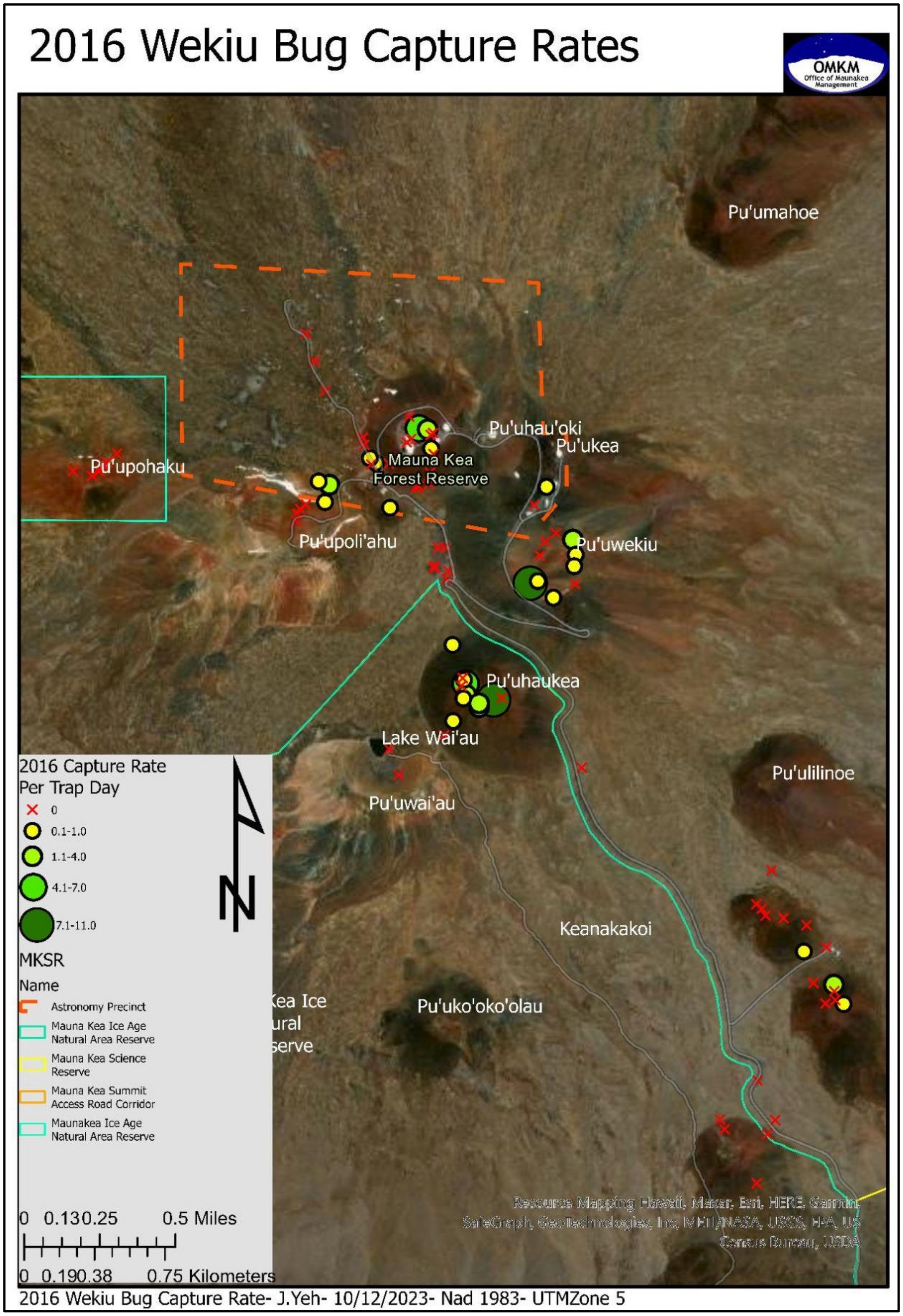

Figure 29. Map of the wēkiu bug capture rates (captures per trap day) at each location during the Annual Wēkiu and Alien Invertebrate Monitoring surveys in 2016.

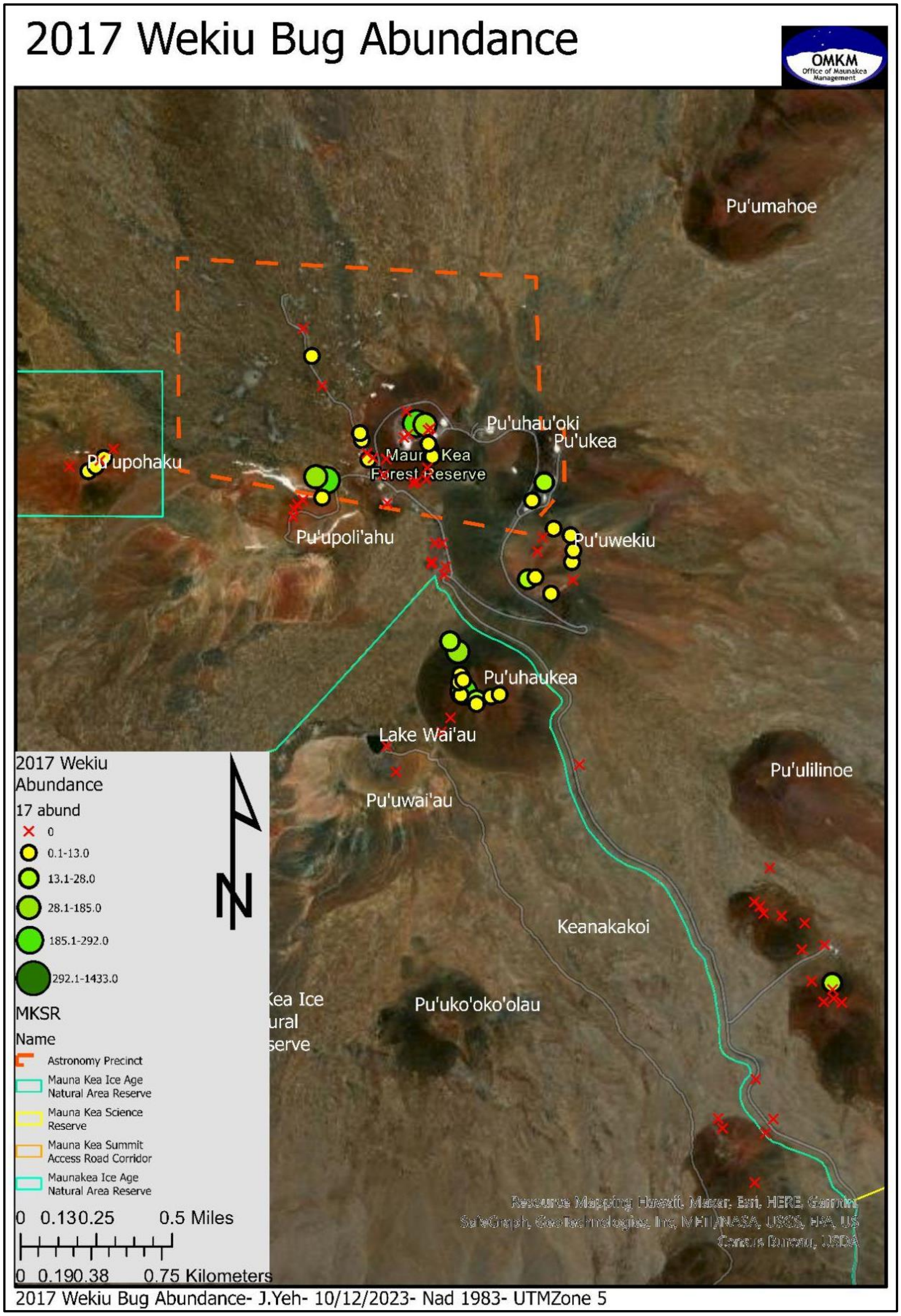

Figure 30. Map of the number of wēkiu bugs captured at each location during the Annual Wēkiu and Alien Invertebrate Monitoring surveys in 2017.

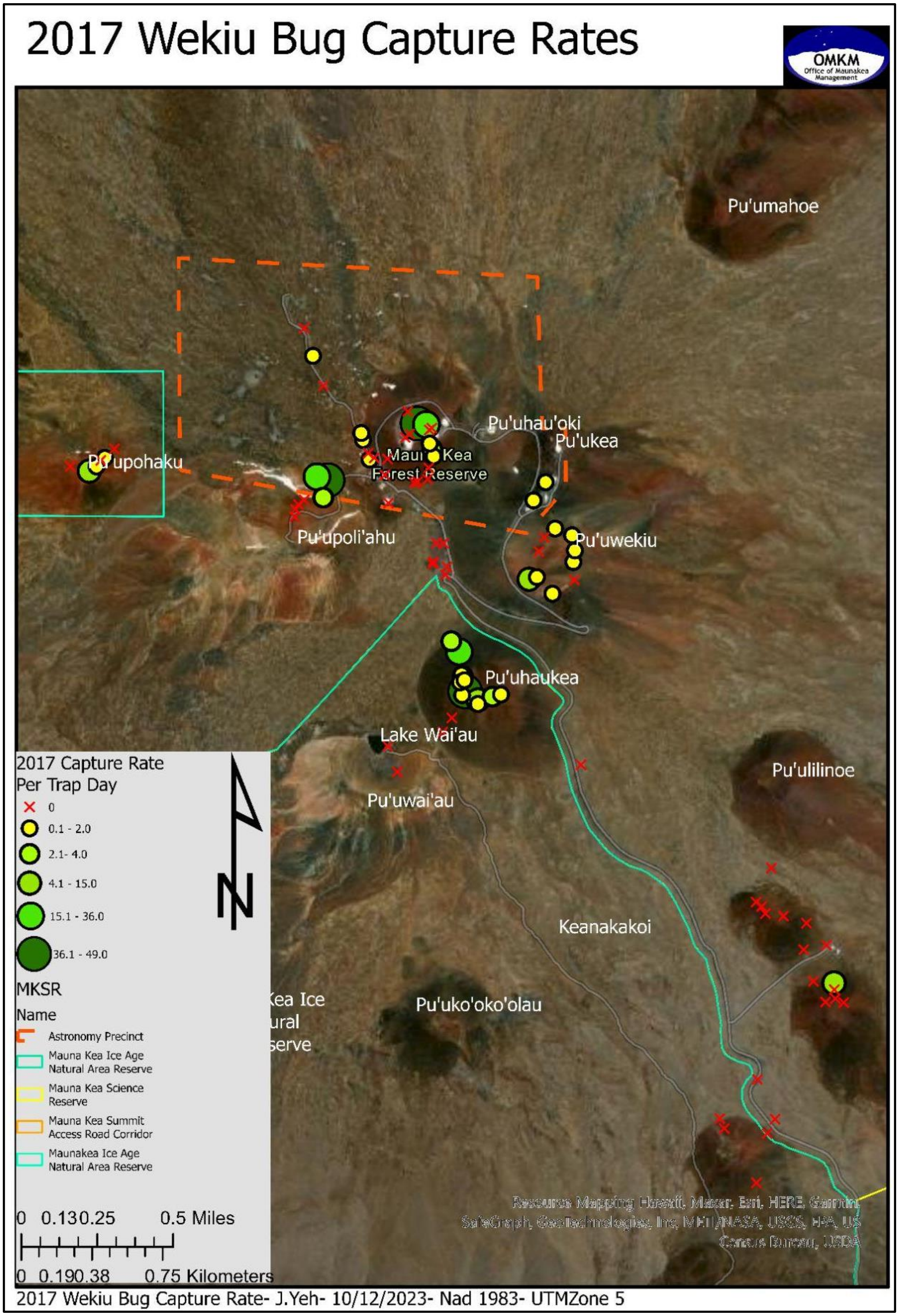

Figure 31. Map of the wēkiu bug capture rates (captures per trap day) at each location during the Annual Wēkiu and Alien Invertebrate Monitoring surveys in 2017.

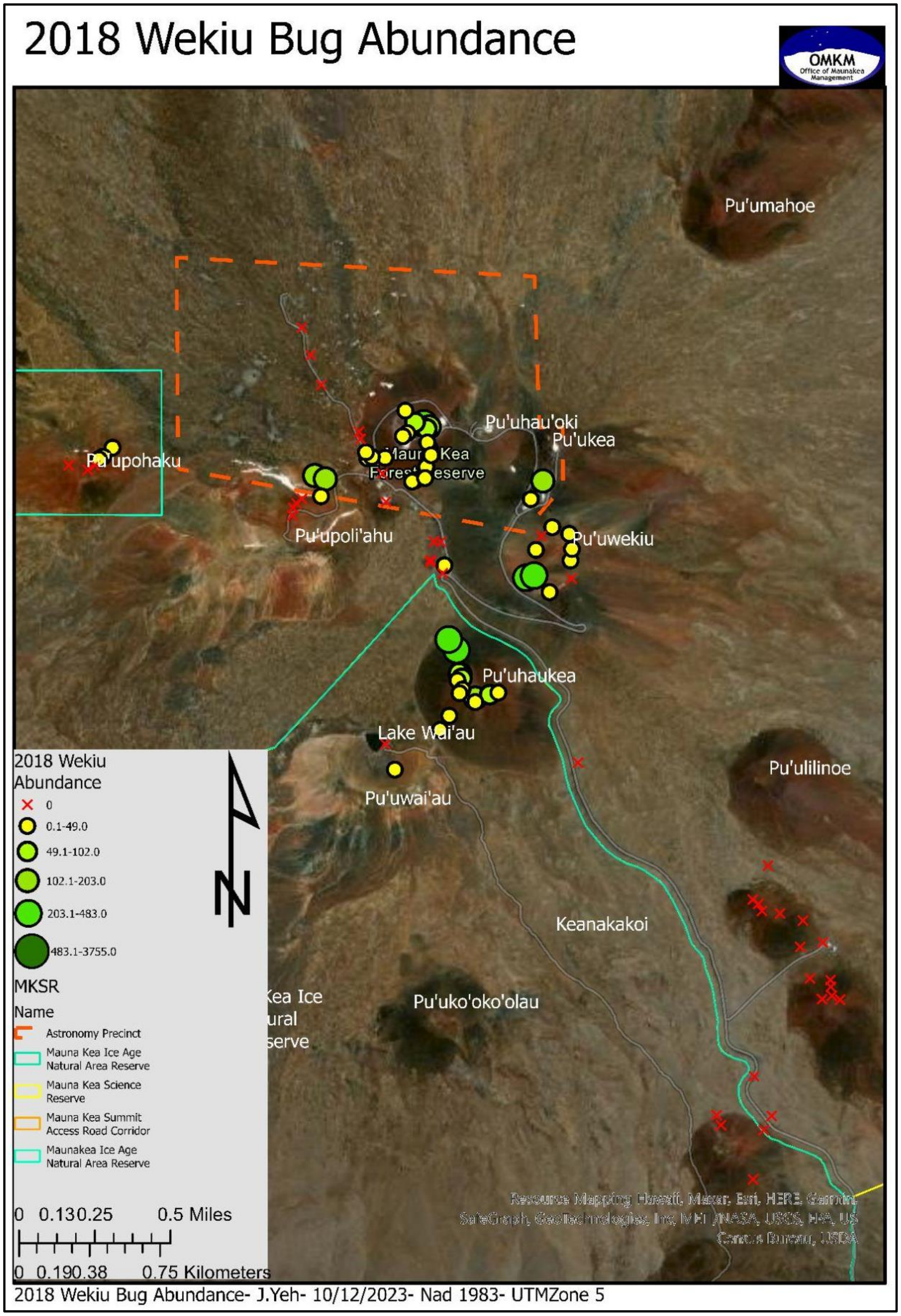

Figure 32. Map of the number of wēkiu bugs captured at each location during the Annual Wēkiu and Alien Invertebrate Monitoring surveys in 2018.

