ARTHROPOD AND BOTANICAL INVENTORY AND ASSESSMENT

THIRTY METER TELESCOPE PROJECT
MAUNA KEA SCIENCE RESERVE
NORTHERN PLATEAU AND HALE PŌHAKU
HĀMĀKUA DISTRICT, ISLAND OF HAWAI‘I

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Prepared for
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EXECUTIVE SUMMARY

The Thirty Meter Telescope (TMT) Observatory Corporation is preparing an Environmental Impact Statement (EIS) for the proposed construction and operation of an optical/infrared telescope within the Astronomy Precinct of the Mauna Kea Science Reserve on Hawaiʻi Island in the State of Hawaiʻi. The proposed telescope facility would be located within the western portion of the area known as the Northern Plateau. During construction, support activities would occur within the existing Batch Plant Staging Area and at a Construction Staging Area within or near the Hale Pōhaku Mid-Elevation Support Facilities.

Sampling of the flora and arthropod fauna in the proposed use areas was conducted September 25 through October 8, 2008. A second visit occurred February 23 – 25, 2009 to evaluate options at the Hale Pōhaku Support Facility. A third visit occurred April 17 – 23, 2009 to sample for Wēkiu bugs in Area E, the Batch Plant Staging Area, and along the three options for the Access Way, and to sample for vegetation and arthropods at the Hale Pōhaku Support Facility.

During the September 2008 sampling, forty-five live-traps were deployed in Area E, along the 4-wheel drive road, at the Batch Plant Staging Area, and at two control sites (Puʻu Poliʻahu and Puʻu Hauʻoki) for a three-day detection of Wēkiu bug (*Nysius wekiuicola*) presence. Three Wēkiu bugs were captured (one 5^{th} instar nymph on Puʻu Poliʻahu, one 5^{th} instar nymph and adult female on Puʻu Hauʻoki). No Wēkiu bugs were detected at any of the sites proposed for construction activity. Sixteen other arthropods were detected at the summit project areas, six of which are endemic to Hawaiʻi.

Two days during the Fall sampling period were spent surveying Area E for lichens and mosses; ten lichen and two moss species were found. Seven species of vascular plants were also detected; two native grasses, two non-indigenous weedy species, and three ferns.

Six days during the Fall sampling period were used to survey for arthropods and plants at the Construction Staging Area near the Hale Pōhaku Support Facilities. Twenty-six species of arthropods, nine endemic to Hawaiʻi, and sixteen species of plants, none that are endemic to Hawaiʻi, were identified there.

During the April 2009 sampling, twenty-four live-traps were deployed in Area E, along the 4-wheel drive road, at the Batch Plant Staging Area and at two control sites (Puʻu Poliʻahu and Puʻu Hauʻoki) for a three-day detection of Wēkiu bug (*Nysius wekiuicola*) presence. One hundred and five Wēkiu bugs of various life stages were captured at the control sites (forty-five on Puʻu Poliʻahu and sixty on Puʻu Hauʻoki). Forty-one Wēkiu bugs of various life stages were detected along the 4-wheel drive road, but none were seen in Area E or at the Batch Plant Staging Area.

Additional sampling at the Hale Pōhaku Support Facility detected seven additional arthropod species, (five endemic, one indigenous, and one purposeful introduction), one endemic snail, and four additional plants (three endemic and one nonindigenous).

The results of the surveys indicate there are no special concerns or legal constraints related to arthropod and botanical resources in the Project areas. No species listed as endangered or threatened species were detected at the Project construction areas (DLNR 1997, Federal Register 1999, 2005, 2006). There are endangered silversword (*Argyroxiphium sandwicense sandwicense*) in an exclosure adjacent to the proposed Hale Pōhaku Support Facility which lies within critical habitat of the endangered bird, *palila* (*Loxioides bailleui*). One species currently proposed for federal listing, *Nysius wekiuicola*, was detected along the 4-wheel drive road. Species of Concern were detected at Area E, (the Douglas' bladder fern, *Cystopteris douglasii*), and at the Hale Pōhaku Support Facility (*Hylaeus difficillis, H. flavipes, and Succinea konaensis*).

Sampling for Wēkiu bugs at the edge of snow on Pu'u Poli'ahu in April, 2009.

1.0 INTRODUCTION

1.1 TMT Project

The TMT Observatory is proposed to be located on Maunakea on Hawaiʻi Island in the State of Hawaiʻi. Maunakea currently hosts eight optical and/or infrared observatories; the first Maunakea observatories were built in the 1960s. The TMT Observatory would be located on a roughly 5-acre site within the 525-acre Astronomy Precinct of the 11,288-acre Mauna Kea Science Reserve (tax map key [TMK] 4-4-15: 9), below the summit of Maunakea. The entire Science Reserve is designated as part of the State of Hawaiʻi Conservation District, resource subzone.

The TMT Observatory would be located in the western portion of the area known as the Northern Plateau within the Astronomy Precinct, within the area identified as Area E in the Mauna Kea Science Reserve Master Plan (UH, 2000). The 2000 Master Plan identified Area E as a preferred location for the future development of a Next Generation Large Telescope (NGLT). Area E, a 36-acre area, was identified as a preferred location because it was anticipated to provide suitable observation conditions with minimum impact on existing facilities, Wēkiu bug habitat, archaeological sites, and viewplanes. Area E ranges in elevation from 13,100 to 13,300 feet; the summit of Maunakea is at elevation 13,796 feet. Area E is located approximately 1/2-mile northwest of the eight existing optical/infrared observatories located near the summit, at elevations of 13,600 to 13,775 feet.

Within Area E, the TMT Observatory would be located at one of two locations:

- Near the end of the existing 4-wheel drive road, at an elevation of approximately 13,150 feet at a location known as "13N" in reference to its elevation and its location on the Northern Plateau, or
- A site designated "E2" by the Project because it is a second site being considered within Area E; the area is approximately 500 feet south of 13N along the existing 4-wheel drive road.

The TMT Observatory would be the primary development of the Project, but not the only one. The "Project" is the sum of the following components:

- "TMT Observatory" refers to the components of the Project located below the summit, in the upper elevations of Maunakea. The TMT Observatory generally consists of the 30-meter telescope, instruments, dome, support building, and parking within a roughly five acre area.
- The "Access Way" refers to the portion of road and other infrastructure that would be provided to access and operate the TMT Observatory. Improvements in the Access Way would generally include a surface roadway and underground utilities. Beyond the core of the SMA facility the route of the Access Way would follow the existing SMA roads and

existing 4-wheel drive road to the extent possible. There are three options being considered for the portion of the Access Way from the Maunakea Access Road through the core of the SMA area:

1. Option 1 – Through SMA. This option would follow the primary SMA road off the Maunakea Access Road, and then proceed through the lava flow before reconnecting with the SMA road.
2. Option 2 – Near SMA. This option would cut off the Maunakea Access Road at the currently blocked old 4-wheel drive road and connect with the SMA road once beyond the SMA core.
3. Option 3 – 4-Wheel Drive Road. This option would follow the currently blocked old 4-wheel drive road and then connect with the SMA road.

- "Mid-Level Support Facility" refers to facilities and improvements located at or near the existing 20 acre Hale Pōhaku facility to support the TMT Observatory. This includes all permanent improvements at or near Hale Pōhaku, which would generally consist of dormitory, office, cafeteria, and recreations facilities in the eastern portion of the lower part of Hale Pōhaku; a parking area in the western portion of the lower part of Hale Pōhaku; and electrical and communications equipment.
- "Headquarters" refers to facility located in the lower elevations of Hawai'i Island to manage activities at and support operation of the TMT Observatory and Support Facility. This includes all permanent improvements at a lower elevation location in Hilo but is not discussed in this report.
- "Satellite Office" refers to the smaller facility located in the lower elevations of Hawai'i Island to provide additional support to the TMT Observatory and TMT Mid-Level Facility. This includes all permanent improvements at a lower elevation location in Waimea but is not discussed in this report.
- "Construction Areas" include:
    1. "Batch Plant Staging Area" is an approximately 4 acre staging area where the Maunakea Access Road forks near the summit. This area would primarily be used for storing bulk materials and a cement batch plant.
    2. "Hale Pōhaku Staging Area" is an area at or near Hale Pōhaku that would be used for construction staging. This area would be used for parking, vehicle washing and inspection prior to proceeding up to the observatory site, and the storage of materials needed for construction work at Hale Pōhaku.
    3. "Port Staging Area" is an existing warehouse and/or yard near the port where Project components are received. This area would be used for receiving materials and assembly of those materials to the extent possible prior to transport to either another staging area or the construction site. This area is not discussed in this report.

1.2 Physical Setting

Maunakea is a dormant shield volcano and the tallest mountain on earth, rising more than 32,000 feet from the ocean floor to its summit, 13,796 feet above sea level. At the summit the night sky is dark and transparent, providing what is considered to be among the best astronomical observation conditions in the world (Parker 1994).

The Mauna Kea Science Reserve (MKSR), an 11,288-acre area at the top of Maunakea, is home to the largest observatory complex in the world. The MKSR is leased by the State of Hawaiʻi to the University of Hawaiʻi (UH), which in turn subleases certain areas to various observatories. Astronomy institutes worldwide make use of the unparalleled astronomical capabilities on Maunakea.

The MKSR is also home to unique plants and animals living in an alpine ecosystem. The summit region is an island within an island, separated from other ecosystems by high elevations as well as vast oceans. The species found there are not only unique; they are sometimes rare[1] and limited in population and area of distribution. For example, the Wēkiu bug lives only in loose cinder habitats on the cinder cones above 11,715 feet on Maunakea (Porter and Englund 2006). There is a similar species, *Nysius aa* that occurs in the upper elevations on Mauna Loa (Polhemus 1998).

The upper elevations of the MKSR receive almost no rainfall and snow accumulates only during the winter season. Temperatures often drop below freezing at night and reach up to 50º F during the day. Solar radiation is extreme, and evaporation rates are high. The harsh environmental conditions limit the composition of the resident floral and faunal communities found there. Under these harsh conditions, only hardy lichens, mosses, and scattered grasses, shrubs, ferns and arthropods have managed to adapt and survive (Cuddihy 1989).

Below 11,700 feet is an alpine shrublands and grasslands ecosystem growing on ʻaʻa lava flows, cinder cones, and air-fall deposits of lapilli and ash (Wolfe and others 1997). Growing well above the tree line (~9,200 feet), and becoming sparser with increasing elevation, are native shrubs, grasses, sedges, and ferns (Cuddihy 1989). The fauna of the alpine shrub zone has not been well studied. Many species of birds have been observed flying in this zone, but because the principal food resources do not occur here, they are presumably just passing through. There may be resident arthropod species in this zone, but no systematic survey has been conducted.

Below the alpine shrublands and grasslands are the *māmane* subalpine woodlands that extend down to the Saddle Road. The open-canopied *māmane* forest is home to the endangered bird,

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[1] There are several terms that are used to describe the status of species. These include:
Endangered species – Any species which is in danger of extinction throughout all or a significant portion of its range.
Threatened species – Any species which is likely to become endangered within the foreseeable future.
Candidate species – Any species being considered by the Secretary of the Interior for listing as an endangered or a threatened species, but not yet the subject of a proposed rule.
Species of Concern – Those species about which regulatory agencies have some concerns regarding status and threats, but for which insufficient information is available to indicate a need to list the species under the Endangered Species Act (ESA).
Rare species – Those species that occur very seldom, but are not classified threatened or endangered.
Sensitive species – Those species which rely on specific habitat conditions that are limited in abundance, restricted in distribution, or are particularly sensitive to development.

palila (*Loxioides bailleui*). The subalpine woodlands are dry most of the year, and *māmane* trees (*Sophora chrysophylla*) intercept fog that provides them and other plant species with the small amounts of moisture they need to survive (Gerrish 1979). The understory of the subalpine forest is comprised largely of native shrubs. In undisturbed areas clumps of the native grasses are the most abundant ground cover. Non-indigenous plants and grasses are the most abundant ground cover in areas that have been disturbed around Hale Pōhaku. The *māmane* forest on Maunakea has a diverse arthropod fauna. More than 200 arthropod species have been collected there.

Cattle grazing has degraded much of the forest along the lower sections of the Maunakea Access Road. The vegetation of the open pastures is largely introduced grasses including rattail grass, velvetgrass, sweet vernal grass, hairy oatgrass, and fescues (Mueller-Dombois and Fosberg 1998).

