INVASIVE ARTHROPOD MONITORING ASSESMENTS OF CONSTRUCTION AND FACILITY ACTIVITIES ON MAUNAKEA, HAWAIʻI

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Abstract

Risks posed to ecosystems by invasive species are dependent on the unique characteristics of the environment and the specific species that may be introduced. This study assesses the ability to detect non-native species threats, evaluates the risks posed by these species, and tests the recommendations to mitigate risks posed by non-native arthropods to alpine habitats on Maunakea, Hawaiʻi. Such non-native species have the potential to drastically alter populations of native biota, affect ecological processes, and impact human health. This work is intended to facilitate improved management capacity on Maunakea while increasing the body of knowledge for addressing management of non-native arthropod species in general.

The occurrence of non-native arthropod taxa collected during 2015-2016 at the subalpine-alpine region (2,800-4,000 m elevation) and lower elevation sites (below 2,800 m) associated with regulated human activities occurring on the mountain are documented in this study. I assessed and recorded sampling effort, arthropod species and morphospecies diversity and trapping techniques at subalpine (Halepōhaku, 2,800 m) and alpine (Astronomy Precinct, 4,000 m) ecosystems on the south slope of the mountain at proposed astronomy facility construction areas. These proposed construction areas and staging sites were surveyed for arthropods over an 11-month monitoring period. I also sampled for and recorded potential invasive non-native species found at lower elevations (20-2,000 m) that may be transported to the subalpine and alpine areas by official users of facilities associated with astronomy-related activities on the summit regions of Maunakea. At the mountain alpine and subalpine areas, potential arthropod invasive species detections consisted almost entirely of spiders for all sampling efforts, with the notable exception of a single ant species found twice at the 2,800 m Subalpine site. Sampling efforts effective at detecting ecosystem or human health threat non-native taxa (as defined in management plans) and non-threat taxa are evaluated through species accumulation curves. Non-threat arthropod taxa accounted for approximately 50% of trap captures, and occasional new morphospecies detections continued throughout the duration of the sampling period. Baited sticky traps detected threat taxa at greater rates than other trapping techniques and this method accounted for 80% of the total threat taxa captured; whereas non-threat taxa were captured more often and in greater numbers using

baited sticky and yellow pan traps than other trapping techniques. Regular monitoring throughout the year using the methods tested will be likely to record many rare events of potential threat taxa introduction so that mitigation efforts (via physical, chemical, or biological control methods) could be enacted to reduce the overall threat risks associated with invasive arthropods. Furthermore, the sampling efforts did not detect some types of threat taxa identified by land management authorities that are known in the areas surveyed (social wasps, *Vespula pensylvanica*), which provides insight into the potential shortcomings of current sampling effort methods. This suggests further study and refinement of invasive arthropod monitoring protocols will require refinement to account for arthropod threats at the Maunakea summit region.

Currently, regular potential invasive species inspection of facilities and locations directly associated with telescope or land management activities on Maunakea is limited to University of Hawaiʻi (UH) managed lands at the summit region and subalpine (Halepōhaku) and does not include sites elsewhere around the island. This study also explores the presence of ant occurrence at these non-high elevation support facilities and surveyed vehicles as possible pathways for invasive species movement associated with telescopes and land management activities on UH managed lands. To evaluate potential invasive arthropod threat introduction from source point sites, surveys were conducted using ant-targeted baited vials, hand searches, and vehicle sampling events as evaluations to compare threat taxa incidence rates between vehicles and facilities typically being used by high elevation telescope support staff. Ant occurrence and sampling techniques were evaluated to determine species presence at all astronomy related support facilities below 2,800 m and if vehicles may be a pathway for species movement between sites. Surveys of sites below 2,800 and facilities revealed ant presence primarily in developed urban locations in Hilo and Waimea, and the numbers of species present were very limited at 2,000 m elevation sites on the southern flank of Maunakea. The dominant ant species found at these 2,000 m elevation sites, the Argentine ant (*Linepithema humile*) although currently not found within the 2,800+ m habitats, is the greatest threat species to the summit region, as it is known to survive high elevation alpine temperatures and ecosystems in other locations (~3,000 m). *L. humile* was found as high as 2,150 m along the sole road that can be traveled to the summit.

Evaluations of practices to prevent transport of species between lower and upper elevation sites included vehicle pathway assessments which revealed that vehicles subject to management authority-recommended decontamination procedures have fewer incidences of threats, that threat Formicidae species were detected using multiple sampling methods, and these methods should be used to increase threat ant species detection. The surveys revealed that threat species of ants do occur at low elevation telescope facility sites and that regular decontamination of vehicles reduced the occurrence of ants. Regular washing of vehicles that drive primarily between Maunakea subalpine and alpine facilities and low elevation support facilities is associated with less threat taxa on or in vehicles. Regular vehicle decontamination and prophylactic bait treatments would be more likely to interrupt establishment and lifecycles of threat taxa in vehicles that occasional undergo episodic cleanings or treatments, therefore regular decontaminations and treatments are recommended.

Section 1. Introduction

The risk associated with the inadvertent movement and successful establishment of exotic arthropod species to new areas is considered a major contributor to the current modifications of ecosystems at the global level (Vitousek et al. 1997), and is a priority concern for land managers worldwide. The consequences of invasive species movement to new areas pose serious implications for conservation efforts meant to keep ecosystem components intact (Cole et al. 1992). In Hawaiʻi, the threat posed by invasive arthropod species to natural ecosystems and agricultural systems is extreme, given that Hawaiian arthropod fauna have been shown to be highly vulnerable to direct predation or competition with the introduction of wide varieties of non-native insect taxa (Gillespie and Reimer 1993, Hölldobler and Wilson 1990, Wilson and Holway 2010).

1.1 Alpine Invasive Species Management

Alpine habitats located on Hawaiʻi Island represent one of the few alpine systems in tropical and subtropical regions of the world (Juvik et al. 2014), and are home to hundreds of naturally occurring endemic plant and insect species and are also threatened by the effects of non-native species (Juvik and Juvik 1984; MKCMP 2009).

Invasive arthropod taxa introduction and establishment risks to the alpine mountain, Maunakea, on the Island of Hawaiʻi, are specific and unique due to the environmental constraints of an alpine environment and the specific activities that occur in the alpine regions of Maunakea. These insects eventually die by succumbing to freezing temperatures and the lack of food and water sources (Howarth and Montgomery 1980). Because of the environmental and atmospheric features of this high mountain, there are unique human activities occurring in the alpine regions that include operation of telescopes and support service facilities, road maintenance, tourism, research and education access, cultural practices, and construction of new facilities or maintenance of existing facilities (Vanderwoude et al. 2015). Recent construction activities planned in the alpine region on Maunakea include decommissioning (removal of) unused telescopes, substrate restoration to more natural conditions, and the potential construction of the Thirty Meter Telescope (TMT). These activities will involve movement of materials and vehicles, which can act as pathways for invasive plants and arthropods species, with ant introduction as a key threat (Vanderwoude et al. 2015).

The Hawaiian Islands lack native ants (Wilson and Taylor 1967). Introduced ant taxa have flourished due to the favorable conditions where there is a stable and favorable climate, an abundance of resources that can be exploited and a relative lack of ant-specific natural enemies (Hölldobler and Wilson 1990; Gillespie and Reimer 1993; Reimer 1994). Many ant species are very effective at dispersal in human modified habitats and have been introduced far beyond their native distribution ranges. These broadly distributed species are commonly referred to as 'tramp ants' (Passera 1994; McGlynn 1999). Their colonies are polygynous, meaning the ant colony is established under multiple, egg-laying queens and are unicolonial where new nests can be formed by budding (Passera 1994). These tramp ants are opportunistic in resource recruitment, with high interspecific aggression, low intraspecific aggression and high colony mobility (Wilson and Taylor 1967; Hölldobler and Wilson 1990; Passera 1994). Most of the species found in Hawaiʻi are restricted to lower elevations (Reimer 1994), however in some high elevation areas, a subset of species has become established, with the Argentine ant, *Linepithema humile*, a notable ecosystem modifier shown to negatively impact native ecosystems in Hawaiʻi (Krushelnycky and Gillespie 2010). The ecological effects of tramp ants on native arthropods are rarely studied, in part, because these ant types often do not spread far from human modified or otherwise disturbed habitats (Krushelnycky et al. 2010). All ant species found in Hawaiʻi are introduced, but vary in the ecological impacts they have by ant taxon and environment in which they are found. Some ant species are found in upper mesic forest areas in Hawaiʻi, but prior observations suggest many species have difficulty attaining high populations in Hawaiʻi's montane habitats due to temperature constraints and limited food resources (Krushelnycky et al. 2005). However, in Pacific island environments, some of these tramp ant species can thrive beyond human modified areas (Loope and Krushelnycky 2007), and persist in native habitats potentially unnoticed for some time. Much of the work surrounding the impacts of invasive ant species in Hawaiʻi has focused on a select few species of the most invasive ants that are associated with adverse effects on native ecological processes (Wetterer 1998; Krushelnycky and Gillespie 2008; Krushelnycky 2015).

It is unclear which, if any, of these high-elevation tolerant species have the potential to become established on the Maunakea summit, or what the effects these potential ant species establishments may have on the Maunakea subalpine and alpine region ecosystems. Many species considered invasive threats encountered at lower elevation sites might not pose a significant invasive threat to the subalpine and alpine Maunakea region given the life history (Reimer 1994; Wetterer 1998; and Krushelnycky and Gillespie 2008). To date, five high priority arthropod pest species (all ants) (Vanderwoude et al. 2015) have been detected within the University of Hawaiʻi managed lands on Maunakea (Management Area): *Tapinoma melanocephalum* and *Plagiolepis alluaudi* found in the alpine Astronomy Precinct, and *Technomyrmex albipes, Cardiocondyla kagutsuchi and Ochetellus glaber* found at the 2,800m subalpine Halepōhaku region. The only species considered a 'resident' in the general area is *C. kagutsuchi*, which has been found occasionally at 2,800 m along a roadside and parking area for a facility managed by the University of Hawaiʻi (UH) (OMKM per coms.). This facility area is the only infrastructure on the sole road to the subalpine and alpine region of Maunakea, and is heavily used by tourists/visitors, employees of the visitor information and education center, and by employees that manage the ground-based telescope facilities at the alpine region (~4,000 m) (MKCMP 2009). The other species have all been detected only in isolated locations and on isolated occasions during regular monitoring surveys.

1.2 Project Purpose

In this study an investigation into the distribution of invasive species with a focus on potential invasive arthropod movement and establishment on the alpine stone desert environment from lower elevations has been conducted. The methods used to inform invasive species introduction mitigation included 1) sampling efforts for many invasive arthropods at alpine summit of Maunakea (~4,000 m) and subalpine (2,800 m) 2) surveys of lower elevation telescope support facility infrastructure sites and 3) a vehicle pathway survey to assess likelihood of invasive species traveling to the alpine environment via vehicles that regularly move between the lower and higher elevation region facilities.

From these studies, refined survey methods for intercepting high-risk invasive species in the alpine region of Maunakea can be recommended to land managers. With comprehensive baseline surveys, taxa introduction pathways, and assessments of actionable invasive threat taxa for Maunakea, land managers will be more likely to dedicate efforts to control threat taxa in a more efficient manner at each stage of invasive threat identification.

The objectives of this project are to 1) recommend refined methods for intercepting invasive threat species taxa by assessing effective threat species trapping techniques at low and high (alpine and subalpine) elevation sites, 2) identify inspection methods for any vehicles and materials based on the taxa encountered through surveys at low and high elevation sites, 3) evaluate presence of threat taxa on vehicles accessing high elevation sites that have gone through standard decontamination procedures, and 4) create a baseline threat species list from low and high elevation sites associated with Maunakea human activities to recommend methods to mitigate inadvertent introductions of threat arthropods.

Section 2 Materials and Methods

The volcanic mountain, Maunakea, on the Island of Hawaiʻi, is a 4,205 m (13,796 ft) post-shield volcano. There are 13 telescope facilities on this mountain above 3,000 m, all of which are located at an elevation where surface soil and substrates regularly freeze during winter months. This ecological region is termed an alpine stone desert, with very little plant life and low rainfall (~25 cm of water per year) (Howarth 1987). Additionally, at ~2,800 m elevation, an astronomy support maintenance facility and employee and researcher dormitory is located in an ecological zone termed subalpine Māmane *(Sophora chrysophylla*) shrubland which is generally above the cloud inversion layer in Hawaiʻi creating a cold and dry environment that occasionally encounters surface freezing and ~60 cm of moisture annually (Gerrish 2013).

As part of the Invasive Species Monitoring Program enacted by the land management authority, University of Hawaiʻi at Hilo (UHH), Office of Maunakea Management (OMKM), and implemented by Big Island Invasive Species Committee (BIISC), a series of arthropod surveys were conducted at the 2,800 m support facility (termed ʻHalepōhaku' facilities) and at the ~4,000 m proposed TMT construction site (Figure 1). These surveys were implemented in response to additional potential telescope construction preparation activities. These arthropod survey sites were chosen in consultation with OMKM and TMT to create a baseline of invasive species data for the proposed facility near the alpine summit area of Maunakea (4,000 m). These study sites were expected to be possible introduction points of invasive species arriving via telescope construction materials and/or represented sites that are considered sensitive due to potential native species that could be directly impacted by introduced taxa.

The study locations were within two general areas managed by OMKM: (1) three stations in the Subalpine within the Halepōhaku management unit and (2) 19 stations in the Alpine within the Maunakea Science Reserve in the Maunakea summit region (Figure 1). These two localities are considered to be environmentally important and are at-risk introduction points related to human activities on Maunakea in high elevation areas (Vanderwoude et al. 2015). Sampling effort and trapping techniques varied greatly between the two regions and is a result of the risk mitigation priorities due to the frequency of the telescope pre-construction activities.