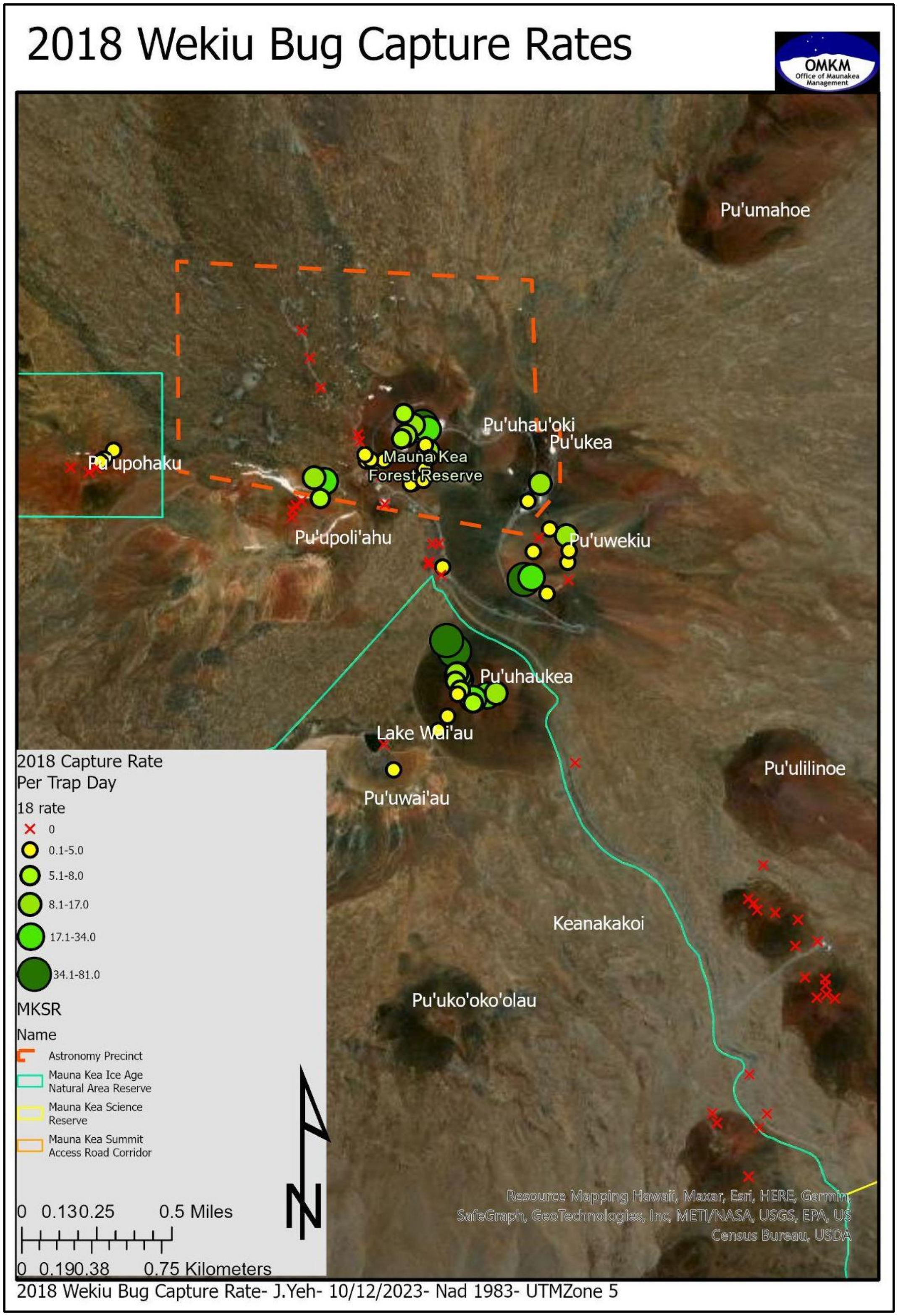

Figure 33. Map of the wēkiu bug capture rates (captures per trap day) at each location during the Annual Wēkiu and Alien Invertebrate Monitoring surveys in 2018.

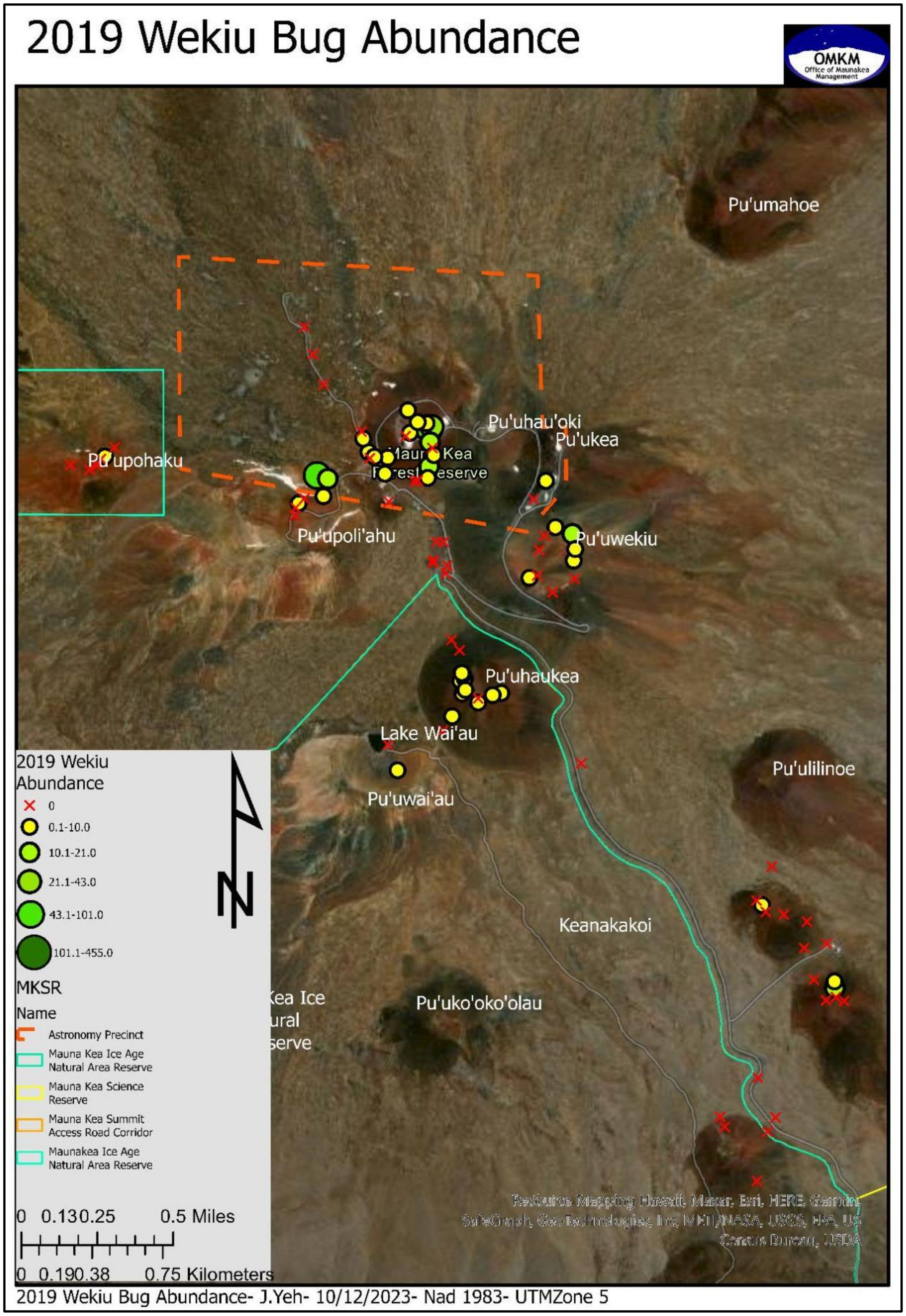

Figure 34. Map of the number of wēkiu bugs captured at each location during the Annual Wēkiu and Alien Invertebrate Monitoring surveys in 2019.

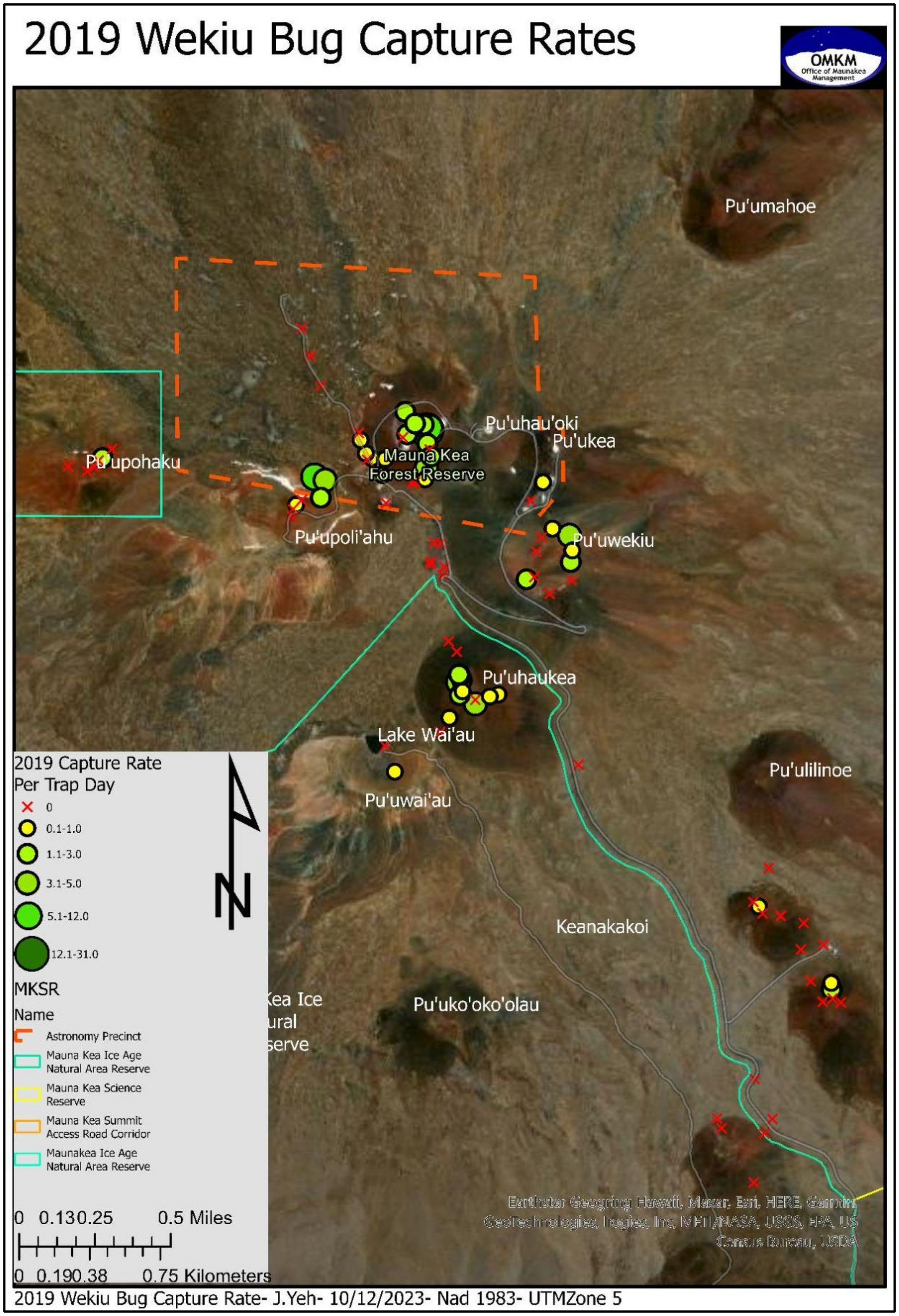

Figure 35. Map of the wēkiu bug capture rates (captures per trap day) at each location during the Annual Wēkiu and Alien Invertebrate Monitoring surveys in 2019.