1.3 Current Study

The Thirty Meter Telescope (TMT) Observatory Corporation, a non-profit organization, is preparing an Environmental Impact Statement (EIS) for the proposed Project. Pacific Analytics, LLC was contracted by Parsons Brinckerhoff, the company preparing the TMT EIS, to conduct an arthropod and botanical inventory and assessment of Area E, the proposed Access Way, the Batch Plant Staging Area, and Support Facility, including a special survey for Wēkiu bugs in the affected summit areas.

The primary objectives of the inventory and assessment are to provide a general description of the flora and arthropod fauna of the TMT Project sites, evaluate the habitats, and search for and assess the potential for threatened and endangered species as well as species of concern (DLNR 1997, Federal Register 1999, 2005, USFWS unpublished).

View of Area E and existing 4-wheel drive road.

2.0 METHODS

2.1 Permit

An application for a Research, Collection and Access Permit was submitted August 14, 2008 to the Hawai‘i Department of Land and Natural Resources (DLNR), Division of Forestry and Wildlife (DOFAW) and after review, a permit (FHM09-170) was granted on September 24, 2008, valid through September 23, 2009. The Wēkiu bugs were sampled under separate Research, Collection and Access Permits (FHM08-135 and FHM09-181) granted to Jesse Eiben, valid from December 1, 2007 through April 1, 2010.

2.2 Schedule and Personnel

Sampling of the flora and arthropod fauna in Area E, the proposed Access Way, the Batch Plant Staging Area, and portions of the Support Facility was conducted September 25 through October 8, 2008. Wēkiu bug traps were opened and operated from September 25 – 28, 2008. A lichen survey in Area E was conducted over two days September 29 – 30, 2008. Arthropod sampling and botanical surveying continued through October 10, 2008.

Additional botanical sampling by was conducted at the Support Facility February 23-24, 2009.

Additional Wēkiu bug and arthropod sampling was conducted at the summit April 20 – 23, 2009 and at the Support Facility April 17 – 23, 2009.

Gregory Brenner, Pacific Analytics, LLC and Jesse Eiben, UH Manoa, were the investigators conducting the arthropod sampling. Dr. Brenner has a PhD in entomology from Oregon State University, Corvallis, and fourteen years of experience studying the arthropod fauna of Hawai‘i, during which he has conducted numerous scientific studies of the arthropods on Maunakea. Mr. Eiben is a Doctoral candidate in the University of Hawai‘i's Department of Plant and Environmental Protection Sciences and has been conducting research on Wēkiu bug autecology and systematics for his dissertation since 2005.

Gregory Brenner and Clifford Smith were the investigators conducting the lichen, bryophyte and botanical sampling. Dr. Brenner is familiar with the flora of Hawai‘i having conducted many scientific studies of the plants on Maunakea and elsewhere in Hawai‘i. Dr. Smith has a PhD in botany and is Professor Emeritus of the Department of Botany, UH Manoa. He is the leading expert in lichens of Hawai‘i, and has conducted research on Hawaiian lichens since 1958.

2.3 Nomenclature

The nomenclature used in this report follows the Hawaiian Terrestrial Arthropod Checklist, Third Edition (Nishida 1997) and the Manual of the Flowering Plants of Hawai‘i (Wagner and others 1990). Hawaiian and scientific names are italicized.

Species are discussed as being endemic, indigenous, non-indigenous, adventive, and purposely introduced. These terms are defined as:

- Endemic – A species native to, or restricted to Hawai‘i.

- Indigenous – A species native to Hawai‘i but that naturally occurs outside of Hawai‘i as well.
- Non-indigenous – A species not native to Hawai‘i.
- Adventive – Not native, a species transported into a new habitat by natural means or accidentally by human activity.
- Purposely introduced – A species released in Hawai‘i for a particular purpose, usually to control a weedy plant or another insect.

2.4 Arthropod Sampling

2.4.1 Trapping

Wēkiu Bug Traps

Pitfall live-traps were used to sample Wēkiu bugs in Area E and at the Batch Plant Staging Area. A live-trap design very similar to those described by Englund and others (2002) and Brenner (2002a) was used to attract Wēkiu bugs. The modifications in design are as follows.

Two 10oz clear plastic cups were used for each trap. The upper cup was punctured with one small hole in the bottom center through which a small absorbent wick made of tissue (Kimtech Science) was pushed. A small amount of water was poured into the bottom of the lower reservoir cup. The attractant shrimp paste was placed in the upper cup contacting the wick, on a few small pieces of rock in the cup, smeared on the side of the cup, and on a cap rock.

Installing pitfall live-trap

The traps were dug into the available ground substrate with a goal of achieving a depth where moisture was present in the ash layer. The lip of the cup was not necessarily placed flush with the ash layer, and there was no wire mesh surround to provide structure surrounding the cups. This cup design has been successful for attracting and capturing Wēkiu bugs during 2007 and 2008 (Eiben, unpublished). A cap rock was placed over the traps and elevated above the ground approximately 0.6 in with smaller rocks.

Most sites selected for sampling used a pair of traps within 16.4 feet of each other in different microhabitat types (ex. large rock jumble vs. ash layer near the surface) to attempt to sample the diversity of the habitat. The traps were checked daily for three consecutive days after installation. Wēkiu bugs captured were removed for the duration of the sampling period to prevent recounts and were held for up to three days in captivity with food and water sources. After sampling was complete, all Wēkiu bugs were released near the trap in which they were captured.

In September, 2008, forty-five pitfall live-traps were used to sample for Wēkiu bugs. Thirty-three traps were installed within Area E, and three traps were placed along the unused portion of the 4-wheel drive road that is blocked (Figure 1), two pairs and one single trap were installed at the Batch Plant Staging Area, and one pair was placed on each of Pu‘u Hau‘oki and Pu‘u Poli‘ahu as controls (Figure 2).

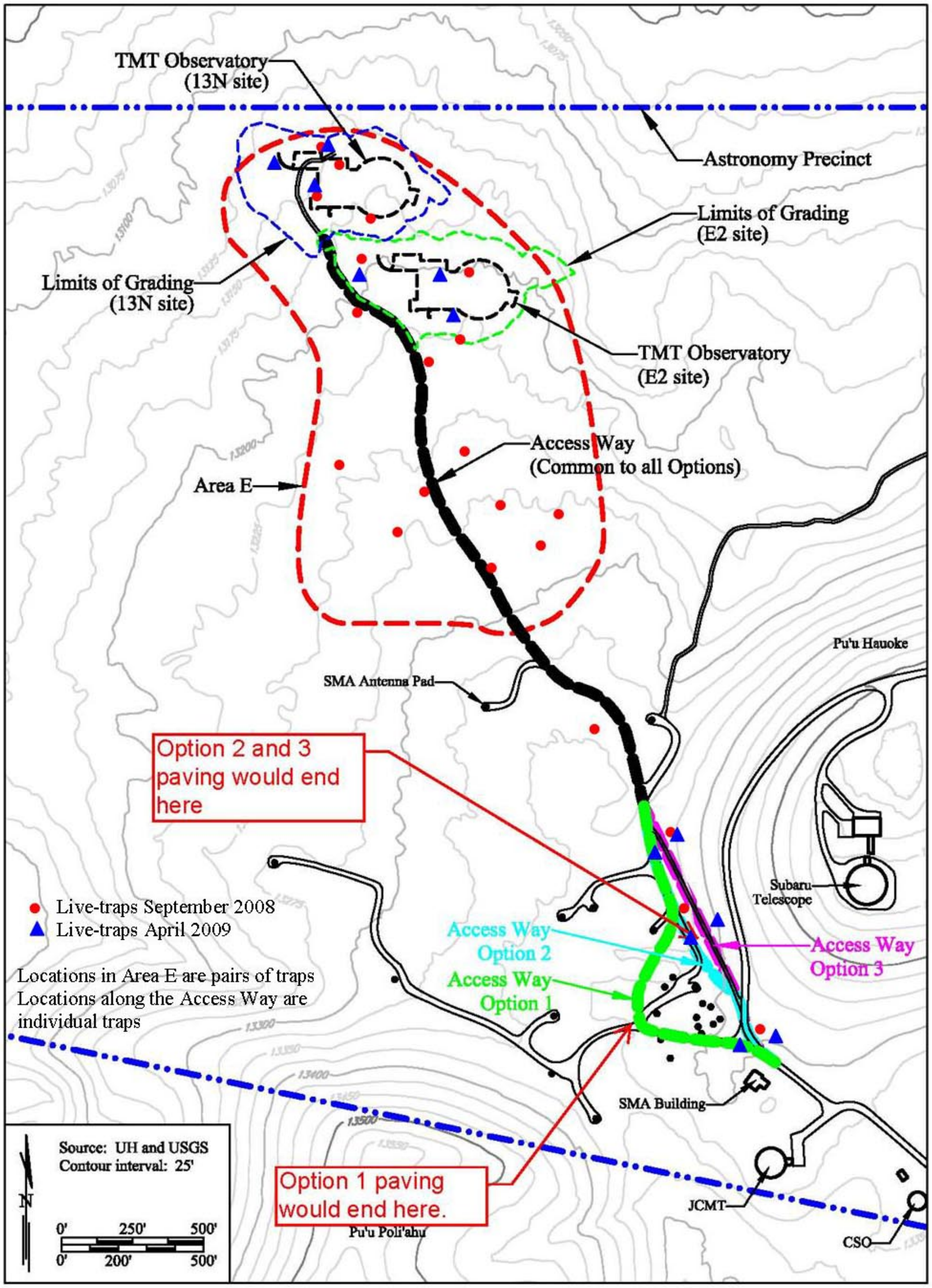


Figure 1. Pitfall Live-Traps sites within Area E and along Access Way options.

In April, 2009, twenty-four traps were used to sample for Wēkiu bugs. Twelve traps were installed within Area E, six traps were placed along the unused portion of the 4-wheel drive road (Figure 1), one pair was installed at the Batch Plant Staging Area, and one pair was placed on each of Pu‘u Hau‘oki and Pu‘u Poli‘ahu as controls (Figure 2).