The third region, outside of direct management control, yet representing the source for invasions, includes all access roads to University lands, support facilities in the towns of Hilo and Waimea, the University of Hawaiʻi at Hilo campus, and airports and harbors. These areas represent focal sites for preventative actions under the Maunakea Invasive Species Management Plan.

2.1 Alpine Survey Areas

The alpine survey areas are located at approximately 4,006 - 4,093 m elevation, receive a mean annual rainfall of 207.5 mm (Giambelluca et al. 2013), and are included at the ʻAstronomy Precinct' for management purposes (MKCMP 2009). The alpine region ecosystem is characterized by freezing nightly temperatures, winter snow with variable duration of snow-pack, low yearly moisture input (~25 cm annually), elevation above the temperature inversion layer of the high wind column, low atmospheric pressure, low humidity, high solar intensity, low density of vegetation, soil substrates consisting of rocks ejected from volcanic events over the past ~500,000 years, and glacial-scoured rock areas from three glacial time-spans since the growth of this volcanic mountain (Juvik et al. 2014). The upper reaches of the alpine stone desert ecosystem are also described as a Aeolian ecosystem where the majority of nutrient deposition is from wind-born insects descending and landing on the summit during their dispersal events from lower elevations. Sampling stations are potential sites for non-native taxa dispersal including locations designated for staging telescope pre-construction equipment, vehicles, existing unpaved parking areas for a concrete batching plant, adjacent to a cultural site, and the proposed TMT construction site. The proposed construction site is the final destination for construction materials if the construction is approved. As such, the alpine summit area is a likely introduction location as it is where construction materials would be arriving or unpacked after shipment to the island (after an initial inspection at or around sea-level at ocean ports and airports).

Alpine survey locations at the proposed TMT construction site were designated for staging telescope pre-construction equipment, vehicles, existing unpaved parking areas for a concrete batching plants, and adjacent to a cultural site. The Alpine sampling sites (n = 14) are located along the TMT pre-construction road and site, the Pu'uhauoki site (n = 1) located on the western slope below the Subaru Telescope, material batch plants (n = 3) located along the access road before the James Clerk Maxwell Telescope near the TMT site, and a final site at the base Pu'upoli'ahu (n = 1) is located adjacent to the TMT site.

2.2 Subalpine Survey Areas

The subalpine arthropod survey areas are located at approximately 2,780 m elevation in a mixed stand forest composed of native shrubs, trees and perennials interspersed with occasional patches of non-native weeds along and open areas of bare soil or rocky outcroppings (MKCMP 2009). This area is referred to as Halepōhaku for management purposes. The area receives an annual mean average rainfall of 660 mm (Giambelluca et al. 2013), and supports dry and mesic forests primarily composed of Māmane *(Sophora chrysophylla)* and many other native grasses, shrubs and non-native species. The site monitored for non-native arthropods is a parking lot that also serves as a construction material staging site, located just below the Halepōhaku Ranger Station. The Subalpine site is a potential invasive species introduction point, as it is utilized as a staging area for construction vehicles and materials associated with telescope construction activities (Vanderwoude et al. 2015).

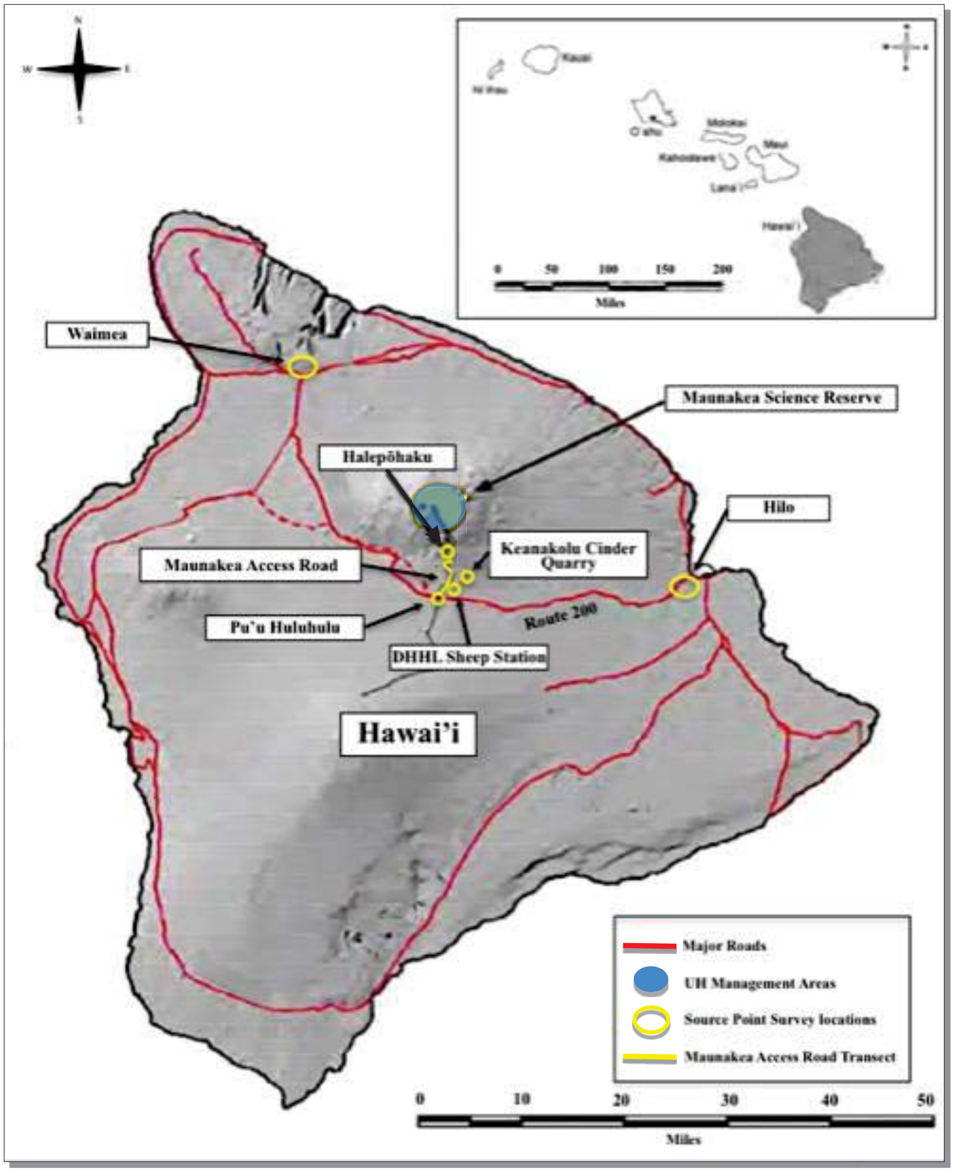

Figure 1. Map of Hawaiʻi Island detailing the Maunakea Science Reserve (UH managed lands) area marked with the blue circle and non-UH managed lands marked in yellow. Inset map shows the position of Hawaiʻi Island amongst the other main Hawaiian Islands. Maps derived from the Maunakea Comprehensive Management Plan (MKCMP 2009).

2.3 Lower Elevation Survey Areas

A total of fifteen sites, separated into five general elevation and environmental localities were selected on the island of Hawaiʻi (see Appendix Figures 12-17). Differences between areas and sites were determined by elevation range, consistency of the vegetative landscape community, general composition of the substrate and geographic district of the island. These sites represent potential invasive threat introduction source points that are associated with UH regulated work on the Maunakea summit region. OMKM staff identified survey sites associated with official activities on the mountain, and represent locations most likely associated with potential invasive species that can be introduced to the summit region. Additional sites identified by OMKM and in consultation with DHHL address other areas of concern and are representative of intermediate habitats that visitors to higher elevations may stop at while enroute. These sites also have official regulatory oversight by OMKM, so mitigation of non-native species, if found, must follow requirements of the respective managing agencies. The five general survey localities identified by OMKM and DHHL include Hilo, Waimea, natural area and visitor parking lot at Pu’u Huluhulu, Maunakea Access Road, and UHH Halepōhaku (Figure 1).

Hilo Town Sites

The eight telescope support facility sites in Hilo on the east side of the island were: (1) UH Hilo Carpool, at 50 m elevation on February 12, 2016 (Figure 1); (2) Maunakea Support Services at 19 m elevation on July 20, 2016; and six sites located in the University Research Park ranging from 75-95 m elevation including (3) the Institute for Astronomy on July 8, 2016, (4) Joint Astronomy Centre on August 15, 2016, (5) the Caltech Submillimeter Observatory on July 14, 2016 (6) Gemini Observatory on July 26, 2016, (7) Subaru Telescope on July 21, 2016, and (8) the Smithsonian Astrophysical Observatory Submillimeter Array facility on July 14, 2016.

Hilo has a tropical rainforest climate with approximately 3,775.2 mm mean average annual rainfall (Giambelluca et al. 2013), and supports a dense assemblage of ornamental and non-native weedy plants that make up the majority of the surrounding plant landscape.

Waimea Town Sites

Two telescope support facility sites in Waimea on the northeast side of Hawai‘i

Island were as follows (Figure 1). (1) California France Hawaiʻi Telescope Observatory on August 4, 2016, at 813 m elevation, and (2) Keck Observatory on August 4, 2016, at 20 m elevation. The Waimea area is considered to have a warm summer Mediterranean climate, and annual mean average rainfall of 807.1 mm (Giambelluca et al. 2013).

South Slope, Maunakea Access Road Sites

Three sites situated near Maunakea Access Road include a Humuʻula Sheep Station that is representative of potential material staging sites, potential inspection or decontamination wash station sites; Pu'u Huluhulu public parking; and Keanakolu cinder quarry that may someday be used as a source of fill-rock if the two locations are ever to be used as inspection or wash stations on the southwest slope of Maunakea, off Route 200 (Figure 1). Pu'u Huluhulu public parking lot was surveyed on March 8, 2016 and March 15, 2016, at approximately 2,005 m elevation. The parking lot survey site is directly adjacent to Hawaiʻi State Department of Land and Natural Resources (DLNR) and Department of Hawaiian Homelands (DHHL) managed kipuka Pu'u Huluhulu, which is a forested area surrounded by a younger lava flow and supports a number of native plant species with an mean average rainfall of 1,074.7 mm (Giambelluca et al. 2013). The DHHL Humuʻula Sheep Station was surveyed on March 10, 2016, at approximately 2,042 m elevation. It is situated near the start of the Maunakea Access Road, is a partially used livestock facilities that is largely overgrown by grasses, sparse groundcover with some pine trees, and has an annual mean average rainfall of 1,014.2 mm (Giambelluca et al. 2013). The DHHL Keanakolu cinder quarry was surveyed on Keanakolu Road on March 15, 2016, at approximately 2,225 m elevation. The site is comprised mostly of volcanic rock cinder with some soil patches, and the surrounding groundcover primarily bunchgrass, and receives annual mean average rainfall of 1267.1 mm (Giambelluca et al. 2013).

A single transect along the margin Maunakeaea Access Road was conducted on November 18, 2016. This road is the only paved connecting corridor between the summit of Maunakea and the rest of the island, and it represents a potential pathway for ants to the summit region of the mountain (Figure 1). The Maunakea Access Road begins at approximately 2,005 to at the Route 200 junction and extends up to Halepōhaku Visitor Center (2,787 m). The access road transect can be characterized as savannah grassland vegetation community that supports bunchgrasses and gradually changes plant composition as elevation increases into a more dry mesic Hawaiʻi native/non-native plant habitat, and receives annual average rainfall of 690 to 1,070 mm, mean average decreases as elevation increases (Giambelluca et al. 2013).

2.3 Arthropod Sampling

Subalpine and Alpine Sampling Protocols

Arthropods were sampled by BIISC staff weekly and monthly in alpine habitats (Astronomy Precinct; 4,000 m) and subalpine habitats (Halepohaku; 2,800 m), over an 11-month period starting February and through December 2015. Sampling efforts included baited vials and baited sticky traps trapping techniques (Figure 2), which are utilized for early detection monitoring efforts by OMKM and recommended to assess risks of arthropod threats to Maunakea (Vanderwoude et al. 2015).

Figure 2. Images of trapping methods used for threat taxa detection by BIISC staff. Starting from the left: Baited vials (left) and baited sticky traps (right).

At the beginning of each sampling event, vials baited with a protein and sugar source (peanut butter, Spam, and sugar water (2:1 ratio) or jam) were placed at the start of sampling site and then were collected after all site traps were set and were allowed to sit for at least 60 minutes (Figure 2). When any arthropods were collected, the sample site identification code, date, collectors, GPS coordinates, method of capture and any other additional notes were recorded on a paper label that was placed into the vial with the sample. Baited sticky trap comprised of cockroach sticky trap, HOY HOY TRAP-A-ROACH (Ossett, England, Killgerm Chemicals Ltd.) baited with a protein and sugar source (peanut butter, Spam, sugar water soaked cotton ball or jam). This trap was then placed under a plastic cover to protect it from the environment and larger animals that can be found on the mountain. Each sticky trap was labeled with a sticker detailing the sample site identification code, date, GPS coordinates and method of capture. Additional sporadic Alpine trapping efforts were conducted by BIISC and OMKM staff at the Alpine, 4000 m, site to augment invasive species interception likelihood primarily during the OMKM annual arthropod monitoring surveys during summer months. The five additional trapping methods during these annual sporadic Alpine surveys were:

1) Hand searches, which consisted of visual searches of the area around the sampling site for approximately 5 minutes and collection of any potential threat taxa observed in the surrounding area by hand using a plastic vial or aspirator with specimen label.

2) Baited pitfall live traps, which were set by digging small holes roughly a size that would allow a 10 oz plastic cup to fit flush with the substrate surface while sunk in the hole. A small amount of water added to the cup, before a second cup with a paper wick that would provide water to any captured specimens that may have been trapped was placed into the first cup, baited with canned tuna smeared on a small rock, then covered with a cap rock and retrieved approximately three to five days after placement (see Eiben and Rubinoff 2010 for details of trap design). Upon retrieval, any specimens that were captured (other than live endemic species, like the wēkiu bug (*Nysius wekiuicola*) and lycosa spiders (*Lycosa Hawaiiensis*) which were released) were placed into plastic vials, with a specimen label placed inside.