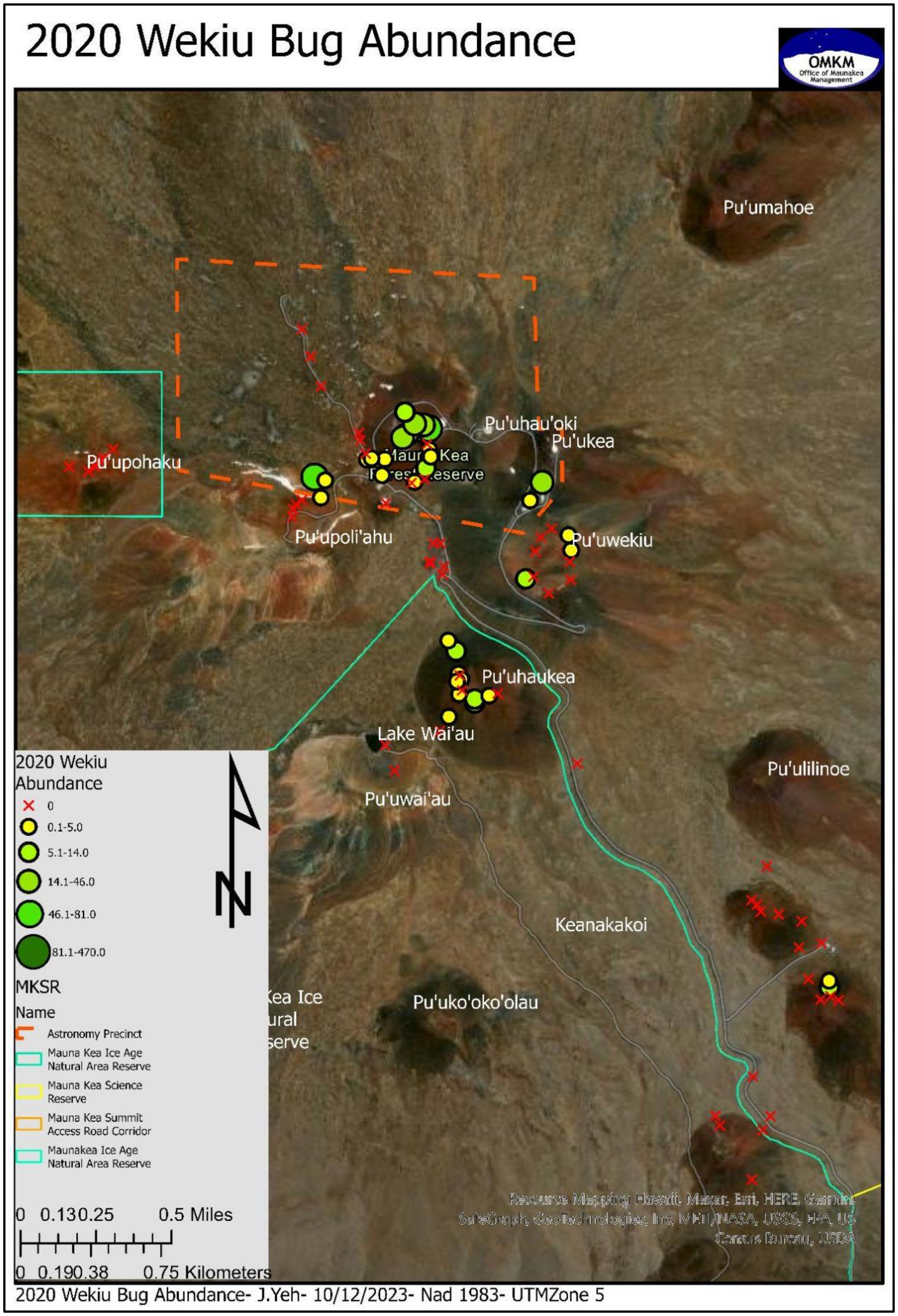

Figure 36. Map of the number of wēkiu bugs captured at each location during the Annual Wēkiu and Alien Invertebrate Monitoring surveys in 2020.

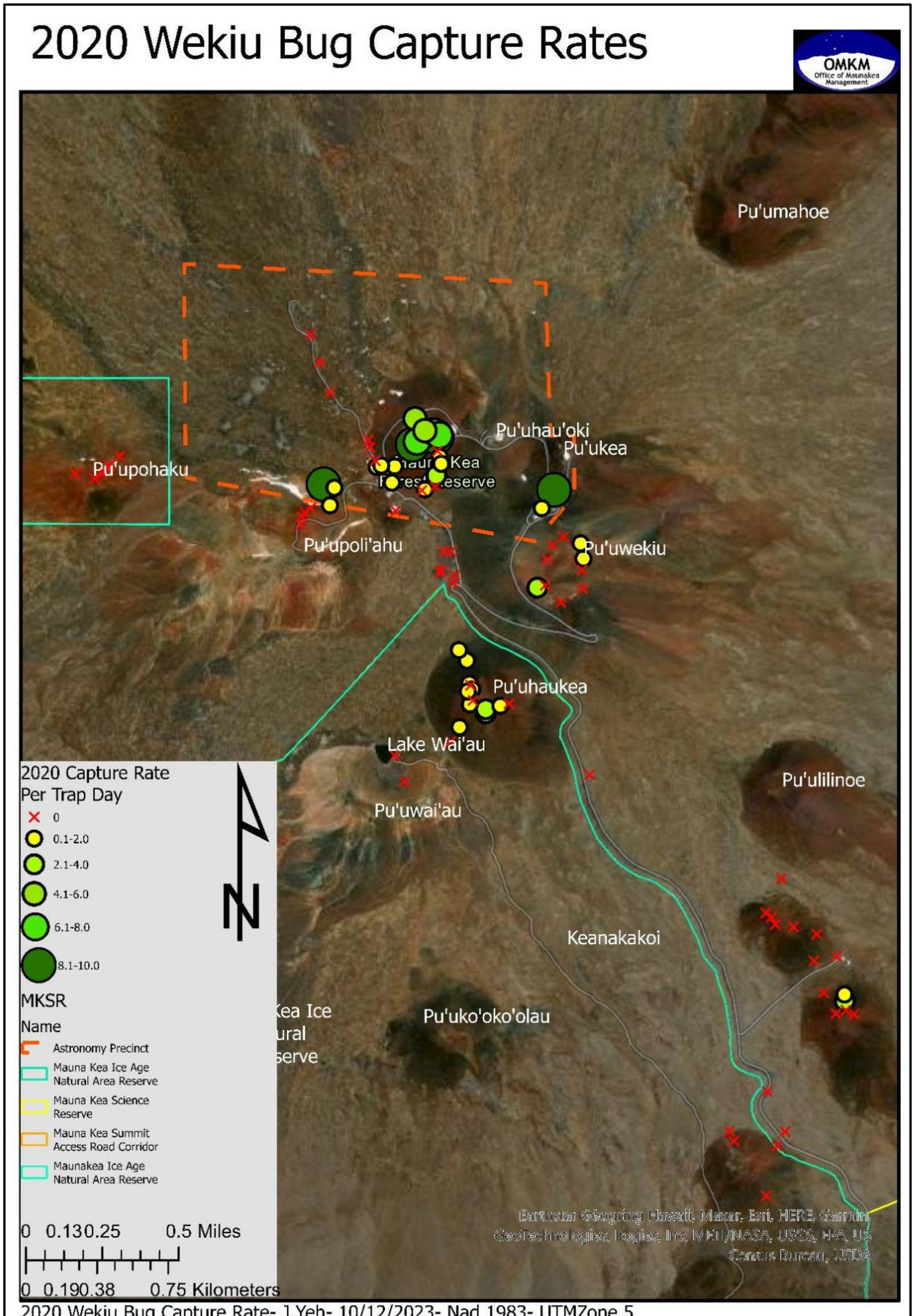

Figure 37. Map of the wēkiu bug capture rates (captures per trap day) at each location during the Annual Wēkiu and Alien Invertebrate Monitoring surveys in 2016.

Appendix H: 2016-2020 Annual Survey Arthropod Capture List

Table 19. All arthropods captured during the 2016-2020 Annual Alien Invertebrate Monitoring surveys listed alphabetically by taxa. Arthropod threats are identified in **bold** font and shaded rows identify new species records to the management area. New record threats are shown in **bold** font with shaded rows. Nativity[12] is either non-native, native, non-native & native within that taxonomic group, or unknown. Notable non-arthropod captures are included at the end of the table.

Taxa	Order	Family	Genus & species	Nativity
1	Acari	Bdellidae	Unknown	Non-Native & Native
2				
3	**Araneae**	**Agelenidae**	***Hololena curta***	**Non-Native**
4				
5	Araneae	Corinnidae	Unknown	Unknown
6	**Araneae**	**Gnaphosidae**	**Unknown**	**Non-Native**
7	**Araneae**	**Linyphiidae**	***Erigone unknown***	**Non-Native & Native**
8	**Araneae**	**Linyphiidae**	***Lepthyphantes tenuis***	**Non-Native**
9	**Araneae**	**Linyphiidae**	***Lepthyphantes unknown***	**Non-Native**
10	**Araneae**	**Linyphiidae**	**Unknown**	**Non-Native & Native**
11	Araneae	Lycosidae	*Lycosa hawaiiensis*	Native
12	**Araneae**	**Salticidae**	**Unknown**	**Non-Native & Native**
13	**Araneae**	**Theridiidae**	***Steatoda unknown***	**Non-Native**
14				
15				
16	**Araneae**	**Trachelidae**	**Unknown**	**Non-Native & Native**
17				
18	Blattodea	Blaberidae	*Pycnoscelus indicus*	Non-Native
19	**Chilopoda**	**Lithobiidae**	***Lithobius unknown***	**Non-Native & Native**
20	**Coleoptera**	**Carabidae**	***Agonum muelleri***	**Non-Native**
21	**Coleoptera**	**Carabidae**	***Trechus obtusus***	**Non-Native**
22				
23	**Coleoptera**	**Cerambycidae**	**Unknown**	**Non-Native & Native**
24	**Coleoptera**	**Chrysomelidae**	**Unknown**	**Non-Native**
25				
26	Coleoptera	Coccinellidae	*Halmus chalybeus*	Non-Native
27	Coleoptera	Coccinellidae	*Harmonia conformis*	Non-Native
28	Coleoptera	Coccinellidae	*Hippodamia convergens*	Non-Native
29				
30				
31	**Coleoptera**	**Latridiidae**	***Aridius nodifer***	**Non-Native**
32	**Coleoptera**	**Scarabaeidae**	***Onthophagus nigriventris***	**Non-Native**
33	**Coleoptera**	**Staphylinidae**	***Aleochara verna***	**Non-Native**
34	**Coleoptera**	**Staphylinidae**	**Unknown**	**Non-Native & Native**
35				
36	**Coleoptera**	**Tenebrionidae**	**Unknown**	**Non-Native & Native**
37	**Coleoptera**	**Unknown**	**Unknown**	**Non-Native & Native**
38				
39	Collembola	Hypogastruridae	Unknown	Non-Native & Native
40	Collembola	Unknown	Unknown	Non-Native & Native
41	Dermaptera	Forficulidae	*Forficula auricularia*	Non-Native
42	Diptera	Agromyzidae	Unknown	Non-Native & Native
43	Diptera	Tipulidae	Unknown	Non-Native & Native
44	Diptera	Anthomyiidae	*Delia platura*	Non-Native
45	Diptera	Anthomyiidae	Unknown	Non-Native
46				
47	Diptera	Calliphoridae	*Eucalliphora lilaea*	Non-Native

[12] Nativity was determined using various resources such as the Insects of Hawaii series (The University of Hawaii Press, Honolulu), the Hawaiian Terrestrial Arthropod Checklist (Nishida 2002), and the revised checklist (Matsunaga et al. 2019).

Diptera	Calliphoridae	*Lucilia unknown*	Non-Native & Native
Diptera	Calliphoridae	Unknown	Non-Native & Native
Diptera	Cecidomyiidae	Unknown	Non-Native & Native
Diptera	Ceratopogonidae	Unknown	Non-Native & Native
Diptera	Chamaemyiidae	Unknown	Non-Native
Diptera	Chironomidae	Unknown	Non-Native & Native
Diptera	Dolichopodidae	Unknown	Non-Native & Native
Diptera	Drosophilidae	*Drosophila suzukii*	Non-Native
Diptera	Drosophilidae	*Drosophila unknown*	Non-Native & Native
Diptera	Drosophilidae	Unknown	Non-Native & Native
Diptera	Ephydridae	*Hydrellia tritici*	Non-Native
Diptera	Ephydridae	Unknown	Non-Native & Native
Diptera	Lauxaniidae	Unknown	Non-Native
Diptera	Lonchopteridae	*Lonchoptera furcata*	Non-Native
Diptera	Lonchopteridae	Unknown	Non-Native
Diptera	**Muscidae**	***Coenosia humilis***	**Non-Native**
Diptera	**Muscidae**	***Haematobia irritans***	**Non-Native**
Diptera	**Muscidae**	**Unknown**	**Non-Native & Native**
Diptera	Nematocera	Unknown	Non-Native & Native
Diptera	Oestridae	*Hypoderma bovis*	Non-Native
Diptera	Oestridae	*Hypoderma unknown*	Non-Native
Diptera	Phoridae	*Megaselia brunneipalpata*	Native
Diptera	Phoridae	Unknown	Non-Native & Native
Diptera	Psychodidae	*Trichopsychoda insulicola*	Non-Native
Diptera	Psychodidae	Unknown	Non-Native & Native
Diptera	Sarcophagidae	Unknown	Non-Native & Native
Diptera	Sciaridae	*Bradysia impatiens*	Non-Native
Diptera	Sciaridae	Unknown	Non-Native
Diptera	Sepsidae	Unknown	Non-Native
Diptera	Sphaeroceridae	*Copromyza unknown*	Non-Native
Diptera	Sphaeroceridae	*Leptocera unknown*	Non-Native
Diptera	Sphaeroceridae	Unknown	Non-Native & Native
Diptera	Syrphidae	*Eristalis tenax*	Non-Native
Diptera	Syrphidae	*Toxomerus marginatus*	Non-Native
Diptera	Syrphidae	Unknown	Non-Native
Diptera	Tephritidae	Unknown	Non-Native & Native
Diptera	Tipulidae	Unknown	Non-Native & Native
Diptera	Unknown	Unknown	Non-Native & Native
Hemiptera	Anthocoridae	*Orius unknown*	Non-Native
Hemiptera	Anthocoridae	Unknown	Non-Native & Native
Hemiptera	Geocoridae	*Geocoris pallens*	Non-Native
Hemiptera	Geocoridae	*Geocoris unknown*	Non-Native
Hemiptera	Lygaeidae	*Neseis ochriasis*	Native
Hemiptera	Lygaeidae	*Nysius nemorivagus*	Native
Hemiptera	Lygaeidae	*Nysius palor*	Non-Native
Hemiptera	Lygaeidae	*Nysius terrestris*	Native
Hemiptera	Lygaeidae	*Nysius unknown*	Non-Native & Native
Hemiptera	Lygaeidae	*Nysius wekiuicola*	Native
Hemiptera	Lygaeidae	Unknown	Non-Native & Native
Hemiptera	Miridae	*Spanagonicus albofasciatus*	Non-Native