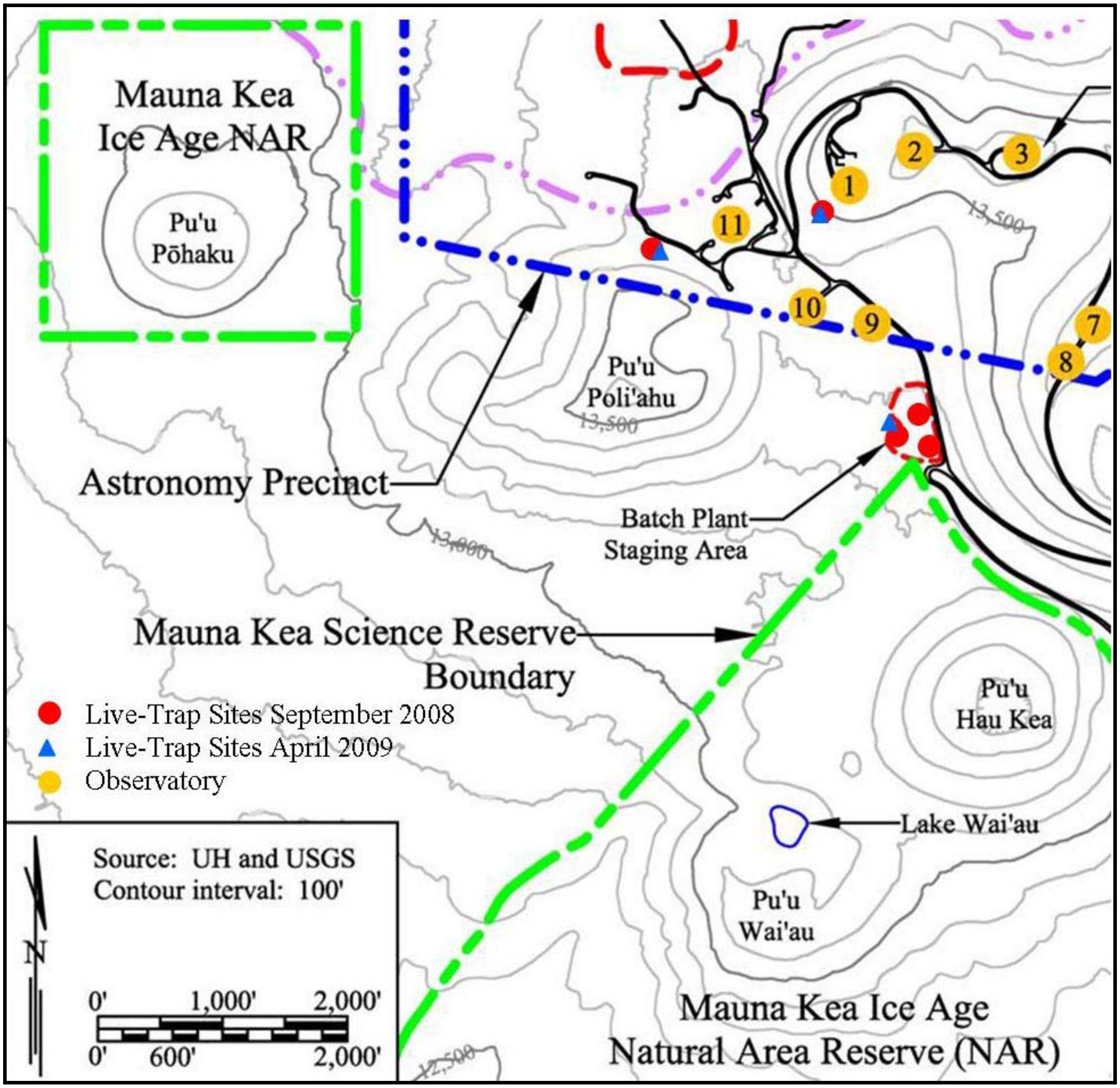


Figure 2. Pitfall Live-Traps sites at the Batch Plant Staging Area, Pu‘u Hau‘oki and Pu‘u Poli‘ahu.

Pitfall Traps

Pitfall traps were used to sample the arthropod ground fauna in Area E, along the 4-wheel drive road, and at the Batch Plant Staging Area, in the same locations used to sample for Wēkiu bugs (Figures 1 and 2), and at the Support Facility (Figure 3). These traps were 10oz cups placed into the ground so that the lip of the cup is level with the substrate. A small amount of soapy water was placed into the trap to kill and preserve specimens that fall into the traps. A cap rock was placed over the traps and elevated above the ground approximately 0.6 inches with smaller rocks.

The target of pitfall trapping in this study was ground-active arthropod species. Three pitfall traps were set at the Batch Plant Staging Area, and eight were installed in vegetation surrounding the Hale Pōhaku Support Facility. Traps were open for 6 to 8 days, October 2 through October 10, 2008. During the Spring 2009 sampling, two traps were set at the Batch Plant Staging Area, and ten at the Hale Pōhaku Support Facility. Traps were open April 17 through April 23, 2009.

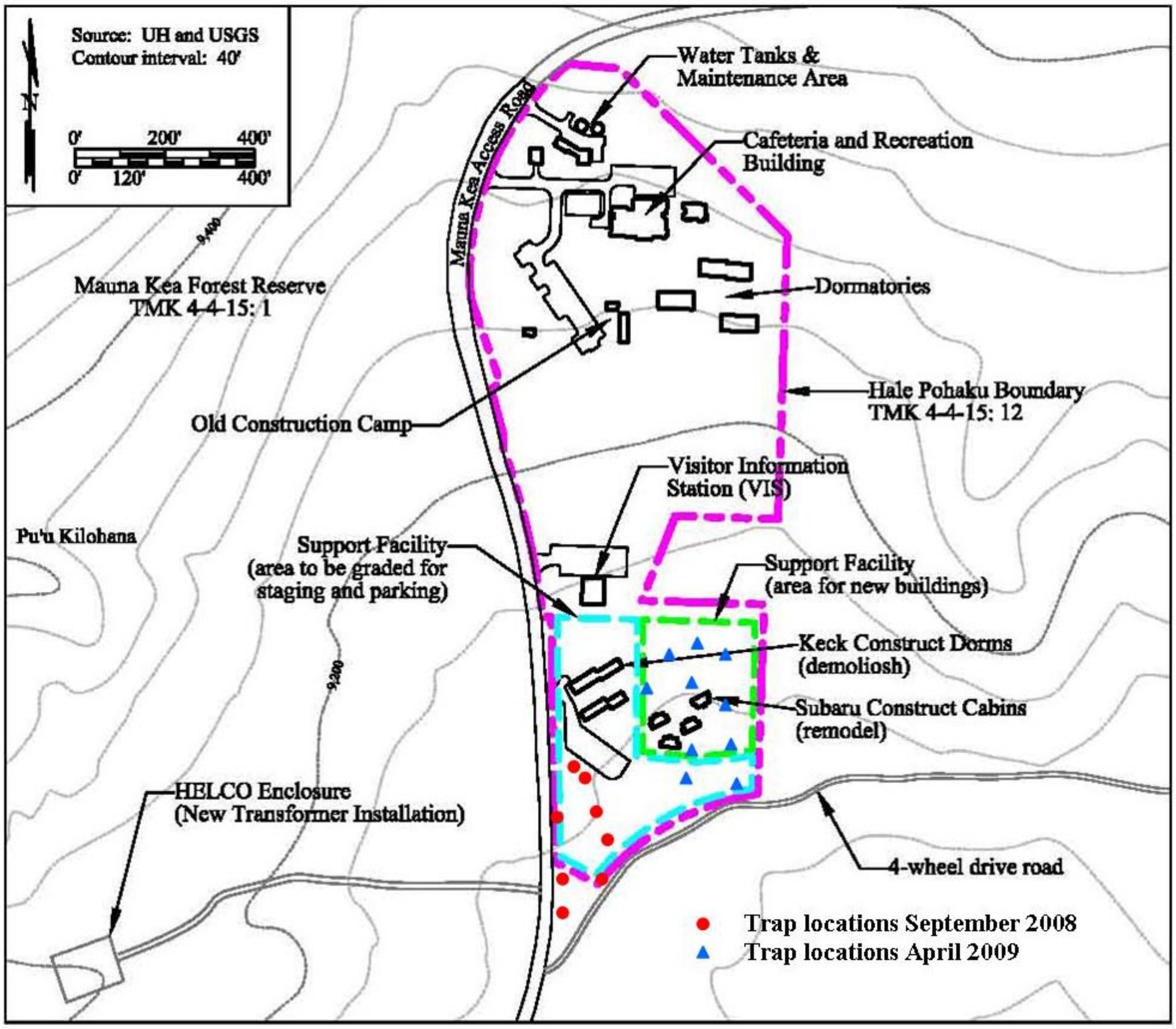


Figure 3. Pitfall Live-Traps sites at the Hale Pōhaku Support Facility.

Bait Trapping

Meat is a good attractant for some flies, ants, and beetles. Some insects are attracted to the smell of the rotting meat and come to the trap. The trap consisted of a small plate filled with soapy water with a rock in the center covered with Spam© (Hormel Foods Corporation). Two bait traps were used at the Batch Plant Staging Area and four bait traps were set at the Hale Pōhaku

Construction Staging Area. The traps were left open for 4 days and checked daily in October 2008.

2.4.2 Foliage Sampling

Approximately four hours per day for eight days (in October 2008 and April 2009) were used to sample foliage in and surrounding the Support Facility. The entire site and the areas of surrounding foliage were sampled.

- Aerial Netting – Flying insects were captured in aerial nets and placed into killing jars. After the specimens died they were transferred into collecting vials and processed in the laboratory at the end of each day.
- Sweep Netting – Grasses, small shrubs and other low-lying vegetation was sampled with a sweep net. The heavy net was brushed along the top of the vegetation or grass, capturing insects. The insects were placed into killing jars, and later into collecting vials for processing.
- Foliage Beating – Foliage was sampled using beating sheets. A 19.7 inch square sheet was placed under a branch and the stem was struck with a short stick. Arthropods on the foliage were dislodged and fell onto the sheet where they were collected with an aspirator into vials.
- Visual Inspection – Plants were visually inspected for arthropods that were not collected by other methods.

Litter Sifting

Rocks and dead logs were turned over and leaf litter was sorted through to locate and collect arthropods. Arthropods were collected into vials using an aspirator or forceps.

Night Sampling

UV lights were used to attract moths and other nocturnal insects. A cloth sheet was hung on a rope at night with an ultraviolet fluorescent tubes placed at the top of the sheet. As insects were attracted and alighted on the sheet, they were captured in vials. High winds some nights required that the sheet be placed on the ground with the light suspended a few feet above it to attract insects.

The phases of the moon can influence the attraction of insects to artificial light (Williams and others 1956). A bright moon may compete with the light source resulting in a reduced catch. The moon was waxing during the September/October 2008 sampling period, with approximately 15 to 50 percent illumination.

The Batch Plant Staging Area with Pu‘u Hau Kea in the background.

2.4.3 Specimen Curation

The contents of the traps were cleaned in 70 percent ethyl alcohol and sorted into the morpho-species for identification. Hard-bodied species, such as beetles, true bugs, large flies and bees were mounted on pins, either by pinning the specimen or by gluing the specimens to paper points. Soft-bodied specimens, such as immature stages, spiders, Collembola, Psyllids, Aphids, small flies and wasps, and centipedes, were stored in vials filled with 90 percent ethyl alcohol.

2.4.4 Identification

Identification to the species level for all specimens was not feasible in the time frame for this study. Important groups of endemic species, species of concern, and potentially threatening non-indigenous species were given first priority for identification. Specimens will be deposited in the B.P. Bishop Museum when sampling and identification are complete.

References for general identification of the specimens included *Fauna Hawaiiensis* (Sharp (ed) 1899-1913) and the 17 volumes of *Insects of Hawai‘i* (Zimmerman 1948a, 1948b, 1948c, 1948d, 1948e, 1957, 1958a, 1958b, 1978, Hardy 1960, 1964, 1965, 1981, Tentorio 1969, Hardy and Delfinado 1980, Christiansen and Bellinger 1992, Liebherr and Zimmerman 2000, and Daly and Magnacca 2003). Other publications which were useful for general identification included *The Insects and Other Invertebrates of Hawaiian Sugar Cane Fields* (Williams 1931), *Common Insects of Hawai‘i* (Fullaway and Krauss 1945), *Hawaiian Insects and Their Kin* (Howarth and Mull 1992), and *An Introduction to the Study of Insects Sixth Edition* (Borror, Triplehorn, and Johnson 1989).

For specific groups specialized keys were necessary. Keys used to identify Heteroptera included those by Usinger (1936, 1942), Ashlock (1966), and Gagné (1997). Keys used to identify Hymenoptera included Cushman (1944), Watanabe (1958), Townes (1958), Beardsley (1961, 1969, 1976), Yoshimoto and Ishii (1965), and Yoshimoto (1965a, 1965b).

2.5 Lichen, Bryophyte, and Botanical Sampling

Prior to field work, a search was made of the literature to review previous botanical, lichen and bryophyte studies conducted in or near the project area. Identification guides were also consulted to prepare the investigators for field identification.

2.5.1 Lichen and Bryophyte Sampling

An intensive walk-through survey method was used to inventory the lichens and bryophytes. Over two eight-hour days, September 29-30, 2008, two people walked through all of Area E with special attention to the TMT Observatory footprint sites, recording lichen and bryophyte species as encountered. All principal habitat types were investigated. Small caves were given extra sampling attention to confirm all species of lichens and bryophytes were detected. Care was taken to avoid disturbance of flagged archaeological sites and any other site that gave the appearance of archaeological significance.

Three habitat types found within Area E were examined. Those types are:

> Type 1 - Pahoehoe lave flows covered about 50 percent of the area. The general topography was essentially flat and smooth with many folds. In several areas small caves were found which ranged from about one foot to almost six feet deep.
> Type 2 - Small islands of ash covered about 10 percent of Area E. The ash was typically covered with small stones or broken lava.
> Type 3 - Rubble of shattered stones constituted about 40 percent of the habitat. Three different subtypes were found in Type 3 habitat;

1. with stones somewhat embedded in ash;
2. where stones rested on ash subsurface; and
3. where there was no evidence of ash between or below the stones.