3) Lethal pitfall traps were set by placing a 10 oz plastic cup flush with the substrate surface in a hole, and followed by the addition of approximately 4 oz of propylene glycol and water solution and finally covered with a cap rock. Upon collection, trapped contents were sieved by placing a mesh screen over a plastic bottle container

while liquid contents were transferred, and all sieved arthropod taxa were placed into a plastic snap cap vial with a specimen label.

4) PBJS (peanut butter/jelly/spam) traps consist of pair of chopsticks smeared with approximately 1 inch of peanut butter and jelly and a small piece of Spam as bait, placed inside of a flattened 4x4 inch wire cage (0.25 inch mesh) with rocks as cover. Upon collection, any arthropods on the trap were collected and then placed in vials with a specimen label.

5) Yellow pan traps consist of setting a 250 ml yellow plastic bowl, filled with approximately 4 oz of propylene glycol solution added to each bowl and then stabilized by a rock in the middle of the bowl. Upon collection, trapped contents were sieved by placing a mesh screen over a liter screw cap container while liquid contents were transferred, and sieved arthropod taxa were placed into a 30 ml plastic snap cap vial with a specimen label.

Lower Elevation Sampling Protocols

Prior to lower elevation (50-2800 m) telescope support facility survey fieldwork, maps were created using Google Earth Pro (Google Inc. 2017), detailing the survey site and proposed bait station location. At each site, observations were made of weather conditions, ant activity, date, time and any other notes pertaining to fieldwork were taken. GPS locations of each trap per sample site were recorded using an elevation application (Elevation4Real version 5.0). Systematic surveys were conducted at each site using visual hand searches and baited vials to detect ant presence (Figure 3). Vials were baited with a protein and sugar source (peanut butter, jelly and hotdog) and set for a 30-45 minute time period. This method has shown to be as effective as other trapping methods for measuring the presence of ant species, including their abundance in relation to seasonal changes and weather patterns (Holway 1998). Baits are usually used to assess the presence of a particular species and are a method of quickly assessing ant populations, but have the disadvantage of only taking into account actively foraging individuals at a particular time. Baited vials were placed out of direct sunlight, near areas where foraging ants might occur. Distance between baited vials varied by site, but remained consistent for each individual site sampling effort. At telescope support facilities, vials were placed approximately 5 m apart, and focused around the edges of facility structures, plant landscapes, walkways, and around parking lots (see appendix Figure 12-14 and 17). At mid-elevation (2,042-2,225 m) field site surveys, vials were set approximately 10 m apart, around the perimeters of parking areas and bordering landscape (see Appendix Figure 15). For the Maunakea Access Road survey, vials were spaced at approximately 350 m apart (see Appendix Figure 16).

Figure 3: Example of an ant survey along the Maunakea Access Road transects. Inset images shows visual hand search (left) and a baited vial (right) trapping methods.

Visual observations targeting potential ant habitats were conducted by looking for; flowering plants, roots of weedy plants, tree bark and detritus, undersides of rocks and near sites where water collects (ravines/ roadsides). Hand captures via visual observation surveys were necessary to capture inconspicuous species that had little interest in baits.

2.4 Vehicle Pathway Decontamination Assessments

Following the same general practices outlined in the OMKM Standard Operating Procedures (Vanderwoude et al. 2015) where vehicles must be regularly cleaned and decontaminated from plant, animal, and earthen materials with the objective of mitigating risks that introduced weed seeds, arthropods and other biological organisms present. These vehicle decontamination procedures were used as sampling events and involved two steps, 1) vehicle interiors were vacuumed around the door edges, floor mats, seating areas, the center console and trunk with a portable vacuum cleaner (Compact Lithium Hand Vacuum Kit, Black & Decker, Inc., U.S.A) at the Institute for Astronomy (IFA) Hilo, Hawaiʻi or the University of Hawaiʻi at Hilo campus (50 m), 2) inspect for, remove, and collect any plant or earthen material adhered to the exteriors of vehicles. Finally the decontamination procedure was completed without sampling by cleaning vehicle exteriors using an automated car wash station (Shell Gas station ‘Deluxe’ (Basic PLUS. Clearcoat and Single Dry setting)).

Ten (10) regulated vehicles that regularly visit UH managed lands on Maunakea were evaluated for potential invasive species. These vehicles regularly underwent standard operating procedures for cleaning, and had over six months of monitored cleaning required by OMKM following the Invasive Species Management Plan procedures (Vanderwoude et al. 2015). The procedures apply to passengers, vehicle operators, immediate personal possessions, and any vehicle operating under a permit (permit examples include, CDUP, Special Use, or other; including those permits issued to the University of Hawaiʻi for observatory purposes) on UH managed lands on Maunakea (Halepōhaku, the summit access road above Halepōhaku, and the Maunakea Science Reserve).

These regulated vehicle types were compared with 10 unregulated vehicles; vehicles not cleaned according to the OMKM SOP cleaning recommendations (i.e. UHH educational vehicles not going to Maunakea summit, university staff, or general tourists). These vehicles are not subject to the monitored cleaning and inspection requirements yet are technically able to travel to the summit without inspection when they are not engaging in activities over which OMKM has any authority. Unregulated vehicles targeted for invasive species inspection in this study appeared superficially clean.

Prior to commencing each survey, air temperature, cloud cover, moisture around survey area, cleanliness of the interior and exterior of the vehicle were recorded. The interiors and exteriors of each vehicle were sampled for insects using baited vials, hand searches, baited sticky traps and debris searches (see appendix Table 10). Four survey methods were evaluated during this study: (1) hand and visual search; (2) baited vials; (3) baited sticky trap; and (4) debris search (Figure 4).

Figure 4. Photos of ant sampling methods used to inspect vehicles (upper left) Hand search; (upper right) Baited vial; (lower left) Baited sticky trap; (lower right) Debris inspection.

2.5 Arthropod Processing and Identification

After collection in the field, all specimens were placed directly into a freezer to euthanize and preserve the individuals until identification. Any new or potential threat taxa were immediately reported to BIISC and OMKM staff to facilitate rapid response protocols for potential invasive threats (see Vanderwoude et al. 2015). Taxa included in triggering rapid response resampling events are: Ants (Order: Hymenoptera, Suborder: Apocrita, Family: Formicidae) and other taxa that are morphologically similar, i.e. look like ants, wasps (Order: Hymenoptera, Suborder: Apocrita, Families: Vespidae, Pompilidae, & Mutilidae) and other taxa that are morphologically similar, i.e. look like large wasps. [Excluded are: Suborder Apocrita, Families: Bradynobeanidae, Falsiformicidae, Rhopalosomatidae, Sapygidae, Scoliidae, Sierolomorphidae, Tiphiidae]), spiders (Order: Araneae), beetles (Order: Coleoptera) [Excluded are Suborder: Polyphaga, Family: Coccinellidae), horn & stable flies (Order: Diptera, Suborder: Brachycera, Family: Muscidae, Subfamily: Muscinae, Tribe: Stomoxyini), centipedes (Order: Scolopendromorpha, Family: Scolopendridae, Genus: *Scolopendra*), and mollusks (Phylum: Mollusca) (Vanderwoude et al. 2015). All other taxa were morphospecies identified and records of the identifications were organized using Microsoft Excel, and then discarded. Specimens captured by baited vial were placed directly into the freezer upon arrival to the lab, then extracted and placed in 5 ml screw cap glass vials with 70% ethanol with the original specimen label. All sticky traps were bagged together by sampling event, and then each trap was individually inspected under a microscope for any arthropod taxa. Any rarely encountered introduced taxa, new or potential threat taxa were excised from the sticky trap by cutting around the individual then gluing onto a note card detailing specimen label information.

Identification and vouchering of insects collected was conducted in the UH Hilo Teaching Research Arthropod Collection (TRAC Lab), using a dissecting microscope (Olympus SZ61), taxonomic specialists, digital records of taxa in Hawai‘i (Nishida, 2002), museum specimen comparisons and arthropod textbooks and relevant scientific publications. Unknown spiders were identified by BIISC staff, and were only identified to order, as further taxonomic detail was not necessary for their project, since no new spider taxa were encountered (no new threats). As such, those species were lumped into their own morphospecies, and will simply account for the occurrence of a spider individual for analysis. These spider morphotypes were known not to be the native *Lycosa* spider, which is easily identifiable by non-experts. All identified specimens and individuals that could not be identified to species level were recorded as numerical morphospecies for statistical analysis (ex. Spider #1, Spider #2, etc). Threats that are categorized as ‘Other’ represent the specimens that were either in poor condition or a minute juvenile that could not be identified beyond family, and at times order. Ant specimens were initially identified to species using the Key to Hawai‘i’s Invasive Ant Species (http://www.littlefireants.com/Hawai‘i%20ant%20key%200508_new.pdf), then identification was further confirmed at the Hawai‘i Ant Lab (HAL), Hilo, Hawai‘i.

2.6 Data Analyses

To create species accumulation curves, the data was formatted into abundance matrices with sample information in the first row, arthropod species or morphospecies information in the first column, and abundance counts in the cells. To predict morphospecies richness by sample effort the computer program, EstimateS version 9 software was used (Colwell 2013) to plot species accumulation curves for each of the sampling efforts, with 100 randomizations without replacement. I used threat and non-threat taxa morphospecies abundance data so the diversity estimates would weigh rare and common species differently. The Chao 1 diversity estimator was used for species accumulation curves, which would be more appropriate for incidence data (Colwell et al. 2012). The Chao 1 estimator (Chao 1 = $s_{obs} + (a^2/2b)$) assumes that rare species can reveal information about the number of unobserved species, and uses the observed number of species and the number of singletons (a) and doubletons (b) (a proxy for rarity) in a sample to give an estimation of the actual number of species present (Colwell and Coddington 1994). Similar to Thompson et al. (2007), I then visually assessed the morphospecies accumulation estimate curves to determine the sample effort at which the asymptote formed a plateau for richness when assessing the number of individuals that should be detected to determine the number of individuals necessary to detect 80% of the taxa for each sample effort.

Of the original arthropods collected, total arthropod abundance for each sampling event was separated in the final dataset and used in the analyses.

To assess differences in threat and non-threat arthropod occurrence between monthly sampling periods and trapping techniques, I used a one-way analysis of variance (ANOVA), followed by a Tukey’s post-hoc analysis using R version 3.3.1 (R Development Core Team 2015). The data for threat and non-threat species was analyzed separately for Subalpine and Alpine, and did not include data from low elevation ant surveys. Trapping techniques were formatted into richness and abundance matrices with sample station code information in the first column, trapping type information in the second column, and arthropod count data in the third column. Arthropod richness was calculated using means (within a month and trapping station) as data points. Arthropod abundance and richness counts were $\log^{10^{-}}$ transformed prior to analysis in an attempt to homogenize the variances and normalize the data sets due to many ‘zero’ records in rare occurrence data.

The incidence rate (presence/absence) of ants found on regulated and unregulated vehicles was compared using a Fisher’s exact test. This was repeated after excluding the debris sampling as these data were haphazardly collected and not a result of specific trapping method. To evaluate differences in ant detection by trap type, I compared ant occurrence between baited vials, sticky traps, hand search and debris search trapping methods for regulated and unregulated vehicles combined using a one-way analysis of variance (ANOVA). Further analysis of incidence rates (presence/absence) of ant incidence between all four sampling efforts for all vehicles were assessed using a Chi-Square test between trap types. The analyses were conducted using R version 3.3.1 (R Development Core Team 2015).

Section 3 Results

3.1 Alpine and Subalpine Arthropod Monitoring Statistics

A total of 6,041 arthropods were collected in the 407 sampling events of the 764 traps that were set during the entire sampling effort in alpine and subalpine habitats. For most of the 81 taxa collected, it was possible to make family-level or morphospecies determinations; as such, all were separated into morphospecies designations for statistical analysis. Taxa that were not identified to species level were separated into morphospecies for the purpose of this study. Genus and species designations between threat and non-threat were not a priority, as the only non-threat Araneae taxon captured was the endemic *Lycosa* spider. Araneae taxa that were identified to genus and species are *Lepthyphantes tenuis (*Blackwall, 1852)*, Eperigone tridentata* (Emerton, 1882) (family Linyphiidae) and *Meriola arcifera* (Simon, 1886) (family Trachelidae). Other Araenae specimens were separated into two general morphospecies that were either in poor condition or a minute juvenile, too small to identify to family, did not appear to be native taxa, and were consistent with previously collected morphospecies prior to 2015.

Of the 160 traps set at the Subalpine site at 2,800 m, 371 individuals of 36 morphospecies were collected (Table 1). Of these, 306 (82.48%) were non-threats, and 65 (17.52%) were threat taxa (Table 2). OMKM and TRAC Lab records show that the ant species is *Cardiocondyla kagutsuchi* and the spiders have all been encountered in previous arthropod sampling events. Of the 49 spider collections (46.94%), nearly half of the taxa (36.73%) belong to the family Trachelidae. The other identified taxa were divided evenly between Linyphiidae (8.16%) and Salticidae (8.16%). Baited sticky traps detected more spider individuals than baited vial traps for the Subalpine trapping efforts (Table 3).

Of the 459 Alpine traps set, 2,873 individuals of 63 morphospecies were detected (Table 1). Of these, 2,821 (98.12 %) were non-threats and 52 (1.81%) were threat taxa (Table 2). Araneae comprised of all threat taxa detected at the Alpine site and were identified as Linyphiidae (28.85%), Salticidae (21.15%), and Trachelidae (11.54%), and

Other Araenae (38.46%). Baited sticky traps detected more spider individuals than baited vial traps for the Alpine trapping efforts (Table 3).