Hemiptera	Nabidae	*Nabis unknown*	Non-Native & Native
Hemiptera	Nabidae	Unknown	Non-Native & Native
Hemiptera	Pentatomidae	*Bagrada hilaris*	Non-Native
Hemiptera	Rhyparochromidae	*Brentiscerus australis*	Non-Native
Hemiptera	Rhyparochromidae	Unknown	Non-Native
Homoptera	Cercopidae	Unknown	Non-Native
Homoptera	Cicadellidae	Unknown	Non-Native & Native
Homoptera	Pseudococcidae	Unknown	Non-Native & Native
Homoptera	Psyllidae	*Acizzia uncatoides*	Non-Native
Homoptera	Psyllidae	Unknown	Non-Native & Native
Hymenoptera	**Apidae**	***Apis mellifera***	**Non-Native**
Hymenoptera	**Braconidae**	***Aphidius gifuensis***	**Unknown**
Hymenoptera	**Braconidae**	**Unknown**	**Non-Native & Native**
Hymenoptera	**Chalcididae**	**Unknown**	**Non-Native & Native**
Hymenoptera	Colletidae	*Hylaeus difficilis*	Native
Hymenoptera	Colletidae	*Hylaeus unknown*	Native
Hymenoptera	**Encyrtidae**	**Unknown**	**Non-Native & Native**
Hymenoptera	**Eulophidae**	**Unknown**	**Non-Native & Native**
Hymenoptera	**Eupelmidae**	**Unknown**	**Non-Native & Native**
Hymenoptera	**Ichneumonidae**	***Diadegma unknown***	**Non-Native**
Hymenoptera	**Ichneumonidae**	***Pristomerus spinator***	**Non-Native**
Hymenoptera	**Pompilidae**	***Anoplius toluca***	**Non-Native**
Hymenoptera	**Pteromalidae**	***Mesopolobus unknown***	**Unknown**
Hymenoptera	**Pteromalidae**	***Pachyneuron unknown***	**Non-Native**
Hymenoptera	**Pteromalidae**	**Unknown**	**Non-Native & Native**
Hymenoptera	**Scelionidae**	**Unknown**	**Non-Native & Native**
Hymenoptera	**Tenthredinidae**	**Unknown**	**Non-Native**
Hymenoptera	**Unknown**	**Unknown**	**Non-Native & Native**
Lepidoptera	Lycaenidae	*Lampides boeticus*	Non-Native
Lepidoptera	Noctuidae	*Agrotis kuamauna*	Native
Lepidoptera	Noctuidae	*Agrotis unknown*	Non-Native & Native
Lepidoptera	Noctuidae	Unknown	Non-Native & Native
Lepidoptera	Oecophoridae	*Thyrocopa unknown*	Native
Lepidoptera	Pyralidae	Unknown	Non-Native & Native
Lepidoptera	Tineidae	Unknown	Non-Native
Lepidoptera	Tortricidae	*Cydia unknown*	Non-Native & Native
Lepidoptera	Unknown	*Unknown*	Non-Native & Native
Odonata	Anisoptera	Unknown	Non-Native & Native
Psocoptera	Unknown	Unknown	Non-Native & Native
Thysanoptera	Thripidae	Unknown	Non-Native & Native

172				
173	Stylommatophora	Vitrinidae	*Vitrina tenella*	Native

References

Matsunaga, J. N., Howarth, F. G., & Kumashiro, B. R. (2019). New state records and additions to the alien terrestrial arthropod fauna in the Hawaiian Islands. *Proceedings of the Hawaiian Entomological Society*, 51, 1-71.

Nishida, G. M. (2002). Hawaiian terrestrial arthropod checklist 4th ed. *Honolulu, Hawai'i: Hawai'i Biological Survey (Bishop Museum) Technical Report, 22.*

Appendix I: Rapid Response Report for Little fire ant (*Wasmannia auropunctata*) from 2016 and 2020 Rapid Response Narrative Report

Introduction and Distribution of *Wasmannia auropunctata* on Maunakea, Hawaii- Report – 2016

Prepared by D. Yogi

Introduction

On May 16, 2016 *Wasmannia auropunctata* (little fire ant), an invasive tramp ant, was discovered in a Halepōhaku kitchen HoyHoy trap on Maunakea, Hawaiʻi by Office of Maunakea Management (OMKM) staff Darcy Yogi. A single *W. auropunctata* specimen was observed in a sticky HoyHoy trap that was deployed for a month in the kitchen storage room.

Figure 38. HoyHoy trap with a tiny little fire ant detected in the upper right hand corner.

The Halepōhaku area has been surveyed at least annually for invasive species since 2007 initially by the Bishop Museum, and starting in 2012 by OMKM staff. Currently, the only other known ant populations within UH managed lands of Maunakea are isolated *Cardiocondyla kagutsuchi* populations along the road corridor shoulder up to Halepōhaku and the lower Halepōhaku parking lots (up to 9300') (Unpub. OMKM *C. kagutsuchi* Delimiting Survey, 2013). This is the first time *W. auropunctata* has been detected within UH managed lands on Maunakea with no previous evidence in any OMKM survey, external research, or literature review (Peck & Banko, 2011; Unpub. OMKM *C. kagutsuchi* Delimiting Survey, 2013; Wetterer et al., 1998; Conant et al., 2007).

Rapid Response is the process of reacting to a new, recent, not previously detected invasive species. Goals in this process include: identifying known life-history information, determining the species' threat level, delineating spatial extent of invasion, and implementing site-specific management recommendations. OMKM initiates rapid response procedures and reports as outlined in the Maunakea Invasive Species Management Plan (ISMP) (Vanderwoude et al., 2015).

Life History

The little fire ant (LFA) (*Wasmannia auropunctata*) is a major tramp ant pest species. LFA are native to the American Neotropical lowland forests, but have since spread globally via transportation routes (Wetterer & Porter, 2003). LFA were first detected in Puna, Hawaiʻi in 1999 (Conant & Hirayama, 2000) although it was previously intercepted by quarantine inspectors from the early 1900s (Swezey, 1945). They are known for their painful sting even though the ants are mildly aggressive (Creighton, 1950). These generalist foragers will tend honeydew-producing insects, which make them a further agricultural pest (Clark et al., 1982; Torres, 1984). LFA can feed at all times and work well together in large numbers for foraging (Meier, 1994; Clark et al., 1982). Worker ants are very aggressive towards other ant species and have the ability to dominate large areas in its non-native range (Brandao & Paiva, 1994; Way & Bolton, 1997; Delsinne et al., 2001). *W.*

auropunctata is known to be an arboreal species in its native range, but it can also populate leaf litter, under rocks, within crevices, inside of organic materials, etc. (Motoki et al., 2013). They have a preference for warm, moist, and shady areas (Motoki et al., 2013). LFA are also readily mobile to move to better or recently available nesting sites (Motoki et al., 2013).

Little fire ant colonies have high densities with multiple queens (polygyny) and low intraspecific aggression (Wetterer & Porter, 2003; Passera, 1994). Their nests are not highly structured, which allow them to populate just about anything (Spencer, 1941). LFA populations can reach upwards of 20,000 individuals per square meter and queen density can be upwards of 75 queens per square meter (Souza et al., 2008, Ulloa-Chacon & Cherix, 1990). LFA are pests within most any anthropogenic environment due to their painful stings and control efforts are very expensive (Motoki et al., 2013). However, being a species native to low elevation tropical forests, its ability to survive at colder, drier high-elevations is uncertain. In conclusion, this ant is an incredibly invasive ant species due to the following characteristics: polygyny, multiple inter-connected nests, high interspecific aggression, use of human commerce for relocation, and mutualistic relationships with other pest insects (Motoki et al., 2013).

Identification

Wasmannia auropunctata is a very small ant (~1.5 mm) with a uniform yellow-gold color. There are two nodes between the thorax and abdomen. The first node (petiole) is hatchet-like, while the second node (postpetiole) is lower and smaller. The antennae have 11 segments with the last two segments being enlarged (2-segmented antennal club). There is an antenna scrobe that extends from the antenna base to the posterior of the head. The propodeum has a pair of slightly incurved long spines that can almost reach the first node. The body is covered with sporadic long, erect hairs (Wetterer & Porter, 2003; Wheeler et al., 1915; Brooks & Nickerson, 2014).

Food & Bait Preferences

W. auropunctata are attracted to fats and oils, which is why they are a common household pest (Deyrup et al., 2000). They are also attracted to dirty and sweaty clothing, but do not prefer sugary foods (Fernald, 1947; Naumann, 1994). Their usual non-anthropogenic food sources can range from plant tissue, seeds, invertebrates, and Homopteran honeydew (Clark et al., 1982). Typical baits used for little fire ant treatment include *Siesta™* (Metaflumizone), *Amdro®* (Hydramethylnon), *Probait®* (Hydramethylnon), *Maxforce Complete®* (Hydramethylnon), and *Tango*™ (S-methoprene) (HAL, 2014). All five baits have been proven effective by the Hawaiʻi Ant Lab and are similar except for *Tango*™, which is used for liquid baits unlike the other four granular type baits (HAL, 2014).

Threat

The Office of Maunakea Management is concerned with the finding of *W. auropunctata* because it is a highly invasive tramp ant species (ISSG, 2006) with high interspecific aggression towards other arthropod species and lower intraspecific aggression allowing them to rapidly and effectively colonize new habitats (Kirschenbaum & Grace, 2007). Their presence can severely reduce biodiversity, disrupt natural communities, and change ecosystem processes (Leathers, 2016). They are not believed to be able to survive outside of facility (building) moderated environment at the Halepōhaku or upper elevation areas on Maunakea (Vanderwoude, 2016 pers comm.).

Initial Detection

Figure 39. Location of *Wasmannia auropunctata* at Halepōhaku.

On May 16, 2016 a single ant was detected inside of a sticky HoyHoy trap from the Halepōhaku kitchen. This trap was a part of OMKM's monthly arthropod facility monitoring efforts. This trap was placed in mid-April and baited with peanut butter, jelly, and spam. This trap (OMKM site ID: HP03) was placed in the kitchen storage room in between the shelf and the baseboard, such that the trap was perpendicular to the floor. The ant was the only specimen present on the trap when retrieved. The ant species was confirmed to be *Wasmannia auropunctata* (little fire ant) by Cas Vanderwoude at the Hawaiʻi Ant Lab on May 17th. Further response and control recommendations were sought from Dr. Cas Vanderwoude (Hawaiʻi Ant Lab), Dr. Jesse Eiben (UH Hilo), and Cynthia King (Dept. Land and Natural Resources).

Initial Detection Notification & Recommendations

OMKM notified the Department of Land and Natural Resources, Hawaiʻi Ant Lab, Mauna Kea Support Services (MKSS) managers, and relevant entomologists within 12 hours of the initial detection. The emergency response committee was not required for this event in order to avoid unnecessarily raising concerns and given the minimal likelihood of colony establishment in this environment. However if additional specimens are detected, then the situation would have to be reevaluated. OMKM recommended that MKSS staff not rearrange any supplies to clean prior to the completion of a delimiting survey in order to prevent the relocation of any potential ant colonies. Ant colony relocation would make it increasingly difficult to detect, monitor, and control any potential invasions by LFA. Nonetheless, proper sanitation was still expected.

Delimiting Survey

On May 17th, a delimiting survey was conducted inside and outside of the HP kitchen area using peanut butter baited vials. A total of 20 baited vials were placed on the ground all around the kitchen and cafeteria areas. The vials were left out for an hour and checked mid-way. No ants or other new threats were detected during this survey effort. On June 2nd, a second delimiting survey was conducted around the HP kitchen. This was to ensure that we did not miss anything from the first survey. The same methods were used, except baited vials were left out for 3 hours instead of 1 hour. No ants or other new threats were detected during this second survey effort.

Delimiting Survey Locations

The survey locations included the Halepōhaku kitchen, cafeteria, and just outside of the kitchen (Figure 40). All baited vials were placed on the ground in areas that may foster alien arthropods such as areas with stored goods, food waste, trash, and moisture. Traps were also placed outside to make sure any potential ant colonies were not moving outside where there is ongoing trash hauling and foot traffic.

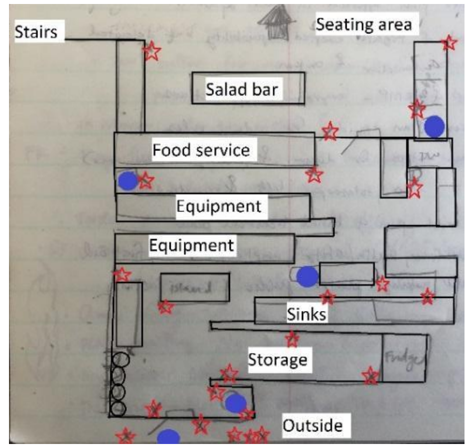

Figure 40. Delimiting survey locations at Halepōhaku. Red stars represent baited vial locations and blue dots show sources of trash.