The undersurfaces of twenty-five rocks were examined each of the three rubble habitats subtypes and counts were made of lichens present to quantify abundance. All rocks that were examined were replaced in their original position as precisely as possible.

Dr. Clifford Smith examines lichens in a lava tube at Area E of the MKSR.

Small samples of all species detected were taken as vouchers. Voucher specimens will be deposited in the B.P. Bishop Museum in Honolulu. Larger specimens were taken of several species whose identity could not be confirmed in the field. These samples were studied in the laboratory or were sent to other lichen experts for identification confirmation.

2.5.2 Botanical Sampling

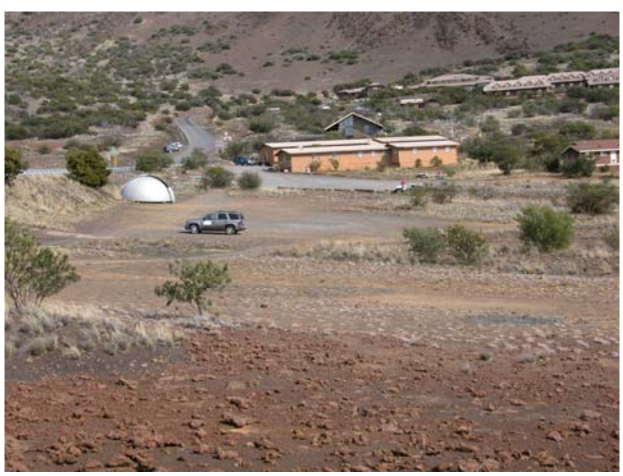
An intensive walk-through survey method was used to record the flora at the three Project construction areas – Area E, the Batch Plant Staging Area, and Mid-Level Support Facility area at Hale Pōhaku. Plant identifications were made in the field. Plants that could not be positively identified were collected for later determination using plant keys and other identification aides. Notes were taken of the distribution of species within and surrounding each of the sites.

The botanical inventory of Area E and the Batch Plant Staging Area was conducted concurrently with the arthropod and Lichen sampling over six days. Plant species were examined repeatedly as they were encountered to confirm identification.

The botanical inventory at Hale Pōhaku was conducted over six days between October 1 and October 10, 2008. Species of plants around the perimeter of the Construction Staging Area were visited several times over the six day period to confirm identifications. Additional botanical sampling was conducted February 23-24, 2009 and April 17-23, 2009 to survey the Mid-Level Support Facility beyond the Construction Staging Area.

2.5.3 Identification

References for general identification of the specimens included *Field Guide to Rare and Unusual Plants on the Island of Hawai'i* (Delay et al 2004), *Handbook of Hawaiian Weeds* (Haselwood and Motter 1966), *Hawaiian Heritage Plants* (Kepler 1984), *Trailside Plants of Hawai'i's National Parks* (Lamoureux 1976), *Hawaiian Forest Plants* (Merlin 1995), *Hawai'i's Vanishing Flora* (Kimura and Nagata 1980), *In Gardens of Hawai'i* (Neal 1965), *Plants and Flowers of Hawai'i* (Sohmer and Gustafson 1987), *A Tropical Garden Flora* (Staples and Herbst 2005), *Ferns of Hawai'i* (Valier 1995), *Manual of the Flowering Plants of Hawai'i* (Wagner and others 1990), and *Hawai'i's Ferns and Fern Allies* (Palmer 2003).



Construction Staging Area at Hale Pōhaku.

3.0 RESULTS and ANALYSIS

3.1 AREA E, THE ACCESS WAY, AND BATCH PLANT STAGING AREA

3.1.1 Arthropods

Previous Studies

The first reports of insects at high elevations on the Island of Hawai‘i were from Maunaloa (Guppy 1897, Meinecke 1916, Bryan 1916). The first published collection of insects from Maunakea was by Bryan (1923), followed by Bryan (1926) and Swezey and Williams (1932). These first investigators believed that the summit areas were "absolutely sterile" and that all the insects found there were aeolian, i.e., blown up from surrounding lowlands by wind. These early reports mention a few species of parasitic wasps, flies, true bugs, and butterflies that were more commonly found at lower elevations. It is interesting to note that the first hint of a high elevation resident was by Guppy (1897), when he mentioned a "parasitical bug" that was feeding on the bodies of dead butterflies. This insect may have been the *a‘a* bug not formally described until 1998 (Polhemus 1998).

Insects from high elevations on Maunakea were not mentioned in the literature again until 1971 (Gagné 1971) when acacia psyllids (a lowland species that infests *koa*) were found in great numbers on observatory walls and washed up in shore debris at Lake Waiau. Howarth (1971) was the first to hypothesize aeolian ecosystems in Hawai‘i in which the major nutrient source is windblown material from outside the ecosystem. While that study was conducted on Kilauea, his new paradigm was soon to be applied to Maunakea.

In 1980, Howarth and Montgomery described the ecology of a high altitude aeolian ecosystem on Maunakea based on new observations of arthropods near the summit (Mull and Mull 1980, Mull 1980). In this landmark paper, the authors report the "discovery" of a new flightless lygaeid bug of the genus *Nysius*, called the Wēkiu bug (Mull and Mull 1980). Ashlock and Gagné (1981) described this new species as *Nysius wekiuicola*.

At least five studies for Maunakea arthropods have been used to support Environmental Assessments (EA) or EISs. In preparation of the EIS for the Mauna Kea Science Reserve: Complex Development Plan (RCUH 1983), an assessment was made of the arthropod fauna and aeolian ecosystem near the summit of Maunakea (Howarth and Stone 1982). That study found Wēkiu bugs in high density on the summit cinder cones, in moderate density on the plateau northeast of the cinder cones, and in low density on the northwest plateau where Area E and the 4-wheel drive road are located (Figure 4). The investigators reported seventeen resident arthropod species, ten presumed to be indigenous Hawaiian arthropods. Besides Wēkiu bugs from the area of study, a Lycosid spider (*Lycosa* sp[2].), two mites (Families Anystidae and Eupodidae), three sheetweb spiders (*Erigone* spp. and one unknown genus), a centipede

[2] The abbreviation "sp." is used when the actual specific name cannot be specified.

(*Lithobius* sp.), two Collembola (*Entomobryoides* spp.), and a noctuid moth (*Archanarta* sp.) were also found. Only the lycosid spider was found in high abundance in Area E and along the 4-wheel drive road. The noctuid moth was widely dispersed but nowhere abundant, and was hypothesized to feed on foliose lichens (Howarth and Stone 1982). A third species of Collembola that was found was unidentified, and its status was unknown.

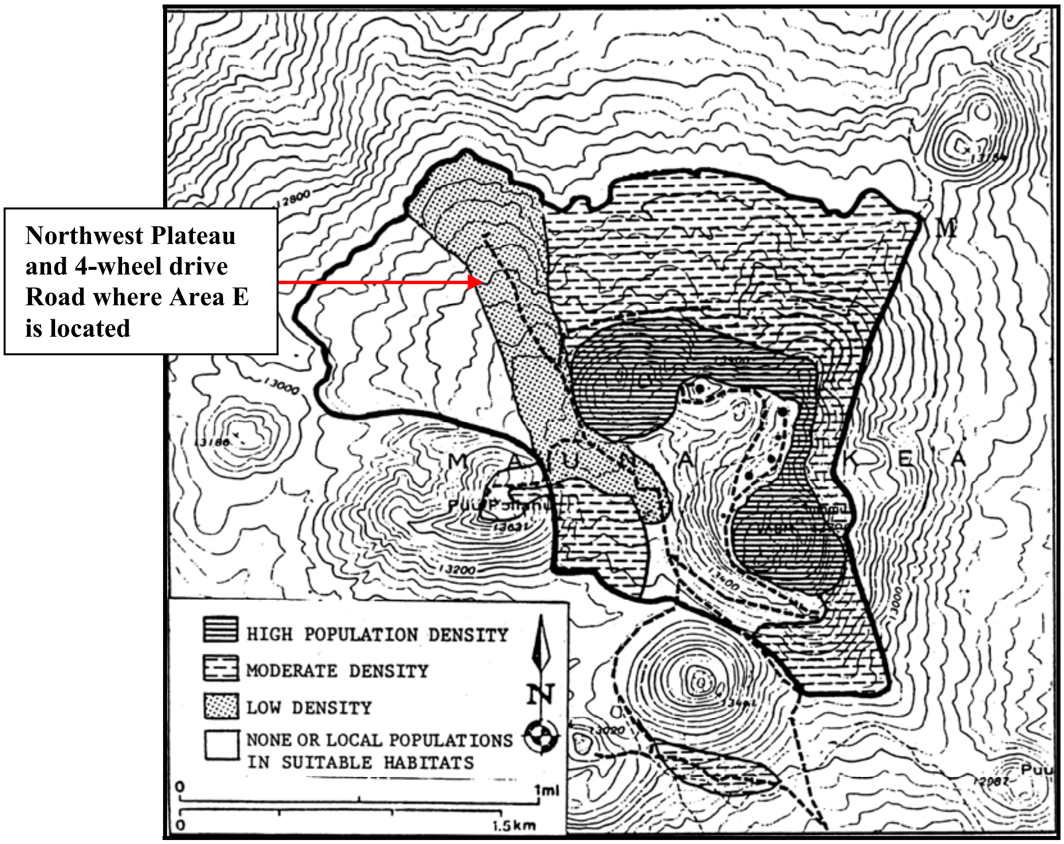


Figure 4. Population Densities of Wēkiu Bugs during 1982 Study.
(Source Howarth and Stone 1982)

The study also reported a large number of transient (aeolian) species presumably that were blown up the mountain by wind, and that represented a food source for resident species.

The study concluded that the lava flows and andesitic rocks of Area E and the 4-wheel drive road were habitat to the noctuid moth, Lycosid spider and centipede, and that Wēkiu bugs were relatively rare because of the rarity of suitable microhabitat. The islands of talus slopes and highly fractured rocks surrounded by lava flows were thought to have moderately high populations of Wēkiu bugs, presumably because the stable rocks provide favorable microclimates.

The next study was a provisional arthropod assessment conducted for the Caltech Submillimeter Observatory (CSO) (Howarth 1982). No Wēkiu bugs were detected during the March sampling, but many of the other species identified from the previous study were found to occur at the CSO site.

The 1988 study of the invertebrate fauna at the proposed Very Long Baseline Array (VLBA) site (Montgomery 1988) found no Wēkiu bugs, but at least four of the resident native species mentioned in the 1982 study along with several non-indigenous species of flies and wasps.

An arthropod assessment of selected areas of the MKSR (Howarth and others 1999) was conducted over two years, 1997 and 1998, to support the revised MKSR Master Plan EIS (UH 1999). The investigators reported nine resident species detected during the sampling, four endemic to Hawaiʻi. A total of sixty-nine species of arthropods were collected in this study, ten that were likely endemic to Hawaiʻi.

In July 1998, twenty-five pitfall traps were placed along the 4-wheel drive road on the North Plateau (now known as Area E). No Wēkiu bugs were detected there during that study, though they were collected on nearby cinder cones.

Wēkiu bugs were relatively rare during the 1997/98 study and analysis revealed an average decline of 99.7% in Wēkiu bug capture rates compared to the 1982 study. The investigators cited possible causes for the decline as changing weather patterns, habitat disturbances, presence of harmful alien species, and long-term population cycles. Because Wēkiu bugs were more abundant in disturbed areas compared to non-disturbed areas, the investigators raised "the possibility that observatory construction had not impacted Wēkiu bug or lycosid spider distributions at the summit, outside of the immediate vicinity of paved and covered areas" (Howarth and others 1999).

A 2001 study by the Smithsonian Institution (Polhemus 2001), found Wēkiu bugs abundant on Puʻu Hau Kea inside the Mauna Kea Ice Age Natural Area Reserve adjacent to the MKSR. The cinder cone was found to be composed almost entirely of deep layers of cinder lying over a basal layer of moist, compacted ash. The study was conducted over four days in June 2001 and deployed traps similar to those used during the 1982 Howarth and Stone study. No other arthropods were reported from the sampling.

Adult Wēkiu bug captured in a live-trap during June, 2005.