Of the 145 traps set for the Sporadic Alpine Traps (see Methods), 2,797 individuals of 49 morphospecies were collected (Table 1). Of these, 2,786 (99.61%) were non-threats and 11 (0.39%) were threat taxa (Table 2). Araneae comprised all threat taxa detected at the Sporadic Alpine traps and are families; Linyphiidae (27.27%), Salticidae (9.09%), Trachelidae (9.09%) and Other Araenae (54.55%). Baited pitfall traps detected more spider individuals than hand searches, yellow pan traps, kill pitfall, and peanut butter jam stick (Table 3).

Despite the less intense trapping effort and overall lower arthropod abundance for Subalpine sampling efforts, more threat detections were found compared to all threats at Apline sites.

Table 1. Summary of arthropod diversity organized by sampling location and type.

	Subalpine		Alpine		Sporadic Alpine Traps	
Order	Abundance	Richness	Abundance	Richness	Abundance	Richness
Acari	14	1	4	1	nc	nc
Araneae	48	7	101	11	18	5
Coleoptera	8	3	14	5	22	5
Collembola	10	1	38	1	4	1
Dermaptera	nc	nc	Nc	nc	1	1
Diptera	193	8	791	12	1952	12
Hemiptera	44	8	1574	13	269	7
Hymenoptera	25	3	182	12	294	10
Homoptera	3	1	57	2	214	2
Lepidoptera	4	1	46	3	6	4
Lithobiomorpha	16	1	Nc	nc	nc	nc
Psocodoea	1	1	6	2	1	1
Thysanoptera	5	1	60	1	16	1
Total	371	36	2873	63	2797	49

*nc = not collected

. Summary of threat and non-threat taxa diversity organized by sampling effort.

	Subalpine		Alpine		Sporadic Alpine Traps	
	Abundance	Richness	Abundance	Richness	Abundance	Richness
Threat	65	8	52	10	11	4
Non-threat	306	28	2821	53	2786	45
Total	371	36	2873	63	2797	49

Table 3. Summary of threat taxa detection organized by trap type for all sampling efforts combined. Sampling at Subalpine and Alpine are baited vials (n=350) and sticky traps (n=269), and Sporadic Alpine trappings are baited pitfall (n=54), hand search (n=11), kill pitfall (n=15), PBJS (n=10) and yellow pan (n=55).

Family	Baited vial	Sticky trap	Baited pitfall	Hand search	Kill pitfall	PBJS	Yellow pan
Linyphiidae	3	16	1	0	1	0	1
Salticidae	1	14	1	0	0	0	0
Trachelidae	0	24	1	0	0	0	0
*Other	7	36	3	0	2	0	1
Formicidae	4	13	0	0	0	0	0

*Non-native juvenile Araneae

Species Accumulation Curves

The accumulation curve representing the number of discrete taxonomic units identified for Subalpine and Alpine sample efforts combined visually resulted in a steep initial slope that becomes less steep as the slope begins to approach asymptotic plateaus (Figure 5). The total threat and non-threat taxa richness of 81 morphospecies was slightly less than the Chao 1 mean estimated arthropod richness of 89.42 species with a 95% confidence interval lower bound of 82.47 and upper bound of 115.90.

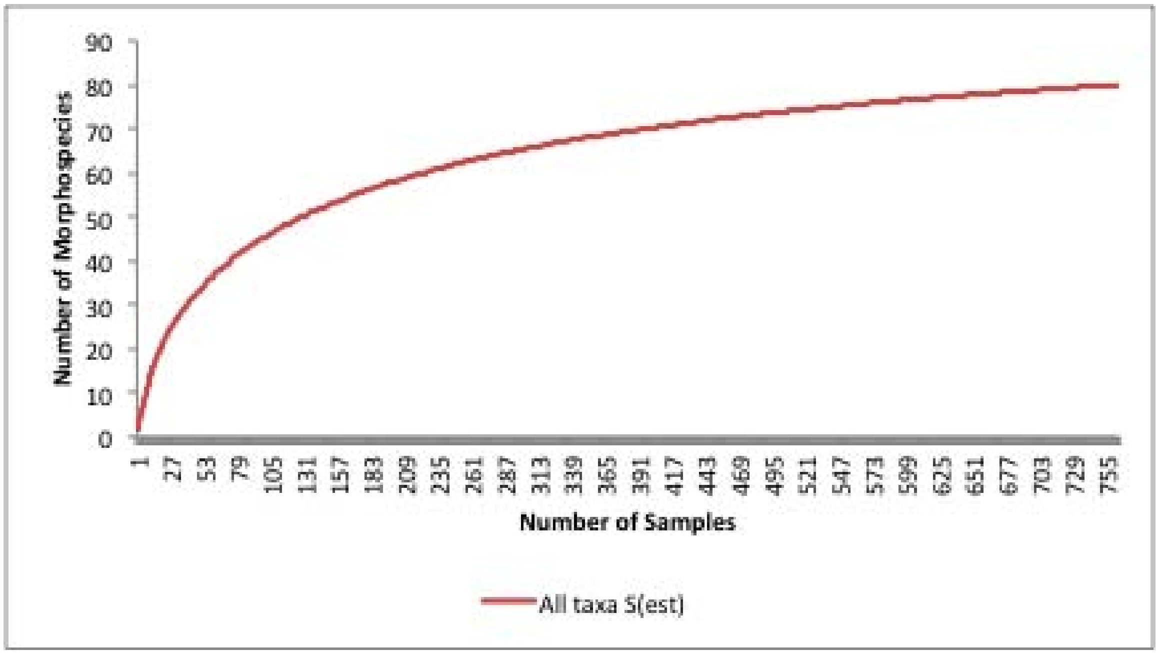

Figure 5. Morphospecies accumulation curves for Subalpine and Alpine taxa for all sampling events (n = 764 trapping effort).

Morphospecies richness curves for the Subalpine sampling effort resulted in a plateau not clearly defined (Figure 6). The sampling required to detect 80% of the total taxa observed would need 86 traps (of 160) given the rate of capture and estimated number of species suggested by the Chao 1 diversity estimate (Figure 6). However, the Chao 1 total species richness was higher than the observed number of morphospecies, indicating that all non-threat taxa were not found in the Subalpine area. The observed non-threat taxa estimated for 86 traps via the Chao 1 was 33.67 species and observed non-threat taxa richness of 22.4 morphospecies, which was less than the Chao 1 mean at 86 samples. At the 86 sample (80% of total diversity) threshold, the estimated arthropod richness had a 95% confidence interval lower bound of 24.31 and upper bound of 86.3 species. The accumulation curve of sampling efforts for Subalpine threat detections resulted in a slope that was less steep than non-threats and the plateau also not clearly defined (Figure 6). The observed threat taxa of 6.42 morphospecies sampled with 83 traps at the 80% diversity threshold, was slightly less than the Chao 1 mean estimated arthropod richness of 7.36 species with a 95% confidence interval lower bound of 6.5 and upper bound of 16.1. Threat taxa were more rarely encountered, therefore the estimated and observed richness had a smaller spread of estimates of number of species than the non-threat taxa which were much more common with higher singleton catch event for some non-threat species.

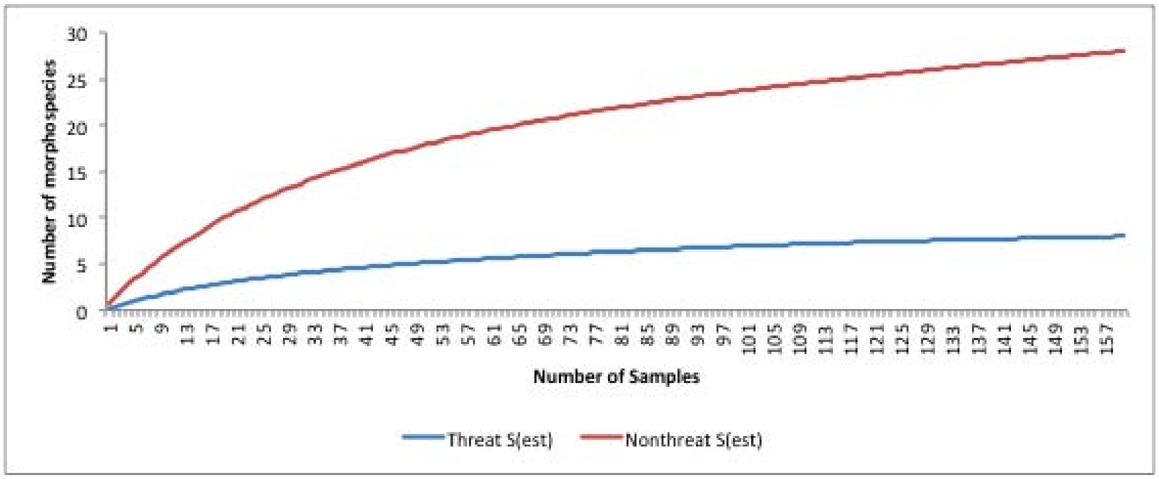

Figure 6. Morphospecies accumulation curves for threat and non-threat taxa for Subalpine (n = 160 trapping effort).

The accumulation curves representing sampling effort for the Alpine surveys resulted in an initial steep slope indicating many common taxa captured often and the plateaus clearly defined (Figure 7). The sampling required to detect 80% of the total taxa observed would need 175 traps (of 459) given the rate of capture and estimated number of species suggested by the Chao 1 diversity estimate (Figure 7). However, the Chao 1 total species richness was higher that the observed number of morphospecies, indicating that all non-threat taxa were not found in the Alpine sampling efforts. The observed non-threat taxa estimated for 175 traps via the Chao 1 was 42 morphospecies and the observed non-threat taxa richness of 51.22 morphospecies, which was less than the Chao 1 mean at 175 samples. At the 175 sample (80% of total diversity) threshold, the estimated arhtrpod richness had a 95% confidence interval lower bound of 43.33 and upper bound of 81.11 species. The accumulation curve representing threat detections for Alpine sampling effort was less steep than non-threats and the plateaus not clearly defined (Figure 7). The observed threat taxa of 8 morphospeceis sampled with 204 traps at the 80% threshold, was slightly less than the Chao 1 mean estimated arhtrpod richness of 8.41 species with a 95% confidence interval lower bound of 8.15 and upper bound of 16.24. Threat taxa were more rarely encountered, therefore the estimated and observed richness had a smaller spread of estimates of number of species than the non-threat taxa which were much more common with higher singleton catch event for some non-threat species.

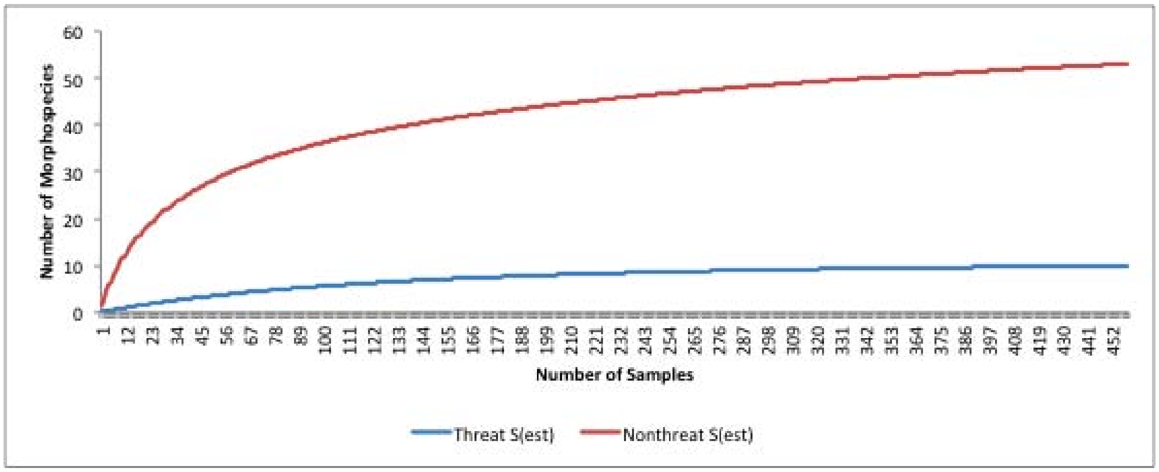

Figure 7. Morphospecies accumulation curves for threat and non-threat taxa for the Alpine sampling (n = 459 trapping effort).

The accumulation curves representing sampling effort for sporadic Alpine traps resulted in an initial steep slope that rapidly became less steep and the plateau not clearly defined (Figure 8). The sampling required to detect 80% of the total taxa observed would need 80% of the total taxa observed would need 74 traps (of 145) given the rate of capture and estimated number of species suggest by the Chao 1 diveristy estimate (Figure 8). However, the Chao 1 total species richness was higher than the observed number of morphospecies, indivating that all non-threat taxa were not found in the Sporadic Alpine traps. The observed non-threat taxa estimated for 74 traps via the Chao 1 was 36 morphospecies and the observed non-threat taxa richenss of 52.82 morphospecies, which was less than the Chao 1 mean at 74 samples. At the 74 sample (80% of total diversity) threshold, the estimated arthropod richness had a 95% confidence interval lower bound of 39.42 and upper bound of 122.75 species. The accumulation curve representing threat detections for sporadic Alpine sampling efforts resulted in a flattened curve to the slope and the plateaus was not clearly defined (Figure 8). The observed threat taxa of 3.1 morphospeceis sampled with 91 traps at the 80% threshold, was slightly less than the Chao 1 mean estimated arthropod richness of 4 morphospecies with a 95% confidence interval lower bound of 3.24 and upper bound of 12.99.