Management Recommendations

Initial Control Recommendations

Control recommendations consisted of a regular heightened pest treatment regimen. After the completion of two delimiting surveys (2 weeks apart), interior baiting would be done inside of the kitchen area. As long as it is consistent with label restrictions, MKSS will place bait stations with *Maxforce Complete*® in the kitchen storage room and surrounding areas. It was also recommended that an exterior barrier treatment also be employed. As long as it is consistent with label restrictions, Ortho Home Defense Max ® (liquid) would be sprayed around sidewalks, foundation cracks, and other cavities within built structures (not on soil, cinder, vegetation, etc.). This barrier treatment is already used by MKSS in other areas and it would prevent any arthropod movement for the next three months.

Long-term Eradication & Monitoring Recommendations

MKSS ensured that their Terminix exterminator knew about the detection of LFA within their kitchen and Terminix treated interior facility areas within one-week of the initial detection report. MKSS plans on expanding their target pest species beyond German cockroaches (*Blattella germanica*) to include the control of ants. This would mean the expanded use of LAMDA-CYHALOTHRIN 0.015%. Additionally, MKSS requires vendor contracts to identify their pest control and prevention plan as a qualification requirement (see Maunakea Invasive Species Management Plan for details).

Table 20. Activity timeline for the rapid response of *W. auropunctata* in 2016.

Activity Type[13]	Lead	Date(s)	Location[14]	Ants obs?	Ant species observed
Facility Monitoring- Traps	OMKM	4/13 – 5/16/2016	Halepōhaku	Yes	*W. auropunctata*
Delimiting Surveys I	OMKM	5/17/2016	Halepōhaku	No	NA
Facility Monitoring – Traps	OMKM	5/23/2016	Halepōhaku	No	NA
Quarterly Facility Monitoring – Traps	OMKM	5/31/2016	Halepōhaku & MKSR	No	NA
Delimiting Surveys II	OMKM	6/2/2016	Halepōhaku	No	NA
Ant baiting	OMKM	6/17-7/19/2016	Halepōhaku	No	NA
Quarterly Facility Monitoring – Perimeter Searches	OMKM	6/7-6/14/2016	Halepōhaku & MKSR	No	NA

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Little Fire Ant (*Wasmannia auropunctata*)
Rapid Response Narrative Report – 2020

Prepared by OMKM Staff

December 2020

It was brought to the attention of OMKM's conservation specialist, Jessica Kirkpatrick, that a 300-gallon IBC water container had been brought up to the greenhouse at the Halepōhaku facility without inspection.

12/3/2020

Weather: Sunny, warm

11:00am –Inspection was conducted on site as soon as possible, at which time several live Little Fire Ants (*Wasmania auropunctata*) were found both inside the lower frame of the container and on the ground where it had been sitting. Raid was sprayed heavily around the base of the container and on the ground where it had been sitting. Amdro ant bait was also spread on the ground in the area.

2:30pm – A check of the container and ground revealed a pile of dead LFA on the ground and a few live ones in the frame of the container. Raid was applied liberally to the container again and the container left on its side to discourage the ants from exiting the frame.

12/8/2020

Weather: Sunny, cool, breezy

10:30am - 11 index cards baited with peanut butter were set out around water tank (6) and in the area where water tank had previously been stationed (5); no ants were observed in either area

12:15pm – Bait cards were checked; no ants observed on cards or in the area.

2:45pm – Bait cards collected; no ants observed on cards or in the area.

12/11/2020

Weather: Sunny, cool, breezy

10:30am - 12 index cards baited with peanut butter were set out around water tank (6) and in the area where the water tank had previously been stationed (6); no ants were observed in either area.

12:25pm – Bait cards were checked; no ants observed on cards or in the area.

2:30pm – Bait cards collected; no ants observed on cards or in the area.

12/22/2020

Weather: Sunny, cool, very light breeze

9:15am - 10 index cards baited with peanut butter were set out around water tank (5) and in the area where water tank had previously been stationed (5); no ants were observed in either area. The water tank is full and some water is present around the spigot.

1:30pm – Bait cards were checked; no ants observed on cards or in the area.

3:20pm – Bait cards collected; no ants observed on cards or in the area.

January 2021

01/05/2021

Weather: Sunny, warm, light breeze

11:00 am - 10 index cards baited with peanut butter were set out around water tank (5) and in the area where water tank had previously been stationed (5); no ants were observed in either area (about 7 *Apis mellifera* were observed near the water spigot, which is leaking slightly)

1:30pm – Bait cards collected; no ants observed on cards or in the area. (about 15 *Apis mellifora* (European honeybees) were observed near the water spigot, which was leaking slightly)

01/13/2021

9:35am - 8 index cards baited with peanut butter were set out around water tank (4) and in the area where water tank had previously been stationed (4); no ants were observed in either area (about 5 *A. mellifera* were observed near the water spigot, which is leaking a bit more than before). Weather: cold, partly sunny, low clouds, breezy with occasional gusts

11:40am – Bait cards checked; no ants observed. About 15 *A. mellifera* observed. Weather: cool, sunny, breezy

12:15pm – Bait cards collected; no ants observed on cards or in the area. About 15 *A. mellifera* were observed. Weather: sunny, breezy, cool

Appendix J: Rapid Response Reports for Carpenter Ant (*Camponotus variegatus*) from 2016 and 2019

Introduction and Distribution of *Camponotus* spp. on Maunakea, Hawaiʻi- Report – 2016

Prepared by D. Yogi

Introduction

On November 26th, a single carpenter ant (*Camponotus* spp.), a pest in Hawaiʻi, was discovered on the sales counter of the Visitor Information Station (VIS) on Maunakea, Hawaiʻi in the early evening peak visitor time by VIS staff Kelly Whelan. The single specimen was observed inside of the VIS at night during stargazing activities. For this report we will be using the most likely species identification, *Camponotus variegatus,* made by the Hawaiʻi Ant Lab (HAL). The specimen could not be confidently identified to species. However, *C. variegatus* is the only species within the genus *Camponotus* that has been confirmed in Hawaiʻi. Nonetheless, other species may have been inadvertently introduced without official confirmation.

The Halepōhaku area has been surveyed at least annually for invasive species since 2007 initially by the Bishop Museum, and starting in 2012 by OMKM staff. Currently, the only other known ant populations within UH managed lands of Maunakea are isolated *Cardiocondyla kagutsuchi* populations along the road corridor shoulder up to Halepōhaku and the lower Halepōhaku parking lots (up to 9300') (Unpub. OMKM *C. kagutsuchi* Delimiting Survey, 2013). This is the first time *Camponotus* spp. has been detected within UH managed lands on Maunakea with no previous evidence in any OMKM survey, external research, or literature review (Peck & Banko, 2011; Unpub. OMKM *C. kagutsuchi* Delimiting Survey, 2013; Wetterer et al., 1998; Conant et al., 2007).

Rapid Response is the process of reacting to a new, recent, not previously detected invasive species. Goals in this process include: identifying known life-history information, determining the species' threat level, delineating spatial extent of invasion, and implementing site-specific management recommendations. OMKM initiates rapid response procedures and reports as outlined in the Maunakea Invasive Species Management Plan (ISMP) (Vanderwoude et al., 2015).

Life History

The carpenter ant (Figure 41), *Camponotus variegatus*, is an infrastructure pest ant species in Hawaiʻi. This species is most likely native to Southeast Asia (Wilson & Taylor, 1967). Carpenter ants have been reported in Hawaiʻi since 1899 and are now present on all major Hawaiian Islands as well as some of the Northwestern Hawaiian Islands (Forel, 1899; Wheeler, 1934). In fact, this species is noted as one of the pioneering ant species in Hawaiʻi (Smith, 1879). They typically occur at lower elevation dry and mesic areas below 500 m (Reimer, 1994). Unlike most ants in Hawaiʻi, this species is nocturnal making it difficult for survey detection as they can forage until midnight or later (Jones, 2011; Reimer, 1994; Yates, 1992).

Figure 41. *Camponotus variegatus* these ants are much larger than the usual ants one may see around the home. (Source: Antbase.net)

This ant species produces smaller colonies, usually around 100 workers and soldiers with a single queen per colony (Kirschenbaum & Grace, 2008). Colonies tend to establish in rotting or termite-damaged wood, but it does not consume wood like termites (Yates, 1992). Indoors, carpenter ants will take advantage of hollow wooden areas such as within hollow-core doors, solid foam insulation, double walls, door and window frames, etc. (Yates, 1992; Jones, 2011). Outdoors, carpenter ant nests are associated with moisture such as tree stumps, termite-damaged wood, wood near skylights, and rotting wood (Yates, 1992; Jones, 2011). Observing six or more foragers indoors is an indication of an active carpenter ant nest somewhere indoors (Yates, 1992). Carpenter ants will travel along well-established trails and may forage as far as 100 feet from their nests (Jones, 2011). Trails can extend through lawns, over wires, across branches and vines, etc. (Jones, 2011). These nests may be identifiable by a dry rustling sound from chewing activity within the nest as well as through observation of sawdust-like piles (Jones, 2011).

Carpenter ants can deliver painful bites along with formic acid injections, but they do not have a stinger (Jones, 2011). Winged swarmers will typically emerge in the spring and summer in order to mate establish new colonies (Jones, 2011). Newly emergent workers will collect food, tend to new eggs, and enlarge the nest (Jones, 2011). Once the nest is established, workers are produced of various sizes in the caste system and worker size will determine primary duties such as larvae tending, nest protection, and foraging (Jones, 2011). The original parent nest will contain the queen, eggs, and young larvae, while satellite nests will contain workers and brood (Jones, 2011). From egg to adult, it takes 70 days to complete maturity (Yates, 1992). Carpenter ant colonies are slow growing. Within the anthropogenic environment these ants carry negative impacts as they bite, damage infrastructure, contaminate stored goods, and present a general nuisance indoors. There is not much information on the ecological impacts of carpenter ants in a non-native environment, but there are no native ants to Hawaiʻi. Therefore, any ant colonization will result in competition of resources with native arthropods as well as potential native arthropod population reduction (Krushelnycky et al., 2005).

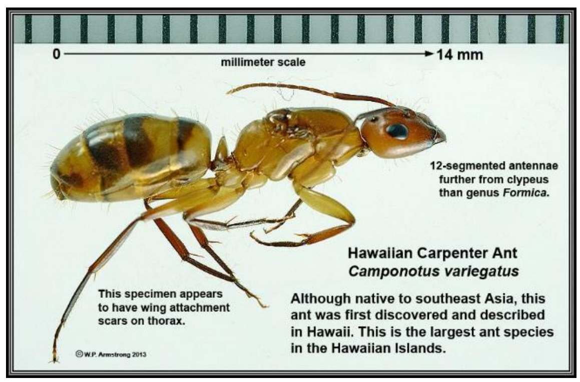

Figure 42. Key characteristics of *C. variegatus* shows its large size and distinctive brown variegation on the thorax. (Source: Armstrong, 2013).

Identification

This carpenter ant species can measure anywhere from 5.0-12.7 mm and are typically yellowish with dark brown stripes on the top of the abdomen (AntWeb, 2016). Ant size varies as the worker caste is polymorphic (AntWeb, 2016). They have 12 segmented antennae with indistinct antennae clubs (AntWeb, 2016). The head will be longer than it is wide and it will not have distinct ocelli (AntWeb, 2016). The waist is 1-segmented and short thin hairs are sparse on the head and mesosoma (AntWeb, 2016). Carpenter ants, in general, have an evenly rounded and arched thorax with only one petiole node between the thorax and abdomen (Jones, 2011). They can look similar to the winged adults of West Indian dry-wood termites and Formosan subterranean termites when the carpenter ants are winged (Yates, 1992).

Food & Bait Preferences

Carpenter ants are generalist foragers as they feed on insects, aphid honeydew, meats, grease, fruits, etc. (Jones, 2011). Due to their nocturnal nature, numerous foragers will come out after sunset in order to obtain food for larvae within the nest (Jones, 2011). Carbohydrates feed the worker caste, but the preferred food is aphid honeydew, which is why carpenter ants are drawn to areas of high aphid infestation (Jones, 2011). Food preference may shift based on the life cycle of the nest as larvae require more protein-based foods (Jones, 2011). The Hawaiʻi Ant Lab did not have any recommended baits for carpenter ants. However, *Maxforce Complete* (Hydramethylnon) is said to work on carpenter ants.

Threat

The Office of Maunakea Management is concerned with the finding of *C. variegatus* because it is within the targeted ant family of Formicidae. All ants compete for resources with native insects and they can be aggressive to native insects. However, carpenter ants are not seen as highly invasive within the guidelines of the Maunakea Invasive Species Management Plan. These ants are monogynous, disperse by flight, do not maintain a high inter-specific aggression, and do not form supercolonies (Jones, 2011, Kirschenbaum & Grace, 2005; Yates, 1992; Vanderwoude et al., 2015). The only invasive characteristic present is mutualisms with Homopterans, which can fuel the colony for further expansion and dominance (Jones, 2011; Yates, 1992; Vanderwoude et al., 2015). Nonetheless, carpenter ants are not believed to be able to survive outside of facility (building) moderated environment at the Halepōhaku or upper elevation areas on Maunakea as this ant requires regularly moist nesting areas (Jones, 2011; Yates, 1992).

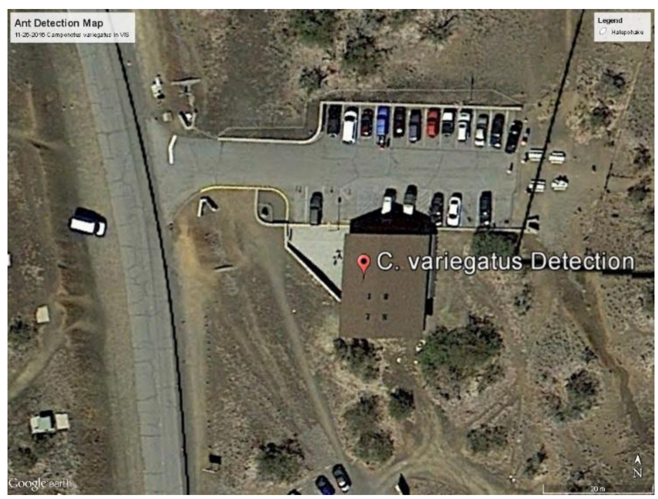

Figure 43. The carpenter ant specimen was detected within the Visitor Information Station where there is a high volume of visitor and vehicle activity.