A long-term baseline monitoring study was started in February 2002 for the Outrigger Telescopes Project proposed for the W.M. Keck Observatory (Brenner 2002a – 2006b). The study comprised ten pitfall live-traps at permanent sampling stations inside Puʻu Hauʻoki crater below the Keck Observatory and at ten permanent sampling stations inside Puʻu Wēkiu. Sampling was conducted quarterly from February, 2002 through May, 2006. Microclimate data were taken using HOBO© data loggers to gain understanding about the relationship between Wēkiu bug abundance and habitat temperature.

Seven thousand nine hundred and twelve Wēkiu bugs were collected over the four and one-half years of sampling. Wēkiu bugs were more abundant on Puʻu Hauʻoki than on Puʻu Wēkiu (Table 1). The results of this study supported the conclusion of the 1999 study, that observatory construction had not impacted Wēkiu bug and lycosid spider distributions at the summit, outside of the immediate vicinity of paved and covered areas.

The study also found that Wēkiu bug activity appeared to vary with temperature (Figure 5), and populations fluctuated year to year. These results suggest that the 1999 study may have been conducted during years of particularly low Wēkiu bug abundance and that the decline reported was an artifact of timing.

While the presence of other arthropods was regularly reported in the Quarterly Reports, many of the same species collected in previous studies were detected during this study (Pacific Analytics unpublished data). The noctuid moth was found to be present on both cinder cones that were sampled, along with Lycosid spiders, centipedes, and many other species.

TABLE 1: Quarterly Baseline Monitoring Average Trap Capture Rates

Location	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	Year Avg.
Pu‘u Wēkiu 2002*	0.03	0.03	0.3	0.2	0.1
Pu‘u Wēkiu 2003	2.8	11.5	0.5	0.0	3.7
Pu‘u Wēkiu 2004	0.00	2.0	0.03	0.06	0.5
Pu‘u Wēkiu 2005	1.14	0.64	1.26	0.12	0.79
Pu‘u Wēkiu 2006	0.00	3.12			1.56
Pu‘u Hau‘oki 2002	1.0	10.3	4.0	4.0	4.8
Pu‘u Hau‘oki 2003	18.5	90.6	12.4	0.8	30.6
Pu‘u Hau‘oki 2004	2.1	8.8	0.4	0.21	2.9
Pu‘u Hau‘oki 2005	15.92	5.09	5.99	0.62	6.91
Pu‘u Hau‘oki 2006	0.00	30.16			15.08

The average number of Wēkiu bugs per trap per 3-days for each of the Quarterly Baseline Monitoring Sampling Sessions.
Yearly average trap capture rates for Baseline Monitoring are in RED.
* - different trap locations on Pu‘u Wēkiu in 2002 (Source Brenner 2006b)

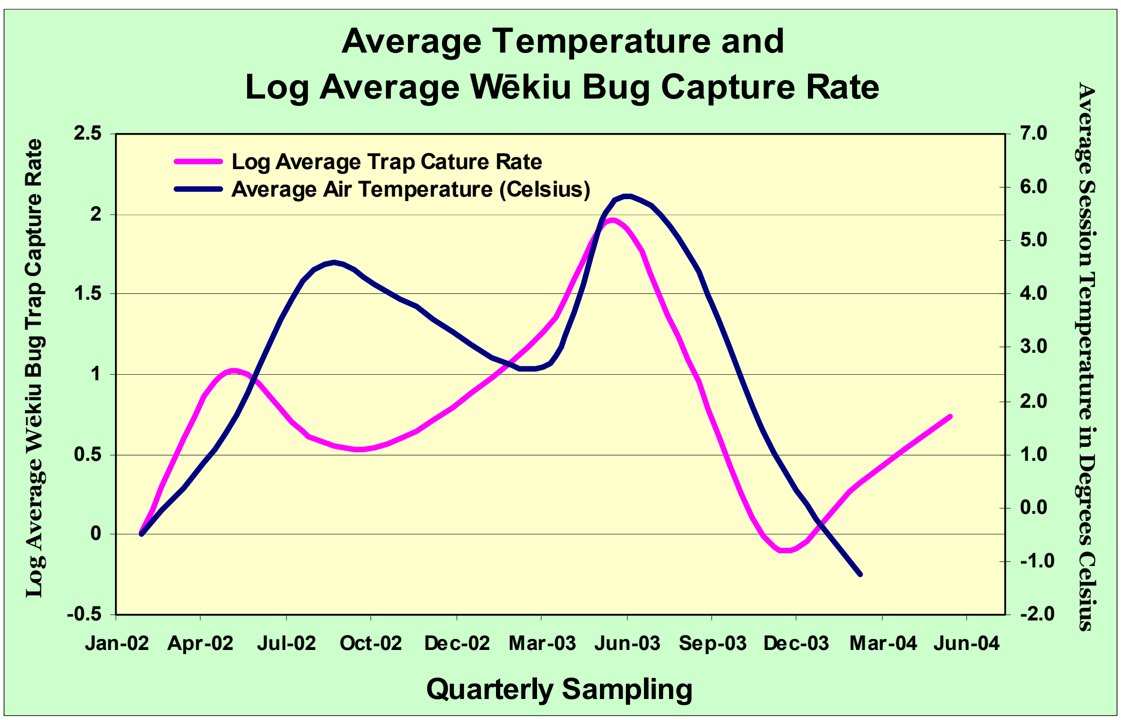


Figure 9. Plot of Baseline Monitoring Session Average Temperature (Celsius) and Natural Log Average Number of Wēkiu Bug Trap Capture Rate per Session on Pu‘u Hau‘oki. (Source Brenner 2006b)

Research conducted in 2005 studied the composition of cinder in known Wēkiu bug habitat on summit cinder cones. This study found evidence of a correlation between the number of Wēkiu bugs captured at adjacent monitoring stations during concurrent sampling and the proportion of cinder less than ~2 inches and greater than ~ 0.5 inches. The study also found that the size distribution of cinder on Puʻu Wēkiu was not different from that on Puʻu Hauʻoki (Brenner and Lockwood 2005).

The study concluded that "By placing 0.5 inch to 2 inch restoration cinder 12-inches to 18-inches deep and allowing it to size-sort over time, we feel that the resulting restoration will be similar to existing Wēkiu bug habitat where high numbers of these bugs have been found." The results of the study may be used for future habitat restoration activities.

Four reports of arthropod research were produced by the B.P. Bishop Museum from October, 2002 through April, 2007 (Englund and others 2002, Englund and others 2005, Englund and others 2006, Englund and others 2007) that give an account of the results of sampling over a large portion of the MKSR. The purpose of these studies was to gather information about the distribution of Wēkiu bugs throughout the MKSR.

These four studies found Wēkiu bugs on at least 15 cinder cones ranging in elevation from 11,715 feet to 13,796 feet. The studies generally conclude that Wēkiu bugs are restricted to rims and inner craters of cinder cones where loose cinders provide interstitial spaces large enough to allow movement through the cinder habitat.

The authors hypothesized that weather, abiotic factors, temperature, and substrate moisture all may influence Wēkiu bug activity. Trap efficiency of pitfall live-traps vs. glycol dead-traps was examined during these studies. It was reported that glycol dead-traps were about forty times more effective at capturing Wēkiu bugs. As a result of these tests, they conclude that there is no quantitative evidence of an actual decline in the population of Wēkiu bugs since 1982 (Englund and others 2002).

A fifth report (Porter and Englund 2006) details the accounts of a study on possible geologic factors that may influence Wēkiu bugs. This study found the Wēkiu bugs appear to prefer non-glaciated cinders and lava spatter in areas where glacial erratics are lacking. They concluded that "Because the [Wēkiu] bugs apparently do not like bedrock substrates, telescopes sited on the glacially modified lava flows in the summit region may have little or no local impact on the bugs" (Page 13 in Porter and Englund 2006).

There have been other studies of arthropods in the higher elevations of Maunakea but these studies are ongoing and their data are not complete or available (S. Nagata personal communication).

In summary, considering the information contained in all reports and published papers, at least 114 species of arthropods have been collected from the MKSR. Many of these species' identifications have not been determined or are undescribed species. Based on known generic distributions, thirty-one of the 114 species were identified as potentially endemic to Hawaiʻi.

As many as twelve indigenous Hawaiian species may be residents of the higher elevations of Maunakea, including Area E (Howarth and Stone 1982, Howarth and others 1999). This potential native resident fauna includes three species of spiders, three species of mites, three species of Collembola, a centipede, a moth, and a true bug. There are non-indigenous species thought to also be residents of this region, including mites, spiders, flies, true bugs, and barklice (Howarth and Stone 1982; Howarth and others 1999).

Some of the non-indigenous arthropods reported may pose a threat to the native Hawaiian arthropods that are residents of the higher elevations of the MKSR, as predators or competitors for food resources.

Current Study Results

<u>Findings</u>

During the Fall sampling period, twenty-two species of arthropods representing ten orders and eighteen families were collected from the Batch Plant Staging Area, Area E, and along the 4-wheel drive road. While as many as seven of these species collected may be endemic to Hawaiʻi, at most four found in Area E could be considered residents of the sites. These include two spiders, the wolf-spider (*Lycosa* sp.) and the sheetweb spider (*Erigone* sp.), the noctuid moth, and perhaps the unknown Collembola species. A fifth indigenous resident species, the Wēkiu bug (*Nysius wekiuicola*) was collected along the 4-wheel drive road.

Lycosid spiders live among rocks.

Despite intensive sampling (123 trap nights), no Wēkiu bugs were detected at the Batch Plant Staging Area, in Area E or along the 4-wheel drive road during the October 2008 sampling (Eiben 2008). Three Wēkiu bugs were detected at the two control sites, Puʻu Hauʻoki and Puʻu Poliʻahu, indicating that this species was active in known habitats.

During the Spring sampling period, one hundred and forty-six Wēkiu bugs were observed in the baited live-traps and in the immediate vicinity of the traps (Eiben 2009). The counts comprise one hundred and two adult males, thirty-nine adult females, and five nymphs. No Wēkiu bugs were captured or observed in Area E or at the Batch Plant. Forty-one Wēkiu bugs were found in the six live-traps placed along the proposed Access Way Options 2 and 3. An additional one hundred and five Wēkiu bugs were observed in and near traps at the two control sites, at sixty Puʻu Hauʻoki and forty-five at Puʻu Poliʻahu. Eighty-five percent of the Wēkiu bugs captured in the live-traps survived and were released into the habitat from which they were collected.

<u>Analysis</u>

The arthropod fauna of Area E, the 4-wheel drive road, and the Batch Plant Staging Area was found to be generally the same as that detected in historic collections. Resident native species detected during this study like the Lycosid spider and sheetweb spiders of the genus *Erigone*, are known from the Northern Plateau as well as being abundant over a large part of the MKSR (Howarth and Stone 1982, Howarth and others 1999). The native noctuid moth is also known from elsewhere in the MKSR and is always noted as being in low abundance (Howarth and Stone 1982, Howarth and others 1999, Pacific Analytics unpublished data). It is unlikely that disturbance and habitat loss due to construction of the Project would significantly impact these species.

The unidentified Collembola that was found at the Batch Plant Staging Area may or may not be endemic to Hawaiʻi. The fact that it was detected only at the Batch Plant Staging Area indicates that this species is able to survive a highly disturbed habitat. The cinder stored at the Batch Plant Staging Area is used for road maintenance and is moved frequently. The rest of the area is used as parking and vehicles regularly move over the open ground. Therefore, it is unlikely that construction activity related to the Project would significantly impact this species.

The other native arthropods that were collected at these sites are not considered residents of the higher elevations of the MKSR and were likely blown into the area by strong winds where they may eventually become prey for the resident species. The Lygaeid bugs found feed on plants and the vegetation at these sites is generally sparse and lacks the host plants necessary to sustain a population of these insects.

The lack of Wēkiu bug detection during the September sampling should not be taken as evidence that this species does not use the areas as habitat. Wēkiu bugs were detected at low density along the 4-wheel drive road in 1982 (Howarth and Stone 1982). Wēkiu bug activity has been found to be seasonally variable and the late September sampling period was not optimal for Wēkiu bug detection (Howarth and others 1999, Brenner 2002a-2006b, Polhemus 2001, Englund and others 2002, Englund and others 2005, Englund and others 2006. Englund and others 2007, Eiben pers. com.). As expected, we observed much higher trap capture rates during the Spring sampling period. Wēkiu bugs have a seasonal occurrence and are usually much more abundant from March through June (Brenner 2006b, Englund et al. 2007).