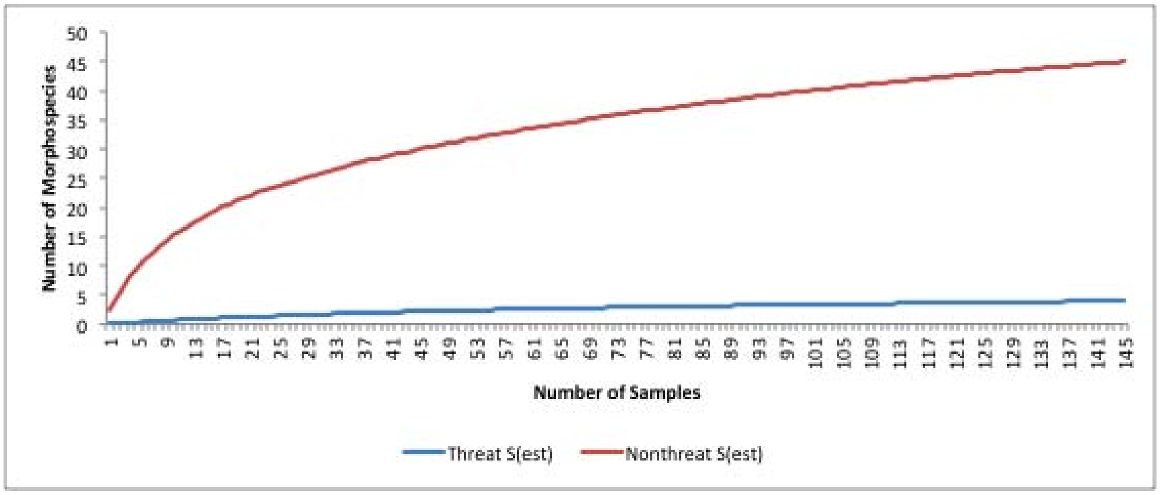

Figure 8. Morphospecies accumulation curves for threat and non-threat taxa for the Sporadic Alpine Traps (n =145 trapping effort).

3.3 Alpine Arthropod Diversity Comparisons

The mean non-threat taxa abundance data for the Alpine sampling effort varied significantly between monthly sampling periods (F = 15.897, P < 0.001) (Table 4). When months were assessed with post-hoc Tukeys comparisons, the ANOVA showed the mean non-threat abundances for August, September, and October were significantly greater than all other months, and abundances during August were greater than June. However, there was no significant difference in non-threat abundance between the other months. There were no significant differences between the mean threat abundance data for the Alpine sampling effort, and threat abundance did not vary significantly between monthly sampling periods (F = 1.51, P = 0.1393). The ANOVA showed no difference in mean threat abundance between monthly sampling periods.

The analysis found the mean non-threat richness data for the Alpine sampling effort varied significantly between monthly sampling periods (F = 2.95, P < 0.005). ANOVA showed that mean non-threat richness for June was significantly greater compared to March. However, there was no significant difference in mean non-threat richness for the other monthly sampling periods. Also, the mean threat richness data for the Alpine sampling effort did not vary significantly between monthly sampling periods (F = 1.61, P = 0.1134). ANOVA showed no differences in mean threat richness between monthly sampling periods.

Table 4. One-Way Analysis of Variance of arthropod threat and non-threat abundance and richness comparisons between Alpine monthly sampling periods.

		Abundance					Richness				
		Sum of Squares	df	Mean Square	F	Sig.	Sum of Squares	df	Mean Square	F	Sig.
Threat	Between Months	0.0014	9	0.00015	1.5104	0.1393	0.006	9	0.00066	1.619	0.113
	Within Months	0.0969	967	0.0001			0.068	166	0.00041		
	Total	0.098	976				0.074	175			
Non-threat	Between Months	1.85	9	0.205	15.897	**<0.001**	0.332	9	0.37	2.543	**0.0028**
	Within Months	12.49	967	0.013			2.072	166	0.012		
	Total	14.34	976				2.404	175			

*The values are shown on a relative scale resulting from a logarithmic transformation of the mean detection of arthropods by trap type ($p < 0.05$; ANOVA).
*Comparisons with *p* values less than 0.05 marked in bold.

3.4 Subalpine Arthropod Diversity Comparisons

The mean non-threat abundance data for the Subalpine sampling effort varied significantly between monthly sampling periods ($F = 3.18$, $P < 0.005$) (Table 5). ANOVA and post-hoc comparisons showed that mean non-threat abundances for February were significantly greater compared to other months, while abundances for August were greater than April. However, there was no significant difference in mean non-threat abundances for the other monthly sampling periods. The Subalpine sampling effort varied significantly between monthly sampling periods ($F = 3.63$, $P < 0.001$). ANOVA showed that mean threat abundances for February were significantly greater compared to all other months. However, there was not a significant difference in mean threat abundances for the other monthly sampling periods.

The analysis of the mean non-threat richness data for the Subalpine sampling effort did not detect significant differences between monthly sampling periods ($F = 1.29$, $P = 0.2805$). ANOVA showed no differences in mean non-threat richness between monthly sampling periods. Also, mean threat richness data for the Subalpine sampling effort did not vary significantly between monthly sampling periods ($F = 1.75$, $P = 0.6588$). ANOVA showed no differences in mean threat richness between monthly sampling periods.

Table 5. One-Way Analysis of Variance of arthropod threat and non-threat abundance and richness comparisons between Subalpine monthly sampling periods.

		Abundance					Richness				
		Sum of Squares	df	Mean Square	F	Sig.	Sum of Squares	df	Mean Square	F	Sig.
Threat	Between Months	0.0312	9	0.0035	3.6131	**0.0003**	0.00743	9	0.00083	0.754	0.659
	Within Months	0.2205	230	0.001			0.05261	48	0.0011		
	Total	0.2517	239				0.06004	57			
Non-threat	Between Months	0.1708	9	0.019	3.1864	**0.0012**	0.10579	9	0.01175	1.264	0.281
	Within Months	1.3699	230	0.006			0.44623	48	0.0093		
	Total	0.028	239				0.55202	57			

*The values are shown on a relative scale resulting from a logarithmic transformation of the mean detection of arthropods by trap type ($p < 0.05$; ANOVA).

*Comparisons with *p* values less than 0.05 marked in bold.

3.5 Alpine and Subalpine Trapping Technique Comparisons

An assessment of the non-threat richness of sampling methods for all sampling efforts combined varied significantly between the sampling types ($F = 61.23$, $P < 0.001$) (Table 6). ANOVA showed that mean non-threat richness for baited sticky and yellow pan traps were significantly greater compared to other trapping types (Figure 9). However, there was no significant difference in mean non-threat richness for the other trapping types used for arthropod surveys (Figure 9).

The mean threat richness for the sampling efforts varied significantly between the trap types ($F = 22.89$, $P < 0.001$). ANOVA showed mean threat richness for baited sticky traps were significantly greater compared to all other trapping types (Figure 9). However, there was no significant difference in mean threat richness for the other trapping types used (Figure 9).

Table 6. One-Way Analysis of Variance of threat and non-threat arthropod richness between sampling types for all sampling efforts combined.

		Sum of Squares	df	Mean Square	F	Sig.
Threat	Between Trap Type	0.039038	5	0.0078077	22.893	**< 0.001**
	Within Trap Type	0.124144	364	0.0003411		
	Total	0.163182	369			
Non-threat	Between Trap Type	1.9449	5	0.38897	61.234	**< 0.001**
	Within Trap Type	2.3122	364	0.00635		
	Total	0.028	369			

*The values are shown on a relative scale resulting from a logarithmic transformation of the mean detection of arthropods by trap type ($p < 0.05$; ANOVA).

*Comparisons with *p* values less that 0.05 marked in bold.

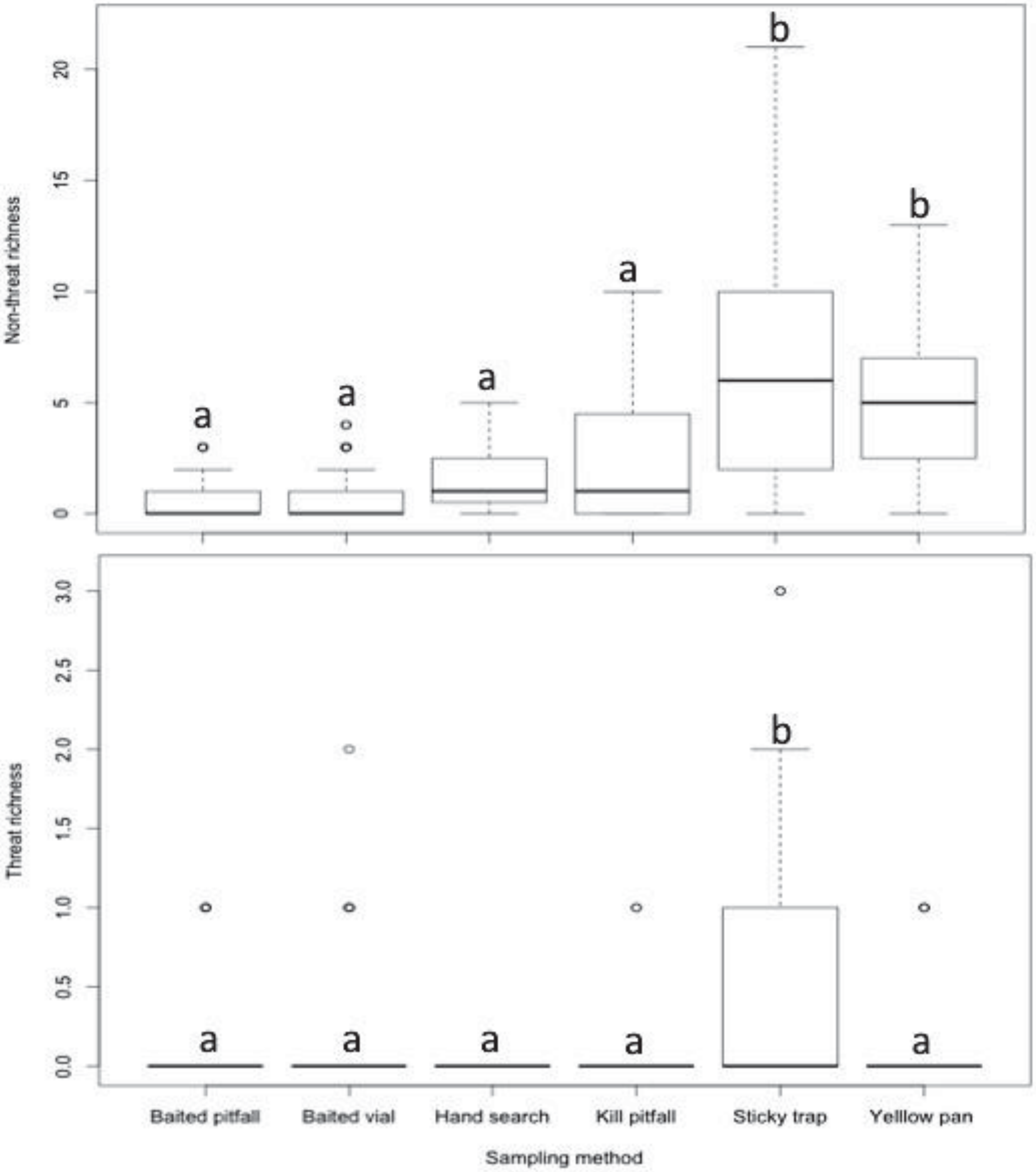

Figure 9. Threat richness proportion resulting from a logarithmic transformation of each sampling type positive of arthropod taxa (where 0.01 = 100%) for all Subalpine and Alpine sample efforts combined. Threat and non-threat richness data were analyzed separately, and means with the same letter are not significantly different (Bars represent ±95% CI) ($p < 0.05$; ANOVA)

3.6 Low Elevation Survey Assessments

Ant presence was detected at 13 of the 15 survey sites with a total of 18 species from 149 vials collected out of the 463 samples during the surveys (Table 7). Ant capture rate and species incidence varied across the 15 sample sites. Ants were consistently detected at the eight Hilo and two Waimea sites. Ants were occasionally found at the Pu’u Huluhulu site, and no ants were found at the Humu'ula Sheep Station or Keanakolu Cinder Quarry sites. Ants were sporadically encountered along the Maunakea Access Road transect up to the Mana Road junction (2,152 m elevation), and no ants were found at the Halepōhaku sites.

Table 7. Summary of survey effort, detailing survey date, elevation (m), number of vials set, number of vials with ants, and the percent incidence of ants at each source point. N =463 total traps; n = 15 sites.

Site	*Survey date	Elevation (m)	Vials set	No. With ants	% With ants
UHH Carpool, Hilo	12-Feb-16	50	16	15	93.8
Institute for Astronomy, Hilo	8-Jul-16	81	26	13	50
Joint Astronomy Center, Hilo	15-Aug-16	92	36	13	36.1
Gemini Observatory, Hilo	26-Jul-16	88	32	7	21.9
Suburu Observatory, Hilo	21-Jul-16	89	36	21	55.6
Maunakea Support Services, Hilo	20-Jul-16	19	13	8	61.5
Caltech Submillimeter, Hilo	14-Jul-16	95	17	5	29.4
Smithsonian Observatory, Hilo	14-Jul-16	76	17	12	70.6
CFH Observatories, Waimea	4-Aug-16	813	20	10	50
Keck Observatories, Waimea	4-Aug-16	820	40	28	70
Halepōhaku, Maunakea	15-Mar-16	2783-2841	78	0	0
Maunakea Access Road, Maunakea	18-Nov-16	2006-2786	44	9	17.9
Pu’u Huluhulu Parking lot, Saddle Rd.	8/15-Mar-16	2006	40	8	15
DHHL Keanakolu Quarry, Mana Rd.	15-Mar-16	2220	24	0	0
DHHL Sheep Station, MK access Rd.	10-Mar-16	2045	24	0	0

** The survey dates are spread through the year show ant presence at support sites and possible source point for invasive species introduction. Inferences made about comparisons between sites will be influenced by the discrepancies in survey dates.*

Hilo Town

A total of 193 traps were set at the eight telescope support facility sites in Hilo, of which 94 collected ants belonging to 16 species. In order of decreasing capture incidence (n), ants captured at six sites located in the University Research Park were *Wasmannia auropunctata* (23), *Anoplolepis gracilipes* (15), *Pheidole moerens* (11), *Brachymyrmex* *obscurior* (6), *Ochetellus glaber* (3), *Tetramorium bicarinatum* (2), *Cardiocondyla obscurior* (2), *Cardiocondyla kagutsuchi* (1), *Monomorium lilioukalanii* (1), *Solenopsis papuana* (1), *Tapinoma melanocephalum* (1), *Technomyrmex albipes* (1), *Technomyrmex difficilis* (1), *Technomyrmex simillimum* (1), and *Tetramorium caldarium* (1). At a one site at UH Hilo carpool *Wasmannia auropunctata* (14) and *Brachymyrmex obscurior* (1) were captured. Captures at Maunakea Support Services included *Pheidole megacephala* (6) and *Wasmannia auropunctata* (2).