Initial Detection

On Saturday, November 26, 2016 Visitor Information Station (VIS) staff member Kelly Whelan observed and collected a single ant specimen inside the VIS building on the sales desk during the early evening hours (between 5-7pm) of peak visitation (Figure 43). OMKM was notified the evening of Saturday, November 26th and the specimen was collected on Tuesday November 29th. On Wednesday, November 30th Hawaiʻi Ant Lab staff Michelle Montgomery identified the specimen as *Camponotus* spp., most likely *Camponotus variegatus*. The Hawaiʻi Ant Lab provided some initial information about this species identifying it as a structural pest and relatively low risk to the environment as this species would be limited to buildings, produce smaller colonies, and are not known to present a substantial ecological risk in ecosystems found at Halepōhaku or above. Additionally, no baiting or control methods were recommended by the Hawaiʻi Ant Lab at this time.

Initial Detection Notification & Recommendations

OMKM was notified the night of detection (Nov. 26, 2016 at 7:00pm) by the VIS manager, Joe McDonough via e-mail. OMKM then notified Dept. of Land and Natural Resources entomologist Cynthia King and Mauna Kea Support Services manager Stewart Hunter right after the specimen was identified on Wednesday November 30th. Once all information was gathered, the rest of the Emergency Response Management Committee (ERMC) was notified on Monday, December 5th. OMKM recommended that the VIS staff collect the specimen and place it in the fridge until it could be picked up and identified the following Monday. No other recommendations were provided to VIS staff for prevention purposes other than to remain alert for any other *C. variegatus* individuals.

Delimiting Survey

A delimiting survey and quarterly perimeter surveys around the VIS were conducted on December 7th. The VIS parking lot and exterior were surveyed for routine quarterly perimeter surveys. Further assessments of the VIS exterior and interior were done for delimiting survey purposes. A total of 40 peanut butter, jelly, and spam vials were deployed (20 for quarterly surveys and 20 for delimiting surveys) for one hour. While vials were deployed, OMKM staff member Darcy Yogi conducted visual and hand searches outside and within the VIS. All vials and searching efforts presented a negative result for *C. variegatus* presence.

Delimiting Survey Locations

The survey locations included the VIS parking lot, exterior, and interior (Figure 44). All baited vials were placed on the ground in areas that may foster alien arthropods such as areas near stored goods, food waste, trash, and moisture. Vials were placed outside of the facility to ensure any potential ant colonies or individuals were not moving outside where there is high volumes of both vehicular and foot traffic from visitor activity.

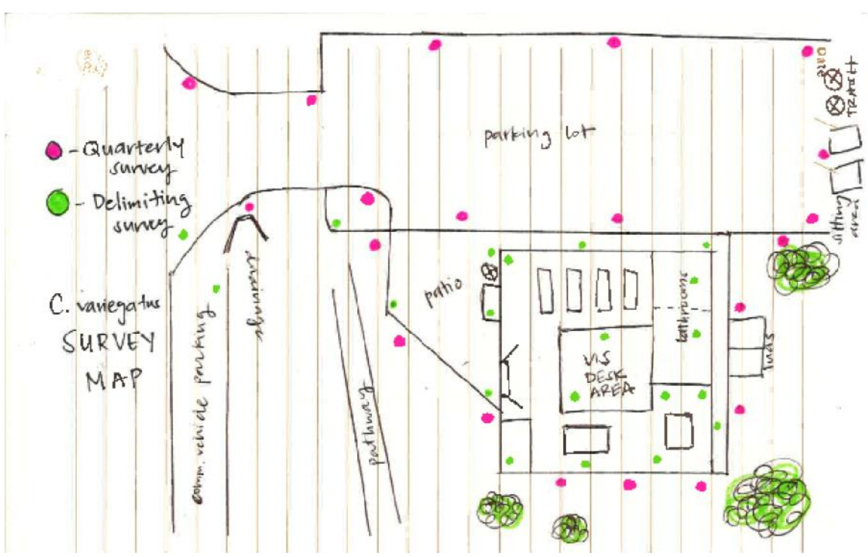

Figure 44. Map of extensive delimiting survey efforts around and inside of the VIS. Purple points are for routine quarterly surveys and green points are specifically for delimiting surveys.

MANAGEMENT RECOMMENDATIONS

Initial Control Recommendations

Control recommendations consisted of delimiting surveys, interior trapping efforts, and interior baiting efforts. Consistent with label restrictions, OMKM placed six bait stations with *Maxforce Complete*® around the interior of the Visitor Information Station (VIS). Trapping efforts consisted of six *Hoy Trap-A-Roach* sticky traps baited with peanut butter, jelly, and spam. Five traps were placed inside of the VIS and one was placed outside of the front doors of the VIS. As no nest was successfully found, trapping and baiting efforts should account for night foraging of this species and potential trails that may be present within the VIS. Interior trapping and baiting efforts continued for a week. Delimiting surveys were conducted both inside and outside of the VIS using peanut butter, jelly, and spam baited vials.

Long-term Eradication & Monitoring Recommendations

Long-term recommendations will be to continue quarterly facility monitoring of the VIS region. If any new specimens are observed, then this section may be updated.

Table 21. Activity timeline for the rapid response of *Camponotus variegatus* in 2016.

Activity Type[15]	Lead	Date(s)	Location[16]	Ants obs?	Ant species observed
Quarterly Facility Monitoring – Traps	OMKM	11/22- 11/29/2016	MKSR and HP	No	NA
Trapping and baiting	OMKM	12/1- 12/7/2016	VIS	No	NA
Initial Indoor Survey I	OMKM	12/1/2016	VIS	No	NA
Delimiting Surveys	OMKM	12/7/2016	VIS	No	NA
Quarterly Facility Monitoring – Perimeter Surveys	OMKM	12/1- 12/20/2016	MKSR and HP	No	NA

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[15] Activity methods can be viewed upon request. OMKM facility monitoring procedures can be found on the OMKM website.

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Detection of *Camponotus variegatus* on Maunakea, Hawaiʻi Rapid Response Report – 2019
Prepared by J. Kirkpatrick

Introduction

On June 19th, a single carpenter ant (*Camponotus variegatus*) queen was discovered at the original entrance of the Visitor Information Station (VIS) in the Department of Transportation Right-of-Way on Maunakea, Hawaiʻi. The single queen specimen was observed around 2:30pm while replacing traffic cones after the placement of quarterly invasive species monitoring facility traps in the VIS. The ant was observed on the asphalt by Office of Maunakea Management (OMKM) intern T. Quinories and was found alive but moving slowly. After a quick hand search of the area, no other ants were found. The ant was identified as a reproductive carpenter ant queen by the Hawaiʻi Ant Lab (HAL) on June 20th, and it was determined that she had detached her wings. Generally, ant queens will detach their wings after they have mated and found a suitable area to start a colony. This species of ant was found once before on University of Hawaiʻi (UH) managed land. A single worker ant was observed on the VIS sales counter on November 26th, 2016. Rapid response surveys at the time found no other individuals leading us to suspect the detection was an isolated incident. Given that this ant species was now found twice in the same relative area, we hypothesize that a small colony of carpenter ants may persist somewhere near the VIS.

Interestingly, OMKM completed their annual arthropod monitoring surveys at Halepōhaku and the VIS just a few days prior to this detection (June 14th – June 17th) and no ants were found, even at the trap site that was ~10 m from the location where the queen ant was detected. OMKM's annual arthropod monitoring includes various trap types designed to target specific groups of arthropods (i.e. wasps, flies, ants); the peanut butter, jelly, and spam sticks target ants. *C. variegatus* feed on honey dew, meat, and fat, so the OMKM trapping effort should have attracted the species if they were actively foraging in that area. Additionally, OMKM's invasive species facility traps that are placed quarterly, did not detect *C. variegatus* in traps that were placed on June 19th and retrieved on June 26th.

Recently (January-June, 2019), the VIS parking lot was enlarged and about half of the asphalt in the original VIS parking lot was demolished, removed, and repaved. Discussion with the Hawaiʻi Ant Lab stated that this ant species can be found under old asphalt. It's possible that the construction activity in the parking lot disturbed the colony, causing the queen to find a new place to settle. Or this may not be the case at all, as ant queens swarm in summer months in Hawaiʻi, and could have swarmed from neighboring or even more distant lands.

The Halepōhaku area (includes the VIS) has been surveyed at least annually for invasive species since 2007 initially by the Bishop Museum, and starting in 2013 by OMKM staff. Currently, the only known resident ant populations within UH managed lands of Maunakea are isolated *Cardiocondyla kagutsuchi* populations along the road corridor shoulder up to Halepōhaku and the lower Halepōhaku parking lots (up to 9300') (Unpub. OMKM *C. kagutsuchi* Delimiting Survey, 2013).

Rapid response is the process of reacting to a new, recent, not previously detected invasive species. Although *C. variegatus* was detected back in 2016, rapid response procedures were again initiated because this individual was a queen, and given that this species was detected once before it's possible that a colony exists in the area. OMKM initiates rapid response procedures and reports as outlined in the Maunakea Invasive Species Management Plan (ISMP) (Vanderwoude et al., 2015).

Life History

This section has been updated from the initial detection report of *Camponotus* in 2016. The carpenter ant, *Camponotus variegatus* is most likely native to Southeast Asia (Wilson & Taylor, 1967). In Hawaiʻi, the species does not feed on wood as its mainland counterparts do (Tenorio & Nishida, 1995). They instead use existing tunnels and holes, causing little to no damage to wood structures. Carpenter ants have been reported in Hawaiʻi since 1899 and are now present on all major Hawaiian Islands as well as on some of the Northwestern Hawaiian Islands (Forel, 1899; Wheeler, 1934). They typically occur at lower elevations in dry and mesic areas below 500 m (Reimer, 1994). Unlike most ants in Hawaiʻi, this species is nocturnal and forages at midnight or later; this behavior makes the species difficult to detect (Jones, 2017; Reimer, 1994; Yates, 1992).

C.variegatus produces small colonies with about 100 (up to 3,000) workers and soldiers and a single queen per colony (Tenorio & Nishida, 1995; Kirschenbaum & Grace, 2008). These ants typically construct two types of nests; a parent nest that houses the queen, eggs and small larvae, and one or more satellite nests that house larger larvae and pupae (Jones, 2017). Parent nests are often associated with moisture and satellite nests are usually placed in drier areas with higher temperatures that enhance development (Jones, 2017). There may be several satellite nests in or around a structure (Jones, 2017). Colonies tend to establish in wood hollowed out by other insects, dead trees, and in any other natural or artificial space that it finds suitable (Tenorio & Nishida, 1995). They may enlarge existing holes and hollowed spaces but do not consume wood (Yates, 1992; Tenorio & Nishida, 1995). Carpenter ants nest both inside and outside of homes and buildings. Inside the home, ants may nest in hollow-core doors, pianos, wall clocks, double walls, door and window frames, etc. (Yates, 1992; Tenorio & Nishida 1995; Jones, 2017). Observing six or more carpenter ant individuals indoors is an indication of an active colony (Yates, 1992). Outside the home, carpenter ants may nest in tree stumps, rotting wood, termite-damaged wood, and wood near skylights (Yates, 1992; Jones, 2017). Foraging workers may be found on plants infested with plant-sucking insects (Jones, 2017). Carpenter ant workers may forage as far as 100 feet from their nests traveling along established trails between feeding sites and nest sites; this includes travel between satellite nests and parent nests (Jones, 2017). Trails can extend through lawns, over wires, across branches and vines, tree trunks, etc. (Jones, 2017). Carpenter ant nests may be identifiable by a dry rustling sound from chewing activity within the nest and through observation of sawdust-like piles (Jones, 2017).

Carpenter ants do not have a stinger, but they deliver painful bites and can inject formic acid into wounds (Jones, 2017). In Hawaiʻi, reproductive (winged) carpenter ants will typically swarm in the summer months to find a new place to establish a colony (Tenorio & Nishida, 1995). Once a new place is found, she seals herself in a small cavity and lays between 15 and 20 eggs (Tenorio & Nishida, 1995). The new young are fed with body fat stored by the queen until they are mature enough to care for the next brood (Tenorio & Nishida, 1995). Thereafter, she becomes an egg-laying machine and once the nest is established, workers of various sizes are produced and take on different duties in the colony such as larvae tending, nest defense, and foraging (Tenorio & Nishida, 1995; Jones, 2017). Carpenter ant colonies are slow growing compared to other species of ants. It takes about 2 ½ months for eggs to mature into new adult workers and after 3-6 years the colony may have up to 3,000 workers with one egg laying queen (Tenorio & Nishida, 1995). Around this time, more winged reproductive individuals are produced and the cycle of swarming and building colonies is repeated (Tenorio & Nishida, 1995). Within the anthropogenic environment these ants have negative impacts as they bite, may feed on foods in your home, and present a general nuisance indoors. There is not much information on the ecological impacts of carpenter ants in a non-native environment, but there are no native ants to Hawaiʻi. Therefore, any ant colonization will result in competition of resources with native arthropods and may cause a reduction in native arthropod populations (Krushelnycky et al., 2005).