The lava substrate in Area E is not considered to be ideal Wēkiu bug habitat (Howarth and Stone 1982, Howarth and others 1999, Brenner and Lockwood 2005). Wēkiu bugs have only been found in Area E during one study, and occurred during a particularly abundant year for the bugs (Howarth and Stone 1982). No Wēkiu bugs have detected at this locality since that study in 1982 until the current study. However, construction activities could potentially impact Wēkiu bugs within the Maunakea Summit Region. Dust generated during excavation and site preparation could drift into Wēkiu bug habitat. Trash and construction materials may also be blown off the site by the strong summit winds. Dust and wind-blown debris are believed to have an adverse impact on Wēkiu bug habitat, but impacts could be mitigated. It is not likely that construction activities within Area E would have a significant impact on the Wēkiu bug populations elsewhere within the MKSR if the recommendations in this report are followed (see Section 4.0 Recommendations).

The loose cinder adjacent to the existing 4 wheel-drive road is highly suitable as Wēkiu bug habitat, consisting of different sized cinders larger than ½ inch in a depth of 2 to 10 inches above the ash layer (Eiben 2009). Construction of the Access Way options 2 and 3 would disturb that habitat.

Wēkiu bugs have never been detected at the Batch Plant Staging Area and are not likely to use the area as habitat. The stockpiled cinder is disturbed regularly because of road maintenance and does not have structure suitable for Wēkiu bug habitat. The Batch Plant Staging Area is disturbed regularly and activity there has not appeared to impact Wēkiu bug populations elsewhere, therefore construction activities there would not likely have any significant impact. However precautions should be taken to prevent accidental habitat damage and the introduction of non-indigenous arthropods to ensure protection of the native arthropod species within the MKSR (see Section 4.0 Recommendations).

3.1.2 Lichens, Bryophytes, and Vegetation

Previous Studies

Early accounts of the high elevation flora of Maunakea began in 1826 (Goodrich 1826). Hartt and Neal (1940) provide an excellent review of the early expeditions to the summit of Maunakea. According to historic reports, few plants grew above 11,000 feet. The early botanists describe the flora as consisting of *māmane* (*Sophora chrysophylla*) extending to about 10,000 feet, and only *Dubautia*, silverswords, ferns, and grasses extending as high as Lake Waiau (Hartt and Neal 1940).

The first reported systematic survey of mosses and vascular plants from the higher elevations of Maunakea occurred in 1935 (Neal 1939). The investigators reported finding a total of 146 species and varieties from an altitudinal range of 5,800 feet to the summit. Only lichens, mosses, and one fern, *Asplenium adiantum nigrum*, were detected at the summit region. The report noted that the fern also was observed at many lower altitudes (Neal 1939, Hartt and Neal 1940).

Botanical surveys of the MKSR conducted for evaluating potential impacts due to construction of observatories started in 1982 (Smith and others 1982). The first of these surveys found six resident vascular plants; two indigenous ferns, two indigenous grasses, and two non-indigenous weeds. These species occur elsewhere in the Hawaiian Islands, and the two grasses (*Trisetum glomeratum* and *Agrostis sandwicensis*) are more common at lower elevations.

One of the ferns, the endemic *Cystopteris douglasii*, is designated as a Species of Concern by the U.S. Fish and Wildlife Service (USFWS) (1999). It is known from high elevations on Haleakalā and Maunakea and may also occur in moist forests on Kauai, Oahu, Lanai, and Maui (HBMP 2008, PBIN 2008). The other fern is the spleenwort, *ʻiwaʻiwa* (*Asplenium adiantum-nigrum*).

Rhizocarpon geographicum on rocks in Area E.

The bryophytes (mosses) from Maunakea were first described by Bartram (1939) and new notes were added in subsequent studies (Bartram 1952). Lichens were not treated systematically until Smith and others (1982) conducted a survey on Maunakea near the summit in their report to support the development of the MKSR Complex Development Plan (RCUH 1983). In this study, which covered the summit region above 13,000 feet, about twenty-five species of lichens and twelve species of mosses were found. Three areas of intense study were found to have a rich variety of lichens, including *Pseudephebe pubescens*, a lichen species never before collected in Hawaiʻi. The investigators concluded that suitable niches for mosses and lichens were dispersed over the summit area and that limited construction above 13,000 feet would not endanger habitats for these species, but recommended that the three areas of rich lichen variety be surveyed before development to determine if construction would remove any populations of *Pseudephebe pubescens*.

During development of the CSO, three species of lichens and two species of mosses were added to the summit list (Sohmer and others 1982). Later studies related to the development of the Subaru Observatory confirmed the findings of the previous studies and added no new species to the list of plants that occur near the summit of Maunakea (Char 1990). The last study completed for observatory development was conducted in 1992 (Char 1992). The investigators mapped areas of high lichen concentrations; one of these concentrations falls within Area E.

Current Study

Findings

Three lichen/bryophyte habitat types were found to occur at Area E and along the 4-wheel drive road (Smith 2008).

Type 1 – Pahoehoe lave flows covered about 50 percent of the area. The general topography was essentially flat and smooth with many folds. In several areas small caves were found which ranged from about one foot to almost six feet deep.
Type 2 – Small islands of ash covered about 10 percent of Area E. The ash was typically covered with small stones or broken lava.
Type 3 - Rubble of shattered stones constituted about 40 percent of the habitat. Three different subtypes were found in Type 3 habitat;

1. with stones somewhat embedded in ash;
2. where stones rested on ash subsurface; and
3. where there was no evidence of ash between or below the stones.

Lichen colony found at Area E.

Ten species of lichens and two species of bryophytes were found within Area E (Appendix B). There is an extremely low cover (<1 percent) of lichens and bryophytes. They are confined to protected habitats almost always on the north-facing sides of rocks or the head of small collapsed lava tubes. In these sheltered, amenable habitats, lichens are locally common.

In 2 quantitative samples from each of these three subtypes, lichens were found only in the subtype b and c habitats. In subtype b, *Lecanora polytropa* was found under 2 of 50 rocks sampled. In subtype c, *Lecanura polytropa* was found under 22 of the 50 rocks sampled, and *Acarospora sp.* was under one of the 50 rocks. None of the *L. polytropa* had fertile thalli.

There is a marked difference in the distribution of the various lichens. The dark to black species (*Rhizocarpon ?hochstetteri, Pseudephebe miniscula, Umbilicaria aprina* and *U. hirsuta*) are found on the open face of northern facing rocks, (*Candelariella vitellina, Lecanora polytropa* and *Lecanora sp.*) at the base of northern facing rocks, and (*Lepraria ?incana*) on the roof of the small lava tubes in Type 1 habitat. The presence of the dark species in the most exposed inhabited areas is in keeping with McEvoy and others (2007) finding that melanic pigments play a photoprotective role in light acclimation. The other species do not have such protection though the apothecia and areoles of *L. polytropa* are often light to dark grey in more exposed situations. *Lepraria* species frequently grow in protected shaded and humid habitats.

It has been hypothesized that the resident native noctuid moth in the Maunakea Summit Region feeds on foliose lichens (Howarth and Stone 1982). This has not been confirmed. The foliose lichens found in Area E do not show evidence of feeding and therefore do not appear to be necessary to support any herbivore trophic level.

***Umbilicaria* lichen on rocks in Area E show no sign of herbivore damage.**

None of the lichen species present contain cyanobacteria so if nitrogen fixation is taking place none of it comes from lichens.

Seven species of vascular plants were found in Area E, two native grass species, two introduced weeds and two native spleenwort ferns, and one bladder fern. Three of these species also occur at the Batch Plant Staging Area (Appendix C).

The spleenwort, *ʻiwaʻiwa* (*Asplenium adiantum-nigrum*), is a species indigenous to Hawaiʻi but found on all major islands in Hawaiʻi and elsewhere in the world (Clapham and others 1962, Wagner and others 1990, Palmer 2003). At higher elevations within the MKSR it grows in well protected areas at the base of rocks, between large boulders, or in rock crevices where water accumulates. Elsewhere in Hawaiʻi it grows on cinder plains, lava flows, and in dry forests in elevations ranging from 2,000 feet to approximately 13,000 feet (Valier 1995). This fern is uncommon in Area E and at the Batch Plant Staging Area, usually occurring as individual plants in protected areas that are sheltered from direct sun.

The spleenwort, *ʻoāliʻi* (*Asplenium trichomanes* subsp. *densum*), is an endemic species of fern. This delicate fern is uncommon in Area E, occurring in crevices of rocks. Also known from Haleakalā, this species is locally abundant in full sunlight in open areas on lava fields and in *kīpuka* from 3,936- 8,856 feet on East Maui and Hawaiʻi (Palmer 2003).

The bladder fern, (*Cystopteris douglasii*), is a species endemic to Hawaiʻi. It occurs in Area E infrequently in open, exposed areas on weathered rock. It is also known from scattered locations throughout the summit (Smith and others 1982).

***ʻiwaʻiwa* grows in rock crevices at Area E.**

<u>Analysis</u>

There is a very low diversity and cover of plants in Area E, along the 4-wheel drive road, and at the Batch Plant Staging Area. The vascular plants appear to be confined to the western side of the larger pahoehoe flows in Area E. The two endemic grasses found both occur throughout the Hawaiian Islands and are more abundant at lower elevations (Wagner and others 1990) and therefore not threatened by construction activities. The indigenous spleenwort ferns have a broad distribution and are more abundant at lower elevations (Palmer 2003), thus would not be significantly impacted by construction activities.

A few individual bladder ferns (*Cystopteris douglasii*) were detected at Area E during our survey. This fern is considered a Species of Concern (USFWS 1999). It occurs on five islands in Hawaiʻi (Palmer 2003, HBMP 2008, PBIN 2008) and has been designated as a Priority Species-5 plant with more than 5,000 individuals and/or more than 40 populations remaining state wide (Evans and others 2006). On East Maui it grows between 1,500 and 3,000 feet in mesic forests and cave mouths (Palmer 2003). On the Island of Hawaiʻi this species is found scattered throughout the higher elevations of the MKSR and on the eastern slopes of Maunaloa in the Pahakuloa Training Area (USACE 2003). Thus, Area E does not provide unique habitat essential for its survival (Char 1990). Populations of this fern in habitats adjacent to Area E and the 4-wheel drive road could be impacted by excessive dust and wind-blown trash that cover these plants and block needed sunlight. Damage to these populations would be reduced by following the recommendations contained in this report (Section 4.0 Recommendations)

The two non-indigenous plant species, *Hypocaeris radicata*, and *Taraxacum officinale* are not abundant at the study sites and have not appeared to have spread since 1999.

Lichens and bryophytes were found to be generally confined to the northerly aspect of rocks or under overhangs and even then the abundance of species is much higher in those areas facing north.

There is a very low diversity and cover of lichens and mosses in Area E. All of the species detected are found at somewhat lower elevations at least on the southern side of the mountain, and none of the species are unique to Hawaiʻi. Project construction activities would not likely have a significant impact on the plant, lichen, and moss species found at the surveyed sites.

3.1.3 Access Way Options

Option 1 – The terrain along this option is similar to that found in Area E, and is not considered to be ideal Wēkiu bug habitat (Howarth and Stone 1982, Howarth and others 1999, Brenner and Lockwood 2005). No sampling has been conducted here, but it is likely that Wēkiu bugs only occupy this area during extreme population explosions that push the insects into marginal habitats.

Option 2 – The terrain along this option has about a 15 percent slope and would require extensive fill and support to be functional. The ground here is a combination of loose cinder and lava and, like the terrain of Option 1, is not considered to be ideal Wēkiu bug habitat,, however ten Wēkiu bugs were detected in adjacent habitat during the Spring 2009 sampling session.

Option 3 – The terrain here is loose cinder and is contiguous with the Puʻu Hauʻoki cinder cone. The cinder here is considered to be ideal Wēkiu bug habitat, although no Wēkiu bugs were collected here during the 2008 sampling, but thirty-one were collected during the Spring 2009 sampling. This option would require cutting into the cinder cone and Wēkiu bug habitat and adding a retaining wall to prevent cinder from encroaching on the newly paved road. The road would also bisect and isolate portions of habitat. While Wēkiu bugs have been observed crossing existing dirt and cinder roads, none have ever been observed on pavement. Because this option disturbs and displaces Wēkiu bug habitat, mitigation measures similar to those proposed for the Outrigger Telescope Project would likely have to be implemented (see Recommendations).