Waimea Town

A total of 60 traps were placed at two telescope support facility sites in Waimea, and 38 collected ants belonging to three species. In order of decreasing capture incidence (n), ants captured at Keck Observatory support facility were *Pheidole megacephala* (25), *Plagiolepis alluaudi* (2), and *Solenopsis papuana* (1); and at CFH Telescope Observatory support facility, *Pheidole megacephala* (10).

South Slope, Maunakea Access Road Sites

Traps were placed at 88 field sites, and eight collected ants from a single species. Ants were only found at the Pu’u Huluhulu site, *Linepithema humile* (n = 8), and no ants were found at the DHHL Sheep Station and Keanakolu Cinder Quarry sites during this study.

Of the 44 traps, nine ants were collected on the Maunakea Access Road transect, belonging to two species. In the order of decreasing capture incidence (n), ants captured were *Linepithema humile* (8) and *Pheidole megacephala* (1). Ants were collected along the transect starting at Route 200 junction at 2,007 m elevation up to the Mana Road junction at 2,151 m elevation.

No ants were collected in the 78 traps at the Halepōhaku sites during this study.

3.7 Vehicle Pathway Species Detections

Sampling efforts conducted to detect the presence of potentially invasive threat taxa on vehicles were successful at detecting and collecting ants from vehicle surveys. The number of regulated vehicles with ants was 60% (n = 6), whereas 70% (n = 7) unregulated vehicles were positive for ants. However, when vacuum debris search samples were removed, 10% (n = 1) of regulated vehicles were positive for ants, and 60% (n = 6) unregulated vehicles were positive for ants.

A total of five species of ants were collected from regulated and unregulated vehicles from sampling efforts. Most of the sampling efforts (70 %, n = 56) had no ants. In order of decreasing total occurrence (n), ants collected were: *Wasmannia auropunctata,* 70.8 % (n = 17), *Ochetellus glaber* 8.3 % (n = 2), *Paratrechina longicornis* 8.3 % (n = 2), *Brachymyrmex obscurior* 8.3 % (n = 2) *and Anoplolepis gracilipes* 4.2 % (n = 1) (Table 8).

Table 8. Summary of ant species occurrence organized by sampling method and separated by vehicle wash type.

Species	Baited vial	Hand search	Sticky trap	Debris search
Unregulated				
Anoplolepis gracilipes	0	0	0	1
Brachymyrmex obscurior	0	0	1	0
Ochetellus glaber	1	0	1	0
Paratrechina longicornis	0	1	1	0
Wasmannia auropunctata	2	3	2	4
Regulated				
Brachymyrmex obscurior	0	1	0	0
Wasmannia auropunctata	0	0	0	6

3.8 Vehicle Pathway Cleaning Assessment

An assessment of all four trapping types revealed no significant difference associated with the occurrence of ants between regulated vehicles (30.4% incidence) and unregulated vehicles (69.6% incidence; Fisher's exact test, p = 0.1, Table 9). When the debris search sampling effort data (dead ants in vacuum bags) was removed from the analysis, results indicated no significant association between ant occurrence in assessing with regulated vehicles (8.3% incidence) and unregulated vehicles (91.7% incidence; Fisher's exact test, p = 0.057, Table 9).

Table 9. Ant incidence for regulated and unregulated vehicles with and without the inclusion of the vacuum debris search.

	Vehicle wash	Ant presence	Ant absence	Vehicles with ants (%)	CI (95 % ±)	Odds ratio	P-value
With debris search	Regulated	6	4	60.0			
	Unregulated	7	3	70.0	0.067 ± 5.78	0.657	1
Without debris search	Regulated	1	9	10.0			
	Unregulated	6	4	60.0	0.0014 ± 1.05	0.086	0.05728

*Comparisons of regulated vs. unregulated vehicles positive for ant presence conducted with and without the inclusion of debris search sampling method ($P< 0.05$; Fisher's exact test).

3.9 Vehicle Pathway Trapping Method Assessments

Comparisons between trapping techniques revealed no significant differences in mean ant incidence (1.012 ± 0.0189 SD) between the total four ant sampling methods ($F = 2.25$, $P = 0.08916$). ANOVA showed no differences in mean detections of ants between baited vials, hand searches, sticky traps and debris search. The data had many zeros and did not have a normal distribution. A parametric test was not ideal, but was conducted, as ANOVA are considered generally robust enough for this analysis (McDonald 2014). A nonparametric statistical analysis was also used as an alternative approach to address the issues with parametric analysis by comparing ant incidence distributions, rather than mean ant detections between trapping techniques.

Analysis of ant incidence for all four trapping efforts and all vehicles revealed ant occurrences ($n = 24$) were not evenly distributed across the four sampling types ($X^2 = 8.57$, df=3, $p<0.05$, Figure 10a). A Chi-square test found significant differences in ant detection distributions between trapping debris searches (45.8% of ant detections), baited sticky traps (20.8%), hand searches (20.8%), and baited vials (12.5 %) (Figure 10b).

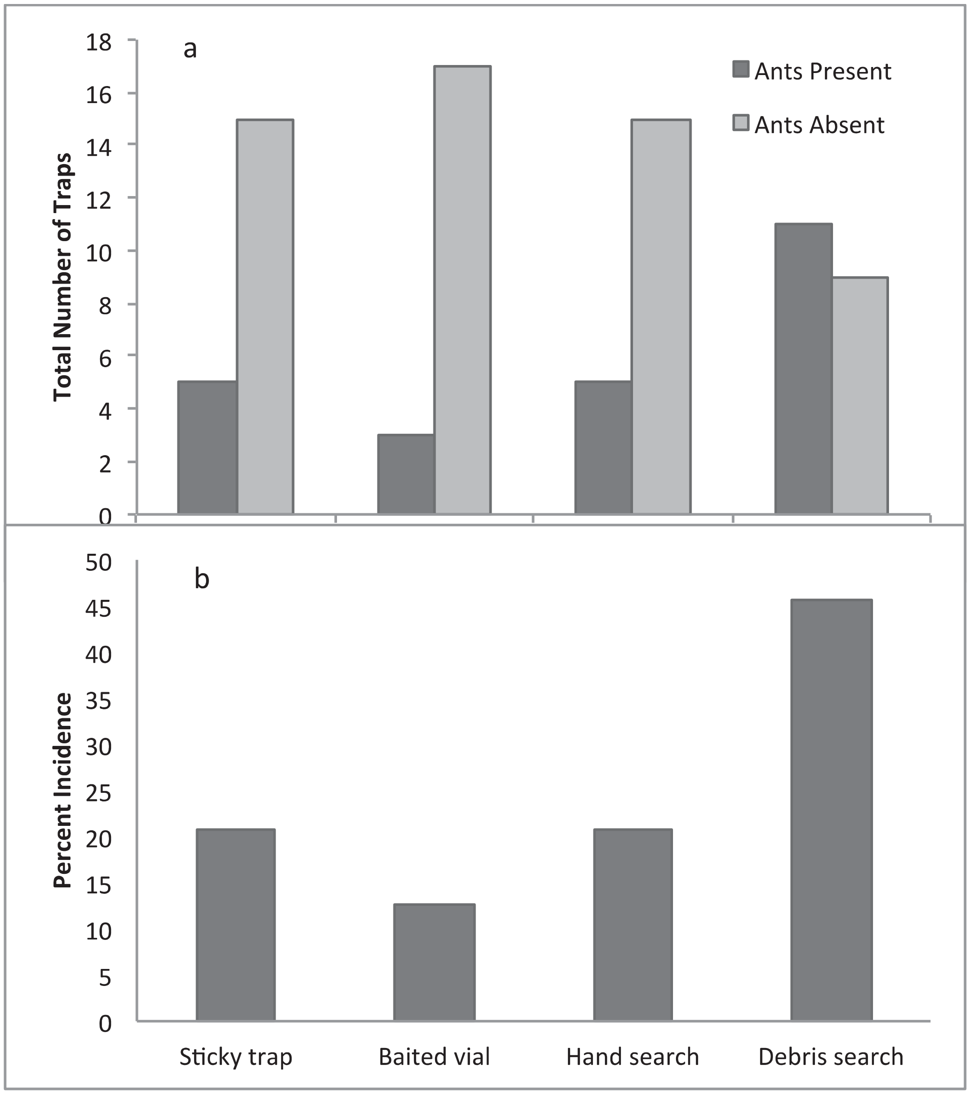

Figure 10. Total numbers of traps and the number of ant detections by the four trapping method (a) and percent incidence (b). Significant differences in ant detection distributions between trapping debris searches (p< 0.05; Chi-square).

Section 4 Discussion

4.1 Threat Detections: Alpine and Subalpine

The alpine and subalpine sampling efforts conducted were successful at detecting invasive threat taxa, as defined in the Maunakea Invasive Species Management Plan (2015), in the two different high elevation zones in alpine and subalpine ecosystems. Surveys were able to detect ten spider threat taxa that were regularly encountered at both sampling locations, and priority threat taxa, family Formicidae, which were found at the Subalpine site and have been reported in the surrounding area at ~2,800 m (OMKM per coms.). It should also be noted that social Hymenoptera, Vespidae, was not collected during these surveys, but are common in the subalpine area, and may infer that the trapping methods used in these surveys were not effective at detecting this taxon. Comparisons of the three sampling efforts conducted by BIISC during the 2015 sampling period found that all ten spider threat taxa occurred during the Alpine sampling effort, whereas seven were found at Subalpine and only four were detected in the sporadic Alpine Traps during the summer sampling efforts. The threat taxon, Trachelidae *M. arcifera*, was the most prevalent spider (<35%) during Subalpine surveys. It should be noted that spider species of the family Agelinidae are regularly encountered around the Subalpine area (Eiben per coms), but were not collected during these sampling efforts. Alpine sampling revealed greater occurrence of smaller and minute Linyphiidae and Salticidae taxa (50%). Substantially less threat taxa were detected in the sporadic Alpine Traps, but sampling efforts were still successful at detecting Linyphiidae in <25% of the total threat occurrence during the sampling.

Although Vanderwoude et al. (2015) considers spiders to not have the same threat potential on Maunakea as ants, spiders have been reported being responsible for killing an estimated 400-800 million tons of prey annually (Nyffeler and Birkhofer 2017) and spiders have been suspected as one of the most important groups of natural enemies of insects worldwide (Seldon 2016). Spiders are successful predators due to their generally high abundance, accompanied by a highly developed sensory system which enables individuals to detect potential prey and predators in the surrounding habitat (Barth 1997, Nyffeler 1999). Furthermore, spiders can have the potential to withstand the varying availability of resources due to pulsed feeding patterns, which enables spiders to withstand starvation when resources are limited and store energy reserves when resources are abundant (Anderson 1974; Sunderland et al. 1999). Dispersal ability is a key trait of successful invaders, and many spider species are excellent dispersers. Many spiders can move by air via ‘ballooning’ using strings of silk that allow the wind to carry the young spider aloft as dispersal mechanisms (Bell et al. 2005). Ballooning is facilitated by size, so smaller species and juveniles of larger species may have greater potential to balloon (Malumbres-Olarte et al. 2013). Spiders also have capability to survive under extreme conditions of cold and UV light during dispersal, which potentially alludes to being readily adaptable to the extreme conditions present at the alpine summit of Maunakea.

The threats detected reflect that smaller taxa such as Linyphiidae and Salticidae were found in greater abundance during the Alpine sampling efforts. Another important factor in the detection of smaller non-native taxa at higher elevation sites on Maunakea is likely due to the aeolian distribution of alien arthropod taxa (Howarth 1987). The minute spiders, particularly juveniles engaging in ‘ballooning’ silk thread dispersal events, were regularly found during the Alpine rather than Subalpine sampling efforts. At lower subalpine elevations, larger taxa have been associated with dispersal moving into and colonizing sites due to their ability to travel longer distances over land, rather than aerially (Malumbres-Olarte et al. 2013). This may explain why larger taxa, such as Trachelidae, were more prevalent during Subalpine surveys. Furthermore, an increasing occurrence of threats can potentially be expected for the subalpine area where greater exposure to human activity and a greater variety of available food arthropod resources can be exploited due to the warmer and wetter environment with more established plant diversity (Gerrish 2013).

Of the spider threats detected regularly throughout alpine and subalpine regions on Maunakea, it is unclear what direct impacts these spiders actually have on the native arthropod fauna. These spiders should be continually monitored as threats, but may not reach a threshold of invasive until the food resources they use have a negative impact on endemic species through predation or competition. Subalpine sites have different cultural and ecological resources when compared to the remainder of the higher elevation Management Area, so threat arthropods will likely have different impacts in different areas. Both sites experience regular human use through the year and are impacted by a number of introduced weedy plant and animal species, with more invasive weeds present at the Subalpine region (Gerrish 2013; MKCMP 2009).