Identification

C.variegatus is the largest ant in Hawaiʻi (Tenorio & Nishida, 1995), measuring from 5.0 to 12.7 mm (3/8- ½ in.); size is dependent on worker caste (AntWeb, 2016). They are typically yellowish with dark brown stripes on the top of the abdomen and have 12 segmented antennae with indistinct antennae clubs (AntWeb, 2016). The head will be longer than it is wide and workers will not have distinct ocelli (AntWeb, 2016). The waist is 1-segmented and short thin hairs are sparse on the head and mesosoma (AntWeb, 2016). Carpenter ants, in general, have an evenly rounded and arched thorax with only one petiole node between the thorax and abdomen (Jones, 2017). When carpenter ants are winged (reproductive individuals), they can look similar to adult termites (Yates, 1992; Tenorio & Nishida, 1995).

Food & Bait Preferences

Carpenter ants in Hawaiʻi are generalist foragers as they feed on insects, aphid honeydew, meats, grease, fruits, and fat (Tenorio & Nishida, 1995; Jones, 2017). Due to their nocturnal nature, numerous foragers will come out after sunset in order to obtain food for larvae within the nest (Jones, 2017). Carbohydrates feed the worker caste, but the preferred food is aphid honeydew, which is why carpenter ants are drawn to areas of high aphid infestation (Jones, 2017). Food preference may shift based on the life cycle of the nest as larvae require more protein-based foods (Jones, 2017). The Hawaiʻi Ant Lab did not have a bait recommendation for carpenter ants, however they suggested that ants be surveyed in early morning or the late afternoon. Pesticide formulations with Dursban or Diazinon can be used on nests outside of the home and Resmethrin can be used to treat nests inside the home (Tenorio & Nishida, 1995). The pesticide *Maxforce Complete* (Hydramethylnon) is said to work on carpenter ants as well.

Threat

The Office of Maunakea Management is concerned with the finding of *C. variegatus* because the entire group (Family) Formicidae are considered to be threats to the environment, as identified in the Maunakea Invasive Species Management Plan (ISMP). All ants compete for resources with native insects and they can be aggressive to native insects. However, carpenter ants are not identified as highly invasive within the guidelines of the ISMP (Vanderwoude et al., 2015). These ants are monogynous, disperse by flight, do not maintain a high interspecific aggression, and do not form supercolonies (Jones, 2017, Kirschenbaum & Grace, 2005; Yates, 1992; Vanderwoude et al., 2015). The only invasive characteristic present is mutualisms with plant-sucking insects

(Homoptera), which can fuel the colony for further expansion and dominance (Jones, 2017; Yates, 1992; Vanderwoude et al., 2015). Although it seems unlikely that carpenter ants can survive at Halepōhaku or at upper elevation areas on Maunakea, this was the second detection of the species at the VIS, leading us to suspect that a colony is established in that area. Even though parent nests are usually associated with moist areas, satellite nests are found in dry areas (Jones, 2017; Yates, 1992). It's possible that there is a satellite nest around the VIS, however a parent nest must also exist to keep the satellite nest alive.

Detection

On Wednesday, June 19, 2019 OMKM intern Taylor Quinories observed and collected a single ant specimen at the original VIS entrance in the Department of Transportation Right-of-Way around 2:30pm (Figure 45). On Thursday, June 20th Hawai'i Ant Lab staff Ersel Hensley identified the specimen as *Camponotus variegatus*. The Hawai'i Ant Lab provided some initial information about this species identifying it as a pest that is relatively low risk to the environment as this species would be limited to buildings, produce small colonies, and are not known to present a substantial ecological risk in ecosystems found at Halepōhaku or above. They also stated that the species is sometimes found under or near old asphalt. *Camponotus variegatus* was first detected in 2016 on the VIS sales counter (Figure 45).

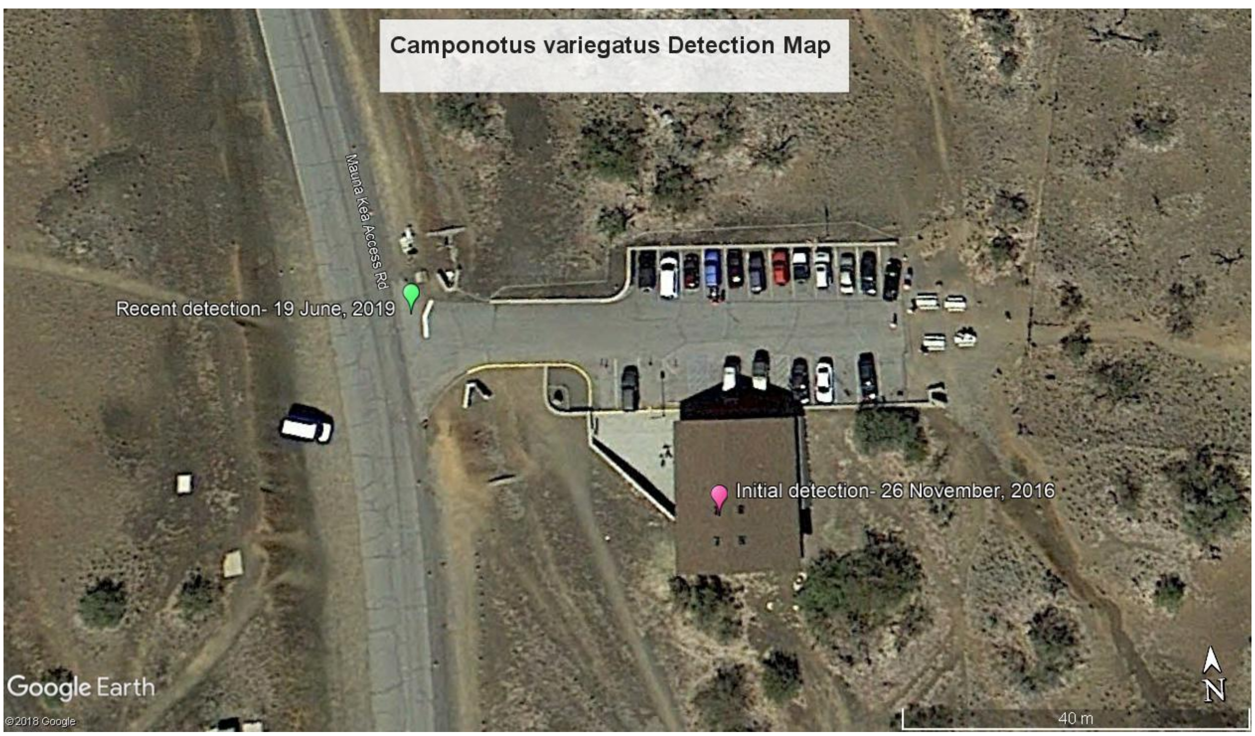

Figure 45. A *C. variegatus* worker was detected in the Visitor Information Station in 2016 and a *C. variegatus* queen was just recently (June 2019) detected in the original VIS entrance in the DOT right-of-way. This area contains high volumes of visitor and vehicle activity.

Detection Notification & Recommendations

OMKM was on site during the ant detection on June 19th, 2019 and the specimen was identified on June 20th. OMKM notified the Department of Land and Natural Resources entomologist Cynthia King via phone call on June 20th and the Emergency Response Management Committee (Vanderwoude et al., 2015) was notified via email on the morning of June 21st explaining the situation and that rapid response procedures had been initiated.

RAPID RESPONSE

Delimiting Survey

Delimiting surveys were conducted around the original VIS parking lot perimeter and entrance on June 25th, 26th, and 27th. Between 10 and 20 vials baited with peanut butter, jelly, and spam, were deployed for at least one hour during each delimiting survey and each survey also included hand searching and weed pulling of invasive plants. Surveys on the 25th were conducted from 10:45am to 11:45am by OMKM staff J. Kirkpatrick and intern T. Quinories. Surveys on the 26th were conducted from 2:30pm to 3:30pm by T. Quinories. Lastly, the survey on the 27th was conducted at 3:30pm by J. Kirkpatrick and vials were left out and checked at 5pm, 11pm, and then again at 6am on June 28th. All vials and searching efforts presented a negative result for *C. variegatus* however, we did find *Cardiocondyla obscurior* on the old retaining wall at the VIS which is a new detection and we also found a reproductive *Cardiocondyla kagutsuchi* (this species is established at Halepōhaku) individual on that same retaining wall.

Delimiting Survey Locations

The survey locations included the exterior perimeters of the original VIS parking lot and entrance and cracks and crevices within the parking lot (Figure 46). All baited vials were placed on the ground in areas that may foster alien arthropods such as retaining walls, drainage areas, in cracks and crevices, and at the edge of asphalt slabs. Vials were not placed inside of the VIS, because the VIS has been closed due to the ingress egress parking lot construction project, and during these ant surveys, renovations were taking place inside of the VIS.

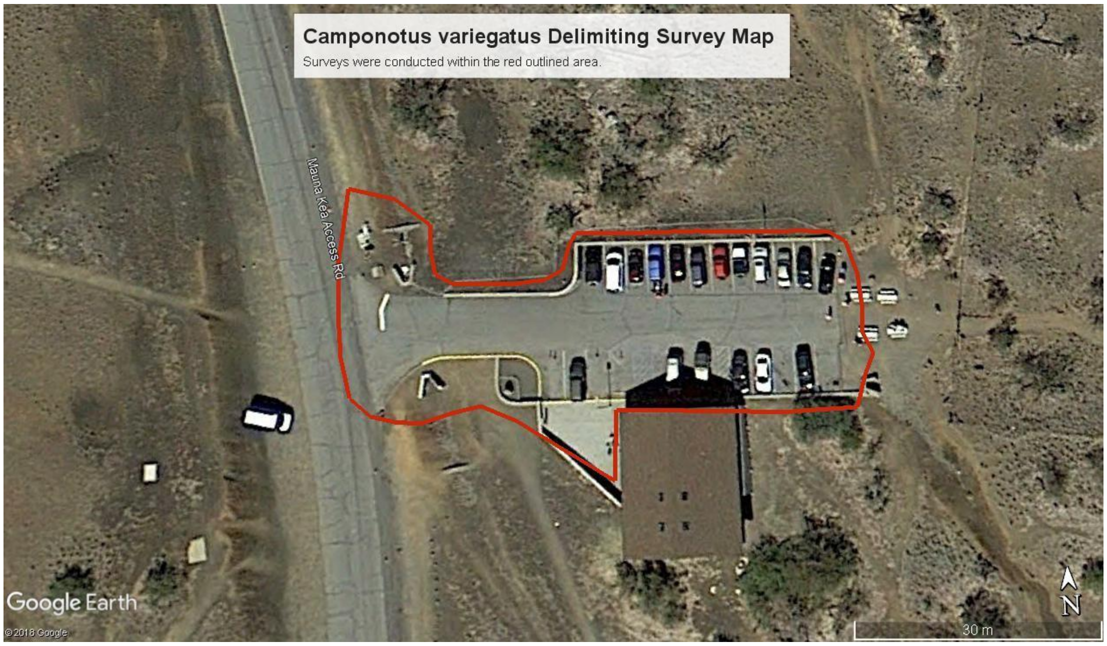

Figure 46. Map of delimiting survey areas around and within the VIS parking lot and entrance. Surveys were conducted within the red outlined area.

MANAGEMENT RECOMMENDATIONS

Rapid Response Recommendations

Rapid Response recommendations consisted of delimiting surveys, continued facility trapping efforts, and development of site-specific control efforts if additional ants or colonies were detected. Delimiting surveys entailed baited vials, pulling of invasive weeds, and hand searches both at night and during the day. Facility trapping is a routine quarterly effort that consists of four *Hoy Trap-A-Roach* sticky traps baited with peanut butter, jelly, and spam that are placed inside and outside of the VIS. One trap was placed in the VIS breaker room, one was placed under the trash can outside of the front doors, another trap was placed in the janitorial closet, and the last trap was placed underneath the VIS bathrooms/ porch. *C. variegatus* was not found during our trapping and survey efforts. Trapping and survey efforts have stopped due to blocked access to the mountain. More survey efforts are needed within and around the area of the VIS.

Long-term Eradication & Monitoring Recommendations

Long-term recommendations will be to continue quarterly facility monitoring of the VIS region. If any new specimens are observed, this section may be updated. Additional results will be included in the 2019 annual invasive species management program report. Given the lack of access, additional detections of this species over the next several months will result in initiation of rapid response reporting procedures.

In addition, the *Cardiocondyla obscurior* detection will not result in initiation of rapid response reporting procedures as our delimiting survey methods on 6/26 and 6/27 also target *C. obscurior* and therefore those surveys functioned as delimiting surveys for the species. According to Mississippi State University, *C. obscurior* is not considered to be a pest species or known to negatively affect native ecosystems, it does however nest in cavities of trees, bushes, in dead twigs, in coconuts, and galls (as opposed to *C. kagutsuchi* which are ground dwelling (MacGown, 2016). Since *C. obscurior* is in the same genera as *C.kagutsuchi* (an established species at Halepōhaku) it is considered a low priority threat species given its small population size, ephemeral behavior (Peck & Banko, 2011), and the site in which it was detected: Halepōhaku (Vanderwoude et al., 2015). We continue to monitor for ants and any future *Cardiocondyla obscurior* detections will result in initiation of rapid response procedures.

Table 22. 2019 Activity timeline

Activity Type[17]	Lead	Date(s)	Location	Ants observed?
Annual Arthropod Monitoring -Traps	OMKM	6/14- 6/17, 2019	MKSR, HP, VIS, and NAR	Yes, *C. kagutsuchi*
Quarterly Facility Monitoring – Traps	OMKM	6/19- 6/26, 2019	MKSR, HP, and VIS	No
C.variegatus detection	OMKM	6/19/2019	VIS	Yes, queen *C.variegatus* (1)
Delimiting Survey I	OMKM	6/25/2019	VIS	Yes, reproductive *C. kagutsuchi* (1) and *C. obscurior* (1)
Delimiting Survey II	OMKM	6/26/2019	VIS	No
Delimiting Surveys III	OMKM	6/27 – 6/28, 2019	VIS	No

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[17] Activity methods can be viewed upon request. OMKM facility monitoring procedures can be found on the OMKM website.