3.1.4 Summary

The results of this arthropod and botanical survey indicate there are no special concerns or legal constraints related to invertebrate and botanical resources in the project areas. No species listed as endangered or threatened were detected at the project construction areas (DLNR 1997, Federal Register 1999, 2005, 2005). One species currently proposed for federal listing, the Wēkiu bug (*Nysius wekiuicola*), was observed along the 4-wheel drive road. Some Wēkiu bug habitat could be disturbed if Option 2 or 3 are chosen for the proposed Access Way. The amount would be small compared to the amount of available habitat for this species and would likely not threaten its survival on Maunakea. One species of concern, Douglas' bladder fern (*Cystopteris douglasii*), was found in Area E, but this species also occurs on Maui and on the eastern slopes of Maunaloa, thus Area E does not provide unique habitat essential for its survival (Char 1990).

3.2 CONSTRUCTION STAGING AREA, HALE PŌHAKU

3.2.1 Arthropods

Previous Studies

Several entomologists have collected in the *māmane* forest near Hale Pōhaku, but no one has published a systematic study of the arthropods found there. Swezey (1954) summarized early sampling and listed forty-one species from *māmane* (*Sophora chrysophylla*) and twenty different species from *naio* (*Myoporum sandwicense*) that occur on the Island of Hawai'i.

Honeybee foraging *māmane* blossoms.

A unpublished 1988 study conducted in the *māmane* near *Pu'u La'au* added forty-seven species of insects and spiders to the list of arthropods from the *māmane* forest on Maunakea (Gagne and Montgomery unpublished). These species could be expected to occur near Hale Pōhaku as well. There is no doubt that the subalpine forest arthropod fauna is larger than these studies indicate and that additional studies will likely expand the list.

A recent survey along the Saddle Road realignment route found 214 species of arthropods (USDOT 1997). This is the closest systematic survey to Hale Pōhaku that has been conducted. Many of the species collected during the study are likely to occur at or near Hale Pōhaku.

No endangered, threatened, or special status arthropod species were detected during any of the previous studies near Hale Pōhaku described above.

Current Study

Findings

Thirty-three species of arthropods and two snails were observed on or near the Mid-Level Support Facility area within Hale Pōhaku. Fifteen of the species detected are endemic to Hawai‘i, seventeen are purposeful or adventives non-indigenous species, and three are of unknown origin. The endemic species include the difficult yellow-faced bee, *Hylaeus difficillis*, the yellow-footed yellow-faced bee, *Hylaeus flavipes*, a succineid snail, *Succinea konaensis*, and several common plant bugs and moths.

Analysis

The arthropod fauna at the Mid-Level Support Facility area consists mostly of non-indigenous species and common endemic species that are abundant throughout the *māmane* forest, and occur on other islands. None of the species found are designated as serious pests, and no ants were detected during the sampling. Two endemic yellow-faced bees were detected, *Hylaeus difficillis*, and *H. flavipes*, both previously designated USFWS Species of Concern. Species of Concern is an informal term, and is not defined in the federal Endangered Species Act (ESA). The term commonly refers to species that are declining or appear to be in need of conservation. Many agencies and organizations maintain lists of at-risk species. These lists provide essential information for land management planning and conservation efforts, but the designation carries no special protection and is no longer used by the USFWS Pacific Region (USFWS personal communication). The difficult yellow-faced bee, *Hylaeus difficillis*, was observed only during the Spring sampling period and normally may forage at higher elevations during warmer weather. This species also occurs on Maui, Lanai, and Molokai and it is unlikely that disturbance due to construction and staging activities of the Project would significantly impact this species. The yellow-footed yellow-faced bee, *Hylaeus flavipes*, was observed during both sampling periods foraging on *māmane*. This species also occurs on Maui and Lanai and construction activities would not likely impact the species.

Little is known about the distribution of the succineid snail. It is known to occur near *Pu‘u La‘au* on the western slopes of Maunakea. The impact of construction activity on this species is unknown.

3.2.2 Botanical

Previous Studies

Many of the same botanists that explored the upper elevations of Maunakea also studied the vegetation of the subalpine *māmane* forest (Hartt and Neal 1940). The upper limits of this forest do not reach above 10,000 feet and many of these early botanists noted seeing sheep and cattle grazing in the area.

At least five botanical studies have taken place at Hale Pōhaku. The first complete study of the flora was conducted for the Hale Pōhaku Master Plan (Gerrish 1979). *Māmane* trees six to twenty-five feet tall were found to cover about 25 percent of the undisturbed area. The ground was covered by several common grasses, hairy horseweed (*Erigeron bonariensis*), common groundsel (*Senecio vulgaris*), and mullein (*Verbascum sp.*). In all, thirty-two plant species were identified, nine native to Hawai‘i. One endemic species, *Stenogyne microphylla*, a trailing perennial vine up to several feet long, with greenish yellow flowers, is considered rare and occurs only on two islands in Hawai‘i.

The second botanical study was conducted in 1985 (Char 1985). In this study of the area twenty-six plant species, nine native to Hawai‘i, were detected where temporary construction housing was built. A small population of the threatened species of Hawaiian catchfly (*Silene hawaiiensis*) was reported in rocky areas on the steep slopes adjacent to and above the maintenance area in the northern/upslope portion of Hale Pōhaku.

Wand mullein (Verbascum virgatum) is common at the Construction Staging Area.

The third botanical survey at Hale Pōhaku was conducted to assess the impacts of the new facilities built to support construction of the Subaru Observatory (Char 1990). A total of thirty-seven plant species were observed. The same nine Hawaiian native plants identified in 1979 could still be found at the site.

The fourth study was conducted as part of the MKSR Master Plan EIS (Char 1999). Fifty-three plant species were found to occur, sixteen native to Hawai‘i.

Māmane tree (Sophora chrysophylla) just outside the boundary of Hale Pōhaku.

The most recent botanical survey at Hale Pōhaku was conducted at the Construction Staging Area to assess potential impacts on *palila* habitat due to use by the proposed Outrigger Telescopes Project (Brenner 2004e).

None of the plants identified in these studies that occur below the Visitors Center are listed as threatened and endangered species, nor are any candidates for listing (USFWS 2006).

Current Study

Findings

During the Fall sampling period, the entire Construction Staging Area (CSA) and the surrounding region within 100 feet of the area boundaries were surveyed for plants. No *māmane* trees were found within the existing construction staging area boundaries, but the area surrounding the existing CSA was found to contain twenty-five. The locations of the sixteen closest *māmane* trees surrounding the CSA were mapped (Figure 10).

The groundcover at the CSA and surrounding area is composed of mixture of low growing introduced plants and grasses. Besides the *māmane* trees, no other native plants were observed, except possibly some scattered bunches of native grasses outside the CSA boundaries.

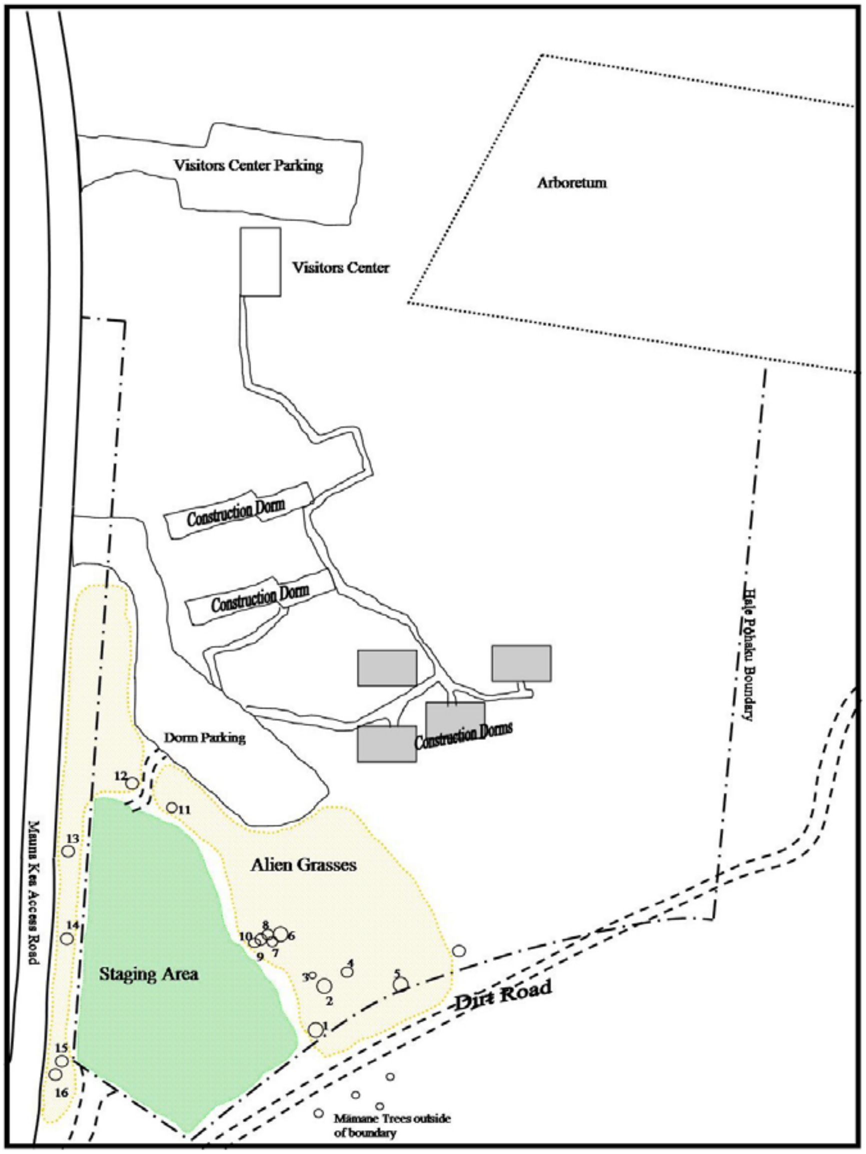


Figure 10. Map of Vegetation Surrounding Hale Pōhaku Construction Staging Area

The ground cover of the site and surrounding area consists of a mixture of grasses, dominated by needlegrass (*Nassella cernua*). The other plants that make up the ground cover include common groundsel (*Senecio vulgaris*), pin clover (*Erodium cicutarium*), woolly mullein (*Verbascum thapsus*), and evening primrose (*Oenothera stricta*).

The entire Mid-Level Support Facility area was sampled during the 2009 sampling periods (see Figure 3). The area east of the existing dorms was found to have a moderate density of *māmane* trees with an understory of indigenous and nonindigenous grasses and shrubs. Indigenous plants include *māmane* trees (*Sophora chrysophylla*), *ʻaheahea* (*Chenopodium oahuense*), hinahina (*Geranium cuneatum*), *māʻohiʻohi* (*Stenogyne rugosa*), littleleaf stenogyne (*Stenogyne microphylla*), *ʻoāliʻi* (*Asplenium trichomanes* subsp. *densum*), Hawaiian bent grass (*Agrostis sandwicensis*), pili grass (*Trisetum glomeratum*), and another grass (*Deschampsia australis*).

Analysis

The CSA is highly disturbed, mostly open ground with almost no vegetation. The few patches of plants consist of introduced weedy species. The vegetation surrounding the CSA is sparsely spaced *māmane* trees with grass and herbaceous groundcover. This surrounding vegetation may be susceptible to fire and care should be exercised to prevent such an occurrence.

Rabbitfoot clover (*Trifolium arvense*) is a low growing introduced weedy plant that occur at the CSA.

No *palila* were seen in *māmane* trees immediately adjacent to the CSA. The principal locality for *palila* is at *Pu'u La'au* and *palila* are rarely seen near Hale Pōhaku. Fire is a threat to the *māmane* forest and precautions should be taken to prevent it. It is unlikely *palila* would be significantly impacted by temporary use of the CSA if the recommendations contained in this report are followed.

The indigenous plants that grow within the Mid-Level Support Facility boundary are common and all occur on other islands in Hawai'i. The proposed approximately 5 acre area studied represents a small fraction of the *māmane* subalpine forest habitat and Project use of the area would likely not substantially impact the vegetation surrounding the site.