At the beginning of 2015 sampling effort, Subalpine sampling efforts detected *Cardiocondyla kagutsuchi* (Formicidae) on two occasions. The baited sticky trap and vial sampling methods both successfully detected ants when they occurred within the management area. *C. kagutsuchi* represents the only ant species known to date that has been able to become established in the UH management area (OMKM per com and this study). Furthermore, *C. kagutsuchi* is collected occasionally around the Subalpine Halepōhaku area (OMKM per com), and has been found relatively close to the Subalpine region at 2,233 m elevation, appearing to be dispersing along Keanakolu-Mana Road between the Hakalau National Wildlife Refuge and the Observatory Road (Peck and Banko 2011). Although trapping efforts detected ants at the Halepōhaku Ranger Station parking lot, further visual inspection conducted by OMKM staff found that the ants appeared to be established around the Maunakea Support Services facility (2,830 m elevation) as well (OMKM per com). Visual surveys around buildings, parking lots found this species around the roots of weedy plants tending root mealybugs and foraging for water thus revealing a greater distribution than traps indicated. Although curious around baits, this species did not recruit in large numbers and did not remain at baits for a prolonged period of time. Supported by Peck and Banko (2011), visual inspections (hand searches) are a more effective survey method than normal baiting practices for this ant species. While *C. kagutsuchi* may not be deemed as problematic as other ant species in the high elevation areas of Maunakea (Krushelnycky and Gillespie 2010), this species could be deemed a precursor indicator of the habitat being likely to also harbor a higher threat species like the Argentine ant, *L. humile*, which has high evidence of negative effects on native Hawaiian arthropods and plants (Krushelnycky and Gillespie 2010)

4.2 Monitoring Methods: Alpine and Subalpine

The species accumulation curves that were created and visually assessed, indicated that monitoring methods (sampling efforts) were adequate to detect arthropod species associated with sampling events for Alpine and Subalpine traps. The shape of the species accumulation curves did not differ significantly between sampling efforts for threat and non-threat taxa, and plateaus were not always clearly defined. Furthermore, Thompson and Wither (2003) asserts that when an assemblage contains a high number of less common or rare taxa, species accumulation curves tend to be less steep and the plateaus not as defined. The threat species accumulation curves were generally flattened for each of the sampling efforts leading to the assessment that sampling efforts were sufficient to detect even rarely encountered threats. Non-threat species accumulation curves exhibited steeper slopes initially, indicative of assemblages with lower numbers of rare species and more common species (Figures 6-8). Some of the taxa that are collected in lower numbers can be perceived as rare and influence the overall visual appearance of the accumulation curve by creating a less steep initial curve and not flattening until many more repetitions of sampling are analyzed. Thompson et al. (2007) asserts that a more realistic estimate of species richness as seen in accumulation curves can be obtained as a product of relatively large number of traps and numbers of individuals collected. Because of the high sample size in the high elevation surveys, even when less individuals are detected, the curves still are a robust way to detect species diversity.

At both survey locations, arthropod detections varied in abundance for threat and non-threat taxa between monthly sampling periods. This pattern shows why regular sampling is necessary to detect different threats or non-threats throughout the year, as the conditions that may support populations of arthropods changes month-to-month. Non-threat abundance was significantly different for sampling efforts at Subalpine and the Alpine (Table 4 and 5). However, threat taxa abundance was different only at Subalpine and was consistent at the Alpine (Table 4 and 5). These differences in numbers of individuals of a given taxon would be influenced by month-to-month environmental variability, but some of the taxa present may be consistent throughout the year. Despite these differences in taxa abundance between sites, overall arthropod richness was not as variable compared to taxa abundance for sample efforts. For example, trends in threat and non-threat richness were relatively consistent throughout the entire 11-month sampling period (Table 4 and 5).

Comparisons of threat richness between the sampling methods indicate that baited sticky traps were able to detect more threat species than other sampling methods (Figure 9). Likewise, comparisons of non-threat species richness between sampling methods indicated that baited sticky traps along with yellow pan traps were more effective at detecting non-threat species than other trapping methods (Figure 9). Baited sticky traps were the most effective trapping technique used at detecting threats, attributed with collecting 80% of the total threat taxa.

Although baited vials captured a variety of threats, sticky traps were exposed to arthropod taxa for greater periods of time as these traps remained active for days at a time, mechanically trapping specimens rather than luring with only bait and captured only during feeding. Baited sticky traps also allowed for sampling at night, and may have proved effective at detecting species with nocturnal predatory activities, which may remain largely unnoticed and therefore difficult to detect (Malumbres-Olarte et al. 2013). Nevertheless, it is important to note that these specimens were commonly minute and usually in poor condition due to the trapping methods, where the adhesive residue of the trap would often permeate into smaller specimens, making identification difficult. Certain threat taxa were only identified to order, as further taxonomic detail was not necessary for this project given the difficulty of definitive identification when captured with adhesive.

4.3 Threat Detections: Low Elevation

The sampling effort for potential source point populations of threat species at elevations lower than ~2,800m had different strengths and weaknesses than the survey methods conducted at high elevations. The lower elevation sites and methods used were likely better suited to detecting more prevalent ‘tramp ant’ species, given the most commonly detected species recruit quickly and in large numbers to baits and potentially ward off other species in the area. The sampling lacked the ability to sample over longer periods of time, which would allow for greater trap exposure to ant species in the area. Furthermore, several other species, although captured rarely across all sites, were still collected in small numbers around baited traps. All ant species that were collected in these surveys have been previously found in Hawai‘i.

Ant species diversity was greatest at telescope support facilities in Hilo at ~50m, with multiple species detected at all eight survey sites. Of the 16 ant species found at the telescope support facilities in Hilo, 41% were *W. auropunctata. Wasmannia auropunctata* was first recorded in Hawaiʻi in 1999 (Conant and Hirayama 2000), and populations have since been found throughout the island in moist areas. Four of the five ant species that have been collected previously at the Management Area (Vanderwoude et al. 2015), were detected during these surveys including *C. kagutsuchi*, *O. glaber*, *T. melanocephalum* and *T. albipes,* which were collected on six occasions at UH Research Park in Hilo. It should also be noted that *P. megacephala* occurred only at the Maunakea Support Services facility in Hilo.

In Waimea, ~200m elevation, the rate of ant presence in vials were similar to telescope support facilities in Hilo, as ants commonly occurred in >50% of baited vials, but Waimea sites had noticeably lower ant species richness than Hilo. Of the three ant species that occurred at the telescope support facilities in Waimea, about 92% were *P. megacephala,* which were generally considered lowland species (Reimer 1994). However, past surveys on Maunakea have found *P. megacephala* individuals reaching elevation of 2,430 m (Wetterer et al. 1998), giving reason to believe that populations of this species may be able to tolerate certain microhabitats near subalpine Halepōhaku, given the dry forest ecosystem similarities described earlier (see Methods, Section 2.2). *Pheidole megacephala* has definitive negative effects on ecosystem processes in Hawaiʻi (Reimer 1994). Small numbers of *S. papuana* and *P. alluaudi* were detected at Keck Observatories Support Facilities in Waimea. The ecological effects of *P. alluaudi* in certain Hawaiian habitats are considered modest (Krushelnycky 2015). Similar to many other tramp ants, this species is associated with forming mutualistic relationships with honeydew producing Hemiptera taxa (Wetterer 2014). Furthermore, *P. alluaudi* has been intercepted at the Alpine region, and therefore represents a known potential threat (Vanderwoude et al. 2015).

Ant occurrence at Pu'u Huluhulu (2,000 m elevation) at the junction of Route 200 and Maunakea Access Road was relatively rare, and of the 44 vials placed, eight detected species *L. humile*. Distribution of ants around the parking lot of this cinder cone area varied, but detection often occurred 5-10 m from the edge of the parking lot. Ants were found around areas that were partially shaded and directly underneat pūkiawe shrubs *(Leptocyphylla tameiameiae*), near the parking lot. *Linepithema humile* has been recently reported in the area (Krushelnycky and Gillespie 2008) and, subsequently, chemical barrier treatments were applied by land management staff to kill these ants along the border of the parking lot (BIISC per coms 2016). In Hawaiʻi, *L. humile* has proven to one of the few ant species able to tolerate cold temperatures found at higher elevations (Huddleston and Fluker 1968), and have been associated with a number of adverse impacts in native Hawaiian ecosystems, reaching elevations up to 2,880 m and has successfully invaded Haleakalā National Park on Maui (Cole et al. 1992). This ant species has also been linked to significant reductions in the abundance of other native invertebrates including key pollinators associated with the Haleakalā silversword (*Argyroxiphium sandwicense*) (Krushelnycky & Gillespie 2010).

Ants were detected rarely along transects on the Maunakea Access Road and occurred between 2,007–2,152 m elevation. Of the 44 vials placed, roughly 20% of vials detected ants that were mostly *L. humile* except a single instance of *P. megacephala* found at a few hundred meters below the DHHL Sheep Station at 2,032 m elevation. Interestingly, Wetterer et al. (1998) reported no *L. humile* along the Maunakea Access Road and found populations of *Cardiocondyla venustula* at approximately 2,000–2,200 m elevation in surveys in the same area, supporting earlier observations that ant populations are growing or shifting in localities on Maunakea. While it is suspected that the initial *L. humile* incursions at nearby Pohakuloa were a direct result of the military supplies movement (Wetterer et al. 1998), the gradual spread of ant populations once limited by the lack of resources can possibly be encouraged by the gradual incursion of invasive weeds and hemipteran insects into previously undisturbed native habitats, thus creating more ecologically matched habitat these ant can exploit.

4.4 Vehicle Pathway Assessments

Although there were not statistically significant differences, ant occurrence was rare on regulated vehicles with only 10 % positive for live ant presence compared to ant presence being more common on unregulated vehicles with 60 % of vehicles found with live ants. For all ant detections, actively foraging individuals aggregating to baits in relatively high numbers occurred twice, while all other ant captures involved a single individual. Ant species *W. auropunctata* and. *P. longicornis* were both found on separate occasions on unregulated vehicles foraging on baits in relatively high numbers, and are associated with lower elevation distributions in Hawaiʻi (Reimer 1994). Vanderwoude et al. (2015) suggested that these species are still a legitimate threat given their invasive nature and the existence of human modified areas at the subalpine Halepōhaku area, even though these species are generally associated with moist environments. Moist conditions are rarely found in the alpine stone desert throughout the year with weather events and protected water seep areas long after singular rain events (Juvik et al. 1978). Subalpine facilities could provide suitable moist and food rich microhabitats for these ants to occupy due to water use and building foundations providing access to deep moist soil. Although captured less often than the two previously mentioned species, it should be noted that species *O. glaber* has been intercepted on the Maunakea (2,800 m) State lands not managed by the University in 2015 (OMKM per coms 2016).

Although significantly different levels of ant occurrence between vehicle types were not statically detected, overall cleanliness of a vehicle, and decontamination methods recommended by OMKM appeared to have biological impacts on ant occurrence. Overall, regulated vehicles were less contaminated with debris than unregulated vehicles, which had greater numbers of ant detections and species occurrence. It should be noted that upon removal of debris sampling, the analysis approached significance from $p = 0.089$ to $p = 0.057$, and given the evidence from debris searches that ants were removed from vehicles in debris, support the notion that using regulatory cleaning protocols to remove debris is likely effective at ant reduction. However, assumptions about the overall efficacy of the cleaning methods at removing all threats are limited from these assessments and should be approached with caution given the discrete and pervasive nature of ants.

While the current practice of regular vehicle washing can remove ants, the ability to account for threats elsewhere throughout the vehicles that are inaccessible to regular wash methods will require other techniques to detect or reduce threat occurrence. For example, visual inspections of regulated 4WD vehicle revealed a crevice between the frame and underbody of the vehicle, where a substantial amount of ash and soil debris accumulated. These areas on vehicles are completely sheltered from washes and most interior sweeping or vacuuming, can potentially provide habitat for arthropod threats to occupy, and were only noticeable after careful inspection by implementing hand searches and manually pulling materials from plastic cladding for sampling. Overall, different situations, vehicles and ant species will allow each trapping technique some success. Rapidly detecting potential invasive species and assessing the mechanisms associated with human assisted dispersal of these species will enable timely management decisions. Also, resources needed to mitigate introductions can be more efficiently funded and maneuvered when risk pathways of new introductions of taxa or likely introduced taxa are known.

Section 5 Conclusions & Recommendations

By evaluating arthropod occurrence and trapping efforts, I was able to show how high elevation monitoring efforts were able to detect the priority threat taxa (spiders and ants) at the start of the monitoring period, and I could assess several trapping techniques' suitability for detecting arthropod threats at the subalpine and alpine region of Maunakea. These preliminary tests provide new insights into the prevalent arthropod taxa found using the sampling methods employed and describes the importance of regular (monthly) monitoring using specific trapping techniques that detect target species. By implementing the methods of this study, a myriad of arthropod taxa and seasonal variations can be aacounted for and used for future land managment work. The information acquired from the accumulation curves can be used to determine future land management decisions by refining monitoring efforts to focus resources and personnel in the most effective ways to reduce the risk of invasive arthropods introduction associated with human activities at the Maunakea summit region.

The actions necessary to effectively reduce risks associated with invasive arthropod introduction will remain a concern for land managers of sensitive habitats. Ideally, multiple trap types should be continually employed to increase the chances of novel taxa detection, and a slight reduction in the total number of traps during a month can be supported by this data. However, rarely encountered taxa, such as newly detected invasive taxa, will always have a higher chance of encounter with more samples. Continuous monitoring data will also be effective at detecting established taxa, instead of occasional migrants, as non-resident rare threat taxa were apparently found on numerous occasions.

The ant occurrence data from the lower elevation support facility source point surveys showed that facilities associated with the summit region do represent a potential threat because priority threat taxa were detected. Surveys of support facility source sites can be used to encourage and refine or improve proactive efforts to address the previously undocumented risks of introduction by ants and other invasive species from these sites. The results from these preliminary support facility surveys provide baseline information for proactive threat risk reductions for land managers. These surveys provide insight into the diffent ant populations present at support sites, and shows that diffent species persist in diffent locations. The preliminary results also identify potential movement of key threat ant populations of *L. humile* found at survey sites at the base of Maunakea Access Road that lead to high elevation habitats of concern. The sampling and trapping effort data can be directly utilized by land managers to refine and develop improved arthropod threat monitoring strategies. New strategies to monitor or eliminate source point ant populations can ultimately streamline resources and personnel in the effort to mitigate the risks associated with invasive arthropod introduction.