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Appendix K: Rapid Response Report for Big-headed ant (*Pheidole megacephala*) from 2018

Detection of *Pheidole megacephala* on Maunakea, Hawai'i Rapid Response – 2018
Prepared by J. Kirkpatrick

Introduction

On October 2, 2018, two big-headed ant (*Pheidole megacephala*) individuals were detected during lab-review of our invasive species facility traps that were placed from September 19th to the 26th in the loading bay room at the Canada France Hawai'i Telescope (CFHT) summit facility. The two ants were found on the sticky facility trap (HoyHoy cockroach traps) by Office of Maunakea Management (OMKM) staff J. Kirkpatrick while screening traps under the microscope. Both ants were dead in the trap and were in a curled position away from the edge of the trap suggesting that the ants had died and blew into the trap. If the ants had instead walked into the trap, they would have been closer to the edge of the trap, and their bodies would have been in an active position than in a curled one. The three other traps placed at the CFHT summit facility during the same trapping episode did not detect ants. This is the first detection of *P. megacephala* on University of Hawai'i (UH) managed lands on Maunakea. As identified in the Maunakea Invasive Species Management Plan (ISMP), *P. megacephala* is a primary target species and given that the CFHT sits atop the cinder cone Pu'ukea which is habitat for the wēkiu bug, it makes this situation a "Very High Priority" for rapid response efforts. In 2016, a UH Hilo graduate student found *P. megacephala* at the CFHT base facility in Waimea (Zarders, 2018). We hypothesize that the ants made it to the summit via a contaminated delivery or vehicle from the CFHT base facility in Waimea, died at the summit, or on the way to the summit, and blew into the trap when it arrived in the loading bay room.

As part of our invasive species facility trap procedures, facility traps are placed quarterly and include a perimeter search around facilities, and observation of arthropod activity in areas where traps are placed. Prior to the September facility trapping effort, the CFHT facility was monitored for invasive species from June 14th to June 20th 2018, and no ants were observed. Within that same month of June, 2018 (6/26 thru 6/29), OMKM conducted their annual arthropod monitoring surveys and placed two traps on Pu'ukea with the closest site ~160m away from the CFHT facility. OMKM's annual arthropod monitoring includes various trap types designed to target specific groups of arthropods (i.e. wasps, flies, ants); the peanut butter, jelly, and spam sticks target ants. Although this trap was ~160 m away from the facility, it still serves as an important dataset that shows ants were not detected outside of the facility months prior to the *P. megacephala* detection.

Facilities in the Mauna Kea Science Reserve (MKSR) and at Halepōhaku (including the VIS) have been surveyed at least annually for invasive species since 2007 initially by the Bishop Museum, and starting in 2013 by OMKM staff. Currently, the only known resident ant populations within UH managed lands on Maunakea are isolated *Cardiocondyla kagutsuchi* populations along the Maunakea Summit Access Road corridor shoulder up to Halepōhaku and near Halepōhaku parking lots (up to 9300') (Unpub. OMKM *C. kagutsuchi* Delimiting Survey, 2013).

Rapid response is the process of reacting to a new, recent, not previously detected invasive species. Given that this is the first time *P. megacephla* has been detected on UH managed lands, that the species is a high priority threat due to invasive traits such as polygeny, high-interspecific aggression, and mutualistic relationship formation, and that the species was found atop a cinder cone that is classified as wēkiu bug habitat, OMKM initiates rapid response procedures and reports as outlined in ISMP (Vanderwoude et al., 2015).

Life History

The big-headed ant, also known as the "brown house-ant", or "coastal brown ant", *Pheidole megacephala* (Figure 47) is believed to be native to Ethiopia or Madagascar given the breadth of sub-species and varieties in those two regions (Wetterer, 2007). Now inhabiting almost every tropical island group, *P.megacephala* spreads through human activities and commerce. In the Pacific, the big-headed ant shows complete dimorphism with distinct minor and major workers; the latter with disproportionately large heads. *P. megacephala* typically form "unicolonial supercolonies" that have multiple queens and act as a single unified group due to the lack of colonial boundaries and intraspecific aggression (Wetterer, 2007).

Figure 47. *Pheidole megacephala*, side view of a minor worker (Source: http://www.antweb.org).

This predacious ant species is a well-known indoor, outdoor, and agricultural pest that can nest inside buildings, forage on nearly anything (Tenorio & Nishida, 1995) including honeydew, dead insects and plant seeds, chew through electrical wires and cables, and damage irrigation lines (Wetterer, 2007; Vanderwoude et al. 2015). Limited by rainfall, *P. megacephala* is rarely found in very wet (> 250 cm/yr) and very dry areas (<38-50cm/yr) (Reimer et al., 1990). Big-headed ants favor shaded and moist areas and although not commonly found in dry environments, they can take advantage of sheltered micro-sites (Hoffmann et al., 1999). Throughout the Hawaiian Islands, big-headed ants dominate the lowlands but their distribution have also been recorded in mid-elevation forests (Perkins, 1913; LaPolla et al. 2000) and at 1,770 m elevation on Maunakea (Wetterer et al. 1998). Because this ant is most common at low elevations, there is a small probability that it could become a major pest at high elevations (Wetterer et al. 1998).

Identification

P. megacephala is a reddish brown medium sized ant; the head and abdomen is slightly darker than the mesosoma, and the entire body is covered with sparse, long hairs (Tenorio & Nishida, 1995; Wetterer, 2007; Warner & Scheffrahn, 2016). Minor workers are ~2 mm in length and major workers, or "soldiers" with allometrically enlarged heart-shaped heads (the posterior half smooth and shiny) are ~3.5 mm in length (Wetterer, 2007; Warner & Scheffrahn, 2016; CABI, 2019). Both workers have a conspicuously swollen postpetiole and 12-segmented antennae; the terminal three segments are enlarged forming a discrete 3-segemented club (CABI, 2019). Workers also have a pair of short propodeal spines facing upward (Warner & Scheffrahn, 2016).

Food & Bait Preferences

Big-headed ants are omnivorous as they feed on sweet sugary liquids such as honeydew, dead insects, soil invertebrates, and plant seeds (Vanderwoude, 2015; Warner & Scheffrahn, 2016). Foraging workers bring food back to the nest to share with the rest of the colony and workers are often observed exchanging regurgitated liquids (trophallaxis) (Warner & Scheffrahn, 2016).

The Hawaiʻi Ant Lab recommended Amdro, Probait, and Maxforce Complete to control big-headed ants.

Threat

The Office of Maunakea Management is concerned with the finding of *P. megacephala* because the entire group (Family) Formicidae are considered to be threats to the environment, as identified in the ISMP. The big-headed ant is identified in the ISMP as a high priority threat due to the species invasive traits including polygeny, high-interspecific aggression, and mutualistic relationship formation with Homopterans (Vanderwoude et al., 2015). Although it seems unlikely that big-headed ants can survive at upper elevation areas on Maunakea (Wetterer et al. 1998; Reimer et al. 1990), sheltered micro sites in or around facilities could potentially provide habitat for the species (Hoffmann et al., 1999).

Detection

On Tuesday, October 2, 2018 OMKM staff J. Kirkpatrick detected two *Pheidole megacephala* individuals in a facility trap that was placed from September 19th through 26th in the loading bay room at the CFHT summit facility (Figure 48). That same day (10/2), Hawaiʻi Ant Lab staff Michelle Montgomery identified the specimens as *Pheidole megacephala*. The Hawaiʻi Ant Lab provided some initial information about this species identifying it as a high risk species given its invasive traits (i.e. aggressive behavior, multiple queens, mutualistic relationships) and ecological impacts (i.e. predation, competition) on Pacific Islands. However, they also stated that *P. megacephala* is an easy species to control.

Detection Notification & Recommendations

On 10/2, the Department of Land and Natural Resources entomologist, Cynthia King, and the Emergency Response Management Committee were notified via email that the ants were detected and that rapid response procedures had been initiated.

Figure 48. Two *Pheidole megacephala* individuals were found in a facility trap placed inside of the loading bay room at the CFHT facility.

RAPID RESPONSE

Delimiting Survey

Delimiting surveys were conducted throughout the loading bay room and around the cement slab that is just outside of the loading bay roll up doors on October 3rd, 10th, and 24th by OMKM staff J. Kirkpatrick. Ten vials baited with peanut butter, jelly, and spam, were deployed for at least 30 minutes inside and outside of the facility on 10/3 and 10/10, and both these surveys included hand searching (no weeds to pull) within the loading bay room and around the outside perimeter of the CFHT facility. Additionally, 5 facility traps baited with peanut butter, jelly, and spam were placed in the loading room on 10/3 and unfortunately only 3 of those traps were found and retrieved on 10/10; all traps retrieved had mouse damage (i.e. chew marks and mouse hair). On 10/18, four facility traps were placed inside of the loading bay room (3 traps) and in the room next to the loading room (1 trap), and only 2 of those traps were found and retrieved on 10/24. We assume the missing traps placed on 10/3 and 10/18 were taken by mice, as there were many reports of mice at the summit during this time. A hand search was not conducted on 10/18 because it was overcast and temperatures were not warm enough for insects to be active. A hand search was conducted on 10/24. No ants were detected in any of the delimiting survey efforts.

All baited vials were placed on the ground in areas that may foster alien arthropods such as the edge of concrete slabs and near doors, trash bins, and drainage areas.

MANAGEMENT RECOMMENDATIONS

Rapid Response Recommendations

Rapid Response recommendations consisted of delimiting surveys, continued facility trapping efforts, and development of site-specific control efforts if additional ants or colonies were detected. Delimiting surveys entailed baited vials, facility traps, and hand searches during warm hours of the day (when insects are active).

Long-term Eradication & Monitoring Recommendations

Long-term recommendations will be to continue quarterly facility monitoring in all facilities in the MKSR. If any new specimens are observed, this section may be updated. These results will be included in the 2018 annual invasive species management program report.

Table 23. Activity log for the rapid response of *Pheidole megacephala* in 2018.

Activity Type[18]	Lead	Date(s)	Location	Ants observed?
Quarterly Facility Monitoring – Traps	OMKM	6/14- 6/20, 2018	MKSR, HP, and VIS	No
Annual Monitoring – Traps	OMKM	6/26- 6/29, 2018	MKSR, NAR, HP, and VIS	No
Quarterly Facility Monitoring – Traps	OMKM	9/19- 9/26, 2018	MKSR, HP, and VIS	No
***P. megacephala* detection**	**OMKM**	**10/02/2018**	**CFHT (MKSR)**	**Yes *P. megacephala* (2)**
Delimiting Survey Effort 1	OMKM	10/03/2018	CFHT (MKSR)	No
Delimiting Survey Effort 2	OMKM	10/10/2018	CFHT (MKSR)	No
Delimiting Survey Effort 3	OMKM	10/18/2018	CFHT (MKSR)	No
Delimiting Survey Effort 4	OMKM	10/24/2018	CFHT (MKSR)	No
Quarterly Facility Monitoring	OMKM	12/18- 12/27, 2018	CFHT (MKSR)	No

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[18] Activity methods can be viewed upon request. OMKM facility monitoring procedures can be found on the OMKM website.

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Appendix L: Pesticide log

The pesticide log for the UH-managed lands from 2016 to 2020, including EPA regulation number, formulation type, the active ingredients in the pesticide, the targeted pest, the application date/time, the dilution rate, the total volume of pesticide applied (ounces), the targeted application rate, and the total area cover (in square feet).

Entry #	EPA Reg No.	Formulation	Active Ingredient(s) & Percentage(s)	Targeted Pest	Application Date/Time	Dilution Rate	Total Volume of Pesticide Applied (ounces)	Targeted Application Rate	Total Area Covered (square feet)
1	279-3206	Liquid	Bifenthrin 7.9%	T. melanocephalum, O. glaber, C. kagutsuchi	1/14/201 10:30am	0.50oz/gal	2	1oz / 1,000 sq ft	2000
2	279-3206	Liquid	Bifenthrin 7.9%	Cardiocondyla kagutsuchi, O.glaber	7/11/20177 7:45am	1oz/gal	1	1oz / 1,000 sq ft	1000
3	279-3206	Liquid	Bifenthrin 7.9%	Cardiocondyla kagutsuchi	8/10/2017 10:30am	1oz/gal	1	1oz / 1,000 sq ft	1100
4	279-3206	Liquid	Bifenthrin 7.9%	Cardiocondyla kagutsuchi	8/17/2017 7:00am	1oz/gal	1.5	1oz / 1,000 sq ft	1500
5	279-3206	Liquid	Bifenthrin 7.9%	Cardiocondyla kagutsuchi	8/24/2017 8:30am	1oz/gal	1.5	1oz / 1,000 sq ft	1500
6	279-3206	Liquid	Bifenthrin 7.9%	Cardiocondyla kagutsuchi	1/3/2019 9:00am	1oz/gal	2	1oz / 1,000 sq ft	2000
7	279-3206	Liquid	Bifenthrin 7.9%	Cardiocondyla kagutsuchi	8/8/2019 2:30pm	1oz/gal	4	1oz / 1,000 sq ft	4000
8	279-3206	Liquid	Bifenthrin 7.9%	Cardiocondyla kagutsuchi	7/10/2020 10:30am	1oz/gal	1	1oz / 1,000 sq ft	1000

Entry #	Site Treated	Name of Certified Applicator	Restricted Entry Interval (REI)	Double Notification Required?
1	HP Upper & Lower Parking Lot	D. Yogi	After spray has dried	No
2	HP firehose bibs/plant benches	D. Yogi	After spray has dried	No
3	Gravel HP parking	F. Klasner	After spray has dried	No
4	VIS parking area 1	F. Klasner	After spray has dried	No
5	HP upper parking lot	F .Klasner	After spray has dried	No
6	HP Commons building main entrance, HP firehose corner near kitchen, and retaining wall between longhouse buildings	J. Kirkpatrick	After spray has dried	No
7	HP Commons building near the Kitchen/ fire hose, along the concrete slab walkway and out towards the plant benches. Also sprayed around the large sinkhole that was just filled in at HP	F .Klasner	After spray has dried	No
8	HP Commons building main entrance and along retaining wall	J. Kirkpatrick	After spray has dried	No