Area Use Options

The area being considered for the Mid-Level Support Facility (Figure 10) is located near the lowest reaches of the Hale Pōhaku boundary.

Primrose (*Oenothera stricta*) is one of the more abundant and showy, introduced weedy plants that occur at the CSA.

The area comprises three general areas; 1) the CSA described above; 2) the land around the Construction Dorms and Cabins; and 3) an area of open ground with scattered *māmane* trees above the existing dorms and east of the existing cabins. There are no native Hawaiian species listed as threatened or endangered, nor any candidates for listing or are species of concern that were found within the entire 4.9 acres being considered. Nine native plant species occur within the area: *māmane* trees (*Sophora chrysophylla*), *'aheahea* (*Chenopodium oahuense*), hinahina (*Geranium cuneatum*), *mā'ohi'ohi* (*Stenogyne rugosa*), littleleaf stenogyne (*Stenogyne microphylla*), *'oali'i* (*Asplenium trichomanes* subsp. *densum*), Hawaiian bent grass (*Agrostis sandwicensis*), pili grass (*Trisetum glomeratum*), and another grass (*Deschampsia australis*). All of these species occur over a wide range and most on other islands in Hawai'i and none are considered rare or threatened.

To the east of the area is a forest reserve with native Hawaiian components, including those found within the area, and a fern (*Asplenium adiantum-nigrum*). The forest reserve is within the designated critical habitat for the federally listed endangered bird *palila* (*Loxioides bailleui*).

The only serious threats to the surrounding forest reserve that is posed by the use of this area for dormitory development and observatory construction activities are the potential for fire and the increased potential for introduction of non-indigenous plants and arthropods. Other impacts may also include wind-blown trash, construction debris and dust. All of these impacts can easily be mitigated or prevented by implementing sensible and well thought out management practices. Planning for development of the area should include considerations for protecting the surrounding forest reserve and *palila* critical habitat.

3.2.3 Summary

The results of this arthropod and botanical survey at the Mid-Level Support Facility area indicate there are no special concerns or legal constraints related to invertebrate and botanical resources in the Project areas. No species listed as endangered, threatened, or that are currently proposed for listing under either federal or State of Hawaiʻi endangered species statutes were detected at the CSA or Area 1 (DLNR 1997, Federal Register 1999, 2005, 2006). The *māmane* forest that surrounds Hale Pōhaku is designated *palila* critical habitat. Care must be taken to reduce all threats to this habitat by use of the Support Facility. By following the recommendations contained in this report those threats could be reduced. Three invertebrate formally designated Species of Concern occur within the Mid-Level Support Facility boundary, the difficult yellow-faced bee (*Hylaeus difficillis*), the yellow-footed yellow-faced bee (*Hylaeus flavipes*), and the succineid snail (*Succinea konaensis*). The habitat for the two bees is extensive on Maunakea, and construction activity at the Mid-Level Support Facility would likely not impact their populations. Little is known about the distribution of the succineid snail, other than that it is known to occur near *Puʻu Laʻau* on the western slopes of Maunakea. The impact of construction activities on this species is unknown.

4.0 RECOMMENDATIONS

4.1 AREA E, ACCESS WAY, AND BATCH PLANT STAGING AREA

Habitat Disturbance should be minimized - The rocks and cinder within Area E are home to lichens, mosses, and endemic arthropods, therefore disturbance should be minimized at the construction site and in the surrounding habitats.

Recommendation 1: Disturbance should be minimized. Construction activities should be limited to the footprint pad and road improvements, and no cinder or other materials should be side-cast into adjacent habitat.

Recommendation 2: Dust can impact lichens, mosses, and ferns and is believed to degrade Wēkiu bug habitat. Water should be applied to excavation sites and cinder stockpiles to minimize dust generation.

Recommendation 3: High winds can spread dust to surrounding habitat. It is recommended that dust-generating activities be suspended during high winds.

Recommendation 4: Soil-binding stabilizers such as DuraSoil are currently being used on unpaved roads within the MKSR. These compounds help reduce dust and road maintenance and their use is encouraged. However, soil-binding stabilizers should be used sparingly, and should never be applied to habitat adjacent to the roads or observatory use areas.

Recommendation 5: Oil spills and other contaminating events have occurred at observatories in the past. While these spills have always been contained immediately and have not resulted in serious ecological damage, care should be taken to avoid any spills. The Project staff and contractors should follow Federal guidelines specifying the use and disposal of oil, gasoline, dangerous chemicals, and other substances used during observatory construction and maintenance.

Recommendation 6: Contractors should minimize the amount of on-site paints, thinners, and solvents. Painting and construction equipment should not be cleaned on-site. Contractors should keep a log of hazardous materials brought on-site and report spills immediately to a designated Project representative and the proper authorities.

Recommendation 7: Construction trash containers should be tightly covered to prevent construction wastes from being dispersed by wind.

Recommendation 8: Construction materials stored at the site should be covered with tarps, or anchored in place, and not be susceptible to movement by wind.

Recommendation 9: If construction materials and trash are blown into habitat, they should be collected with a minimum of disturbance.

Recommendation 10: Option 3, developing the existing 4-wheel drive road as the Access Way, should be avoided because it disturbs, displaces, and isolates portions of Wēkiu bug habitat. It would likely require mitigation measures similar to those suggested for the Outrigger Telescopes project, such as habitat restoration in the Pu‘u Hau‘oki. Option 2 crosses marginal Wēkiu bug habitat and would likely have no significant impact on Wēkiu bugs, but may entail some mitigation. The ideal option from a biological resources view is Option 1. It disturbs a minimal amount of only marginal habitat.

Introduction of non-indigenous arthropods and plants should be avoided – Non-indigenous arthropods can be a threat to native species that reside at or near the summit. Ants are especially threatening and their introduction should be strictly prevented. Introduced plants can change the microhabitat conditions if they become established, thereby facilitating the establishment of other non-indigenous species.

Recommendation 11: Earthmoving equipment should be free of large deposits of soil, dirt and vegetation debris that may harbor alien arthropods and weed seeds.

1. Pressure-wash and/or otherwise remove alien arthropods and weed seeds from equipment and materials before moving them from lower elevations and up the Maunakea Access Road. This cleaning should be done in baseyards in Hilo or Waimea before continuing up Saddle Road.
2. Inspect large trucks, tractors, and other heavy equipment before proceeding up Maunakea Access Road from Hale Pōhaku. Clean and wash as necessary prior to proceeding up to the summit area.

Recommendation 12: All construction materials, crates, shipping containers, packaging material, and observatory equipment should be free of alien arthropods when delivered to the summit.

1. Inspect shipping crates, containers, and packing materials before shipment to Hawai‘i
2. Inspect construction materials before transport to the summit area

Recommendation 13: Outdoor trash receptacles should be provided for ready disposal of lunch bags and wrappers. These receptacles should be secured to the ground, have attached lids and plastic liners, and be collected frequently to reduce food availability for alien predators.

Recommendation 14: The construction site and staging areas should be monitored to detect new introductions of non-indigenous arthropod and plant species. New alien arthropod and plant introductions detected during monitoring should be eradicated immediately.

1. Ant eradication
2. Yellowjacket eradication
3. Alien spider eradication
4. Weed eradication

4.2 CONSTRUCTION STAGING AREA, HALE PŌHAKU

Habitat Disturbance should be minimized – While the Construction Staging Area and the immediate surrounding area within Hale Pōhaku are highly disturbed, a native ecosystem exists nearby. Care should be taken to avoid disturbance of that ecosystem.

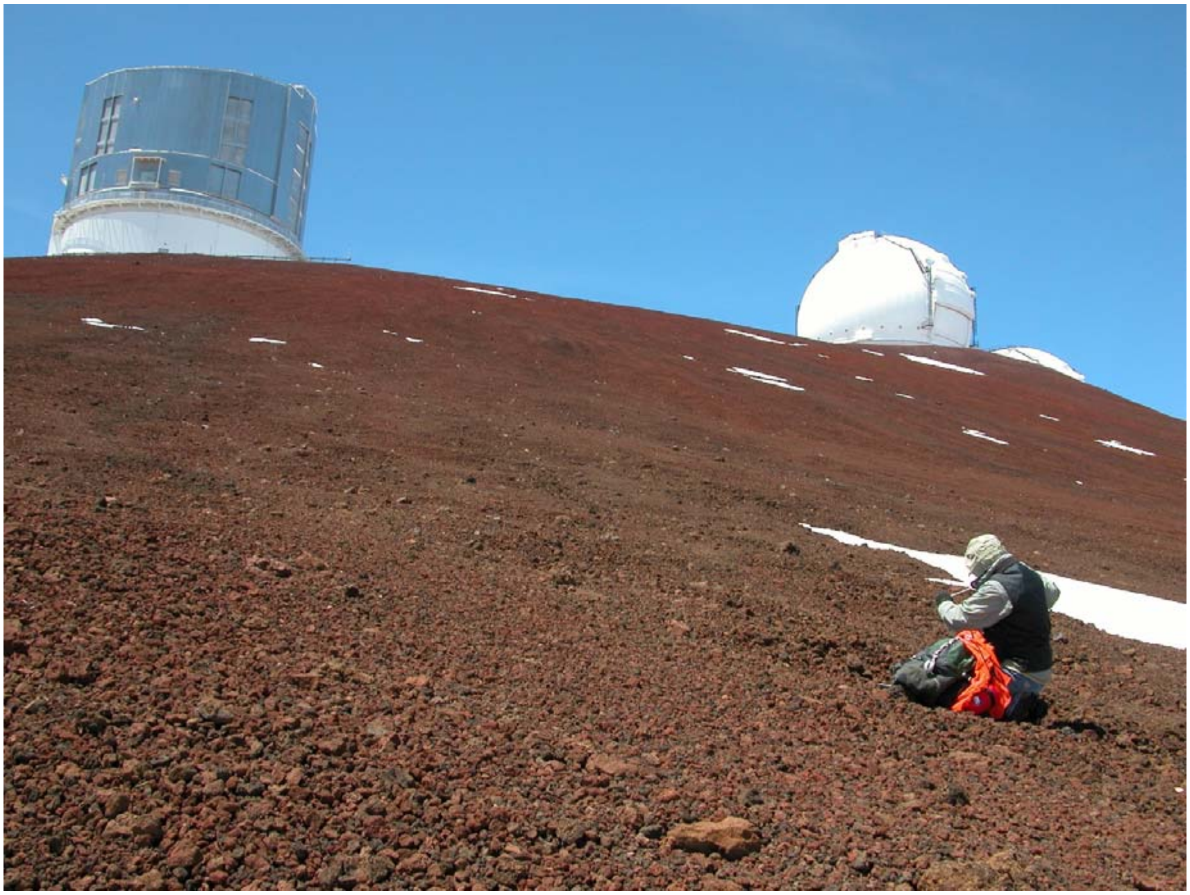
Recommendation 1: In previous botanical surveys conducted at this site it was recommended that efforts be directed to managing the natural resources on and around the site. The recommendations included plantings of native species and removing introduced species, such as mullein and the newly arrived Madagascar ragwort. These recommendations are still valid today.

Recommendation 2: Because of increased tourist traffic and resident recreational use of the surrounding area, it is possible that more non-indigenous species will be introduced. Construction vehicles and containers for the Project should be cleaned and inspected for alien species before proceeding up the Maunakea Access Road. These inspections are likely to intercept other alien species that may cause harm to the surrounding critical habitat at Hale Pōhaku.

Recommendation 3: Other habitat protection measures mentioned for Area E are also applicable at Hale Pōhaku. For example, control of trash, dust, and material is important to minimize disturbance to adjacent habitat. And, it is good practice to limit the amount of hazardous materials to decrease the potential for spills.

Recommendation 4: Another important habitat protection measure especially applicable at Hale Pōhaku is prevention of fire. The *māmane* forest surrounding the construction staging area is dry and susceptible to fire, and once started, a fire may be difficult to control. It is best to take precautions to prevent fire, such as advising personnel of the susceptibility of habitat to fire, limiting smoking to designated areas away from dry grass, and limiting the amount of activity that would cause sparks or fire that may spread to adjacent habitat. It is advisable to have fire extinguishers on hand and the construction staging area personnel should be trained in their use. These are practical measures that are usually applied at construction sites, but are especially important in natural areas where fire may have an impact on endangered species and their habitats