By conducting threat taxa vehicle pathway and movement assessments, I was able to determine that vehicles can act as pathways for invasive ants, even though only non-reproductive ants were seen. Vehicle pathway assessments provide useful information about the sampling efforts and the arthropod threat taxa associated with vehicles, while simultaneously demonstrating some of the limitations of current protocols. For example, the incorporation of undercarriage sprays that focuses on lower corners of wheel wells between mud-flap (functioning as pockets for soil/dirt, plant matter and arthropods) along with thorough visual inspections can reduce contaminants, and therefore reduce ant occurrence. Given the biological trends in these results, vehicles accessing the subalpine and alpine region in official capacities are recommended to continue implementing current decontamination protocols and prophylactic bait treatments would be more likely to interrupt establishment and lifecycles of threat taxa in vehicles that undergo occasional episodic cleanings or treatments. Furthermore, it is best to keep cleaning activities at lower elevation sites to reduce the risk of depositing arthropods as a function of the decontamination process. By detecting potential invasive species at support sites of human activities conducted at high elevation Maunakea facilities and assessing the mechanisms associated with human assisted dispersal of these threat species, management authorities will be better enabled to make timely management decisions. Also, resources needed to mitigate introductions can be more efficiently funded and maneuvered when risk pathways of new introductions or likely introduction taxa are known.

Appendices

The original dataset includes records of arthropod specimens that were collected from the BIISC sampling effort that spanned a total of 11 months. These original data from OMKM and by request from the author, Jorden Zarders at zarders@Hawai‘i.edu.

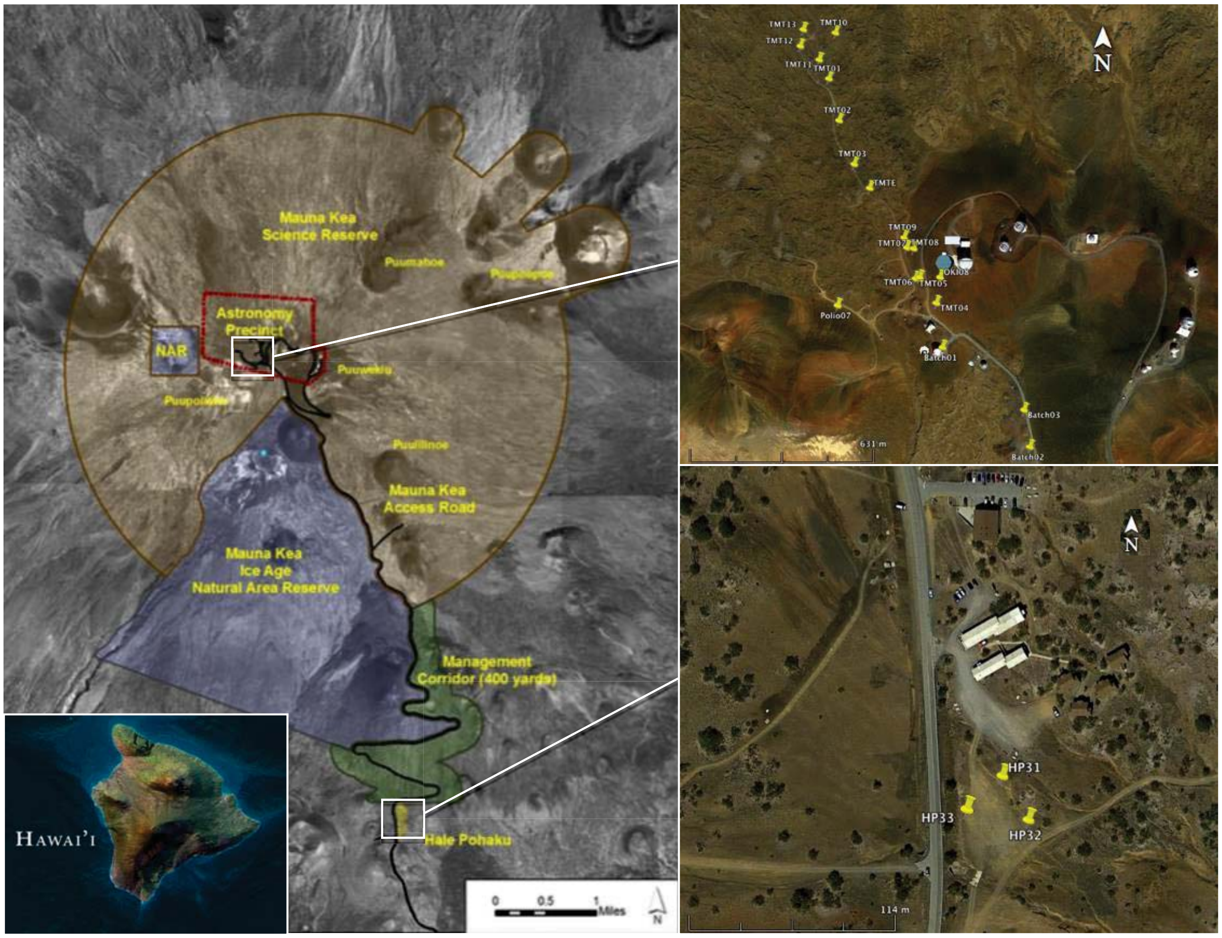

Figure 11. Map (left) detailing the two sampling locations. The sample stations market with yellow pins at the Alpine (upper right) (n = 19) and Subalpine (bottom right) (n = 3). Inset map shows the UH Management Area position on Hawai‘i Island. Maps derived from the Maunakea Comprehensive Management Plan (MKCMP 2009); Google Earth Pro (2013).

Figure 12: Maps of support facilities ant surveys in Hilo, Hawaiʻi at UH Hilo Carpool Services parking lot (left), and at Maunakea Support Services (right). Yellow pins indicate approximate location of trap placement. Pins situated over building represent baited vial sites under the covered open area of the structure; Google Earth Pro (2013).

Figure 13: Maps of telescope support facilities ant surveys in Hilo, Hawaiʻi (clock-wise) at, the Joint Astronomy Centre (top left), Institute for Astronomy (top right), Suburu Observatory along with Smithsonian Astrophysical Observatory (bottom right), Caltech Submilimeter Observatory (bottom left), and Gemini Observatory (middle left). Yellow pins indicate approximate location of trap placement. Pins situated over building represent baited vial sites under the covered open area of the structure; Google Earth Pro (2013).

Figure 14: Maps of telescope support facilities ant surveys in Waimea, Hawai'i at Keck Observatory (left) California France Hawai'i Telescope Observatory (right). Yellow pins indicate approximate location of trap placement Pins situated over building represent baited vial sites under the covered open area of the structure; Google Earth Pro (2013).

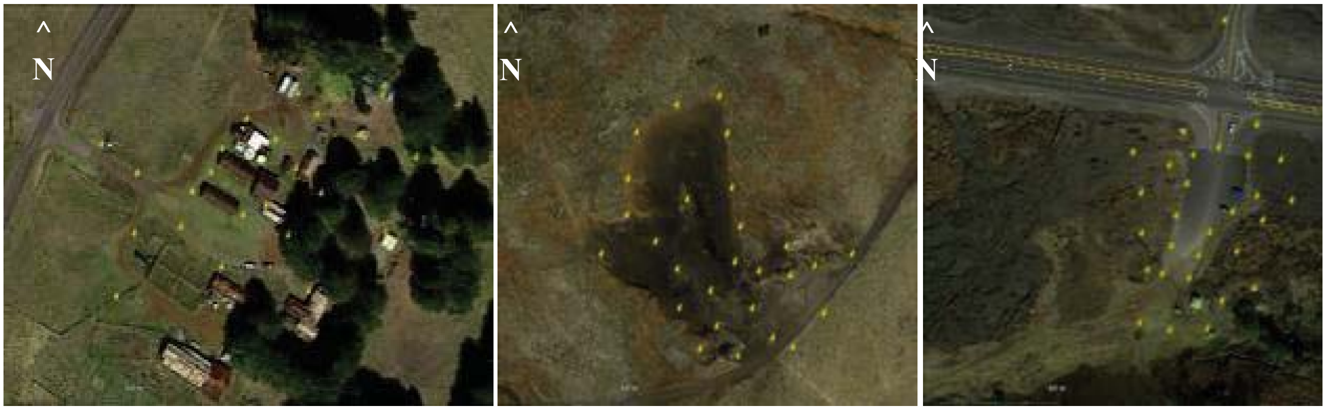

Figure 15: Maps of ant surveys conducted at field sites near the of the Maunakea Access Road, Hawai'i at Pu'u Huluhulu parking lot (left), DHHL Sheep Station (middle), and Keanakolu Pu'u Cinder Quarry (right). Yellow pins indicate approximate location of trap placement. Pins situated over building or trees represent baited vial sites under the covered open area of the structure; Google Earth Pro (2013).

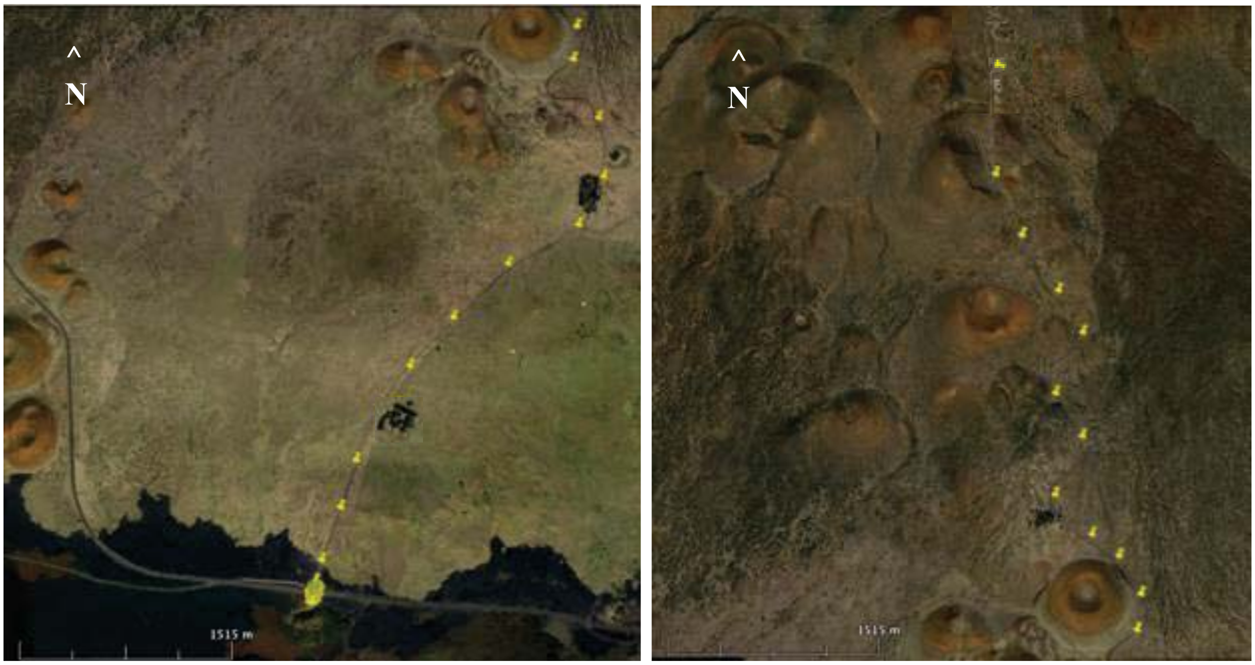

Figure 16: Maps of ant surveys conducted along a transect on the Maunakea Access Road, Hawai‘i starting at the Route 200 junction near the bottom of the access road (left), and ending at Halepōhaku (right). Yellow pins indicate approximate location of trap placement; Google Earth Pro (2013).

Figure 17: Maps of ant surveys for Halepōhaku, Hawai‘i at the Onizuka Center for International Astronomy and Halepōhaku Rangers Station (left), and the Maunakea Support Services facilities and dormitories (right). Yellow pins indicate approximate location of trap placement. Pins situated over building represent baited vial sites under the covered open area of the structure; Google Earth Pro (2013)

Table 10. Detailed descriptions of each trapping method used for single vehicle pathway survey assessment.

Survey method	Trap type	Trapping duration	Sample effort (n)	Vehicle trap placement	
				Interior	Exterior
Hand search	Visual searches and collection any arthropod threats by hand using a 30 ml plastic snap cap vial or aspirator.	5 minutes	2	Inspection (n=1) for arthropods around the floor mats, seating areas, the center console and trunk.	Inspection (n=1) for arthropods around the front and rear bumper, near windshield wipers, under footsteps, wheel wells and wheels.
Baited vial	30 ml plastic snap cap vial baited with peanut butter, jam and hotdog.	45 minutes	14	Traps (n=2) placed in the interiors of vehicles under the front seat near the center console and trunk.	Traps (n=12) placed around the exterior of vehicles, with placement varying per vehicle type but consistently set around the bumpers, windshield wipers, footsteps, wheel wells and wheels.
Baited sticky trap	Sticky traps (ZoroZoro brand cockroach traps, Taisho Pharmaceutical Co., Ltd, Japan) baited with peanut butter, jam and hotdog.	7 days	2	Sticky traps (n=2) placed under the front passenger seat and in the trunk.	No sticky traps (n=0) set on exterior of vehicles.
Debris search	Extraction of debris from vehicles. Contents were volumetrically measured, weighed, and inspected for the presence of arthropods using a dissecting microscope	5 minutes	2	Vacuumed (n=1) around the door edges, floor mats, seating areas, the center console and trunk. Vacuumed contents transferred to plastic resealable bags, and then cleaned post use.	Collect (n=1) debris and earthen material from around the front and rear bumper, near windshield wipers, under foot steps, wheel wells and wheels by hand and transferred into plastic resealable bags.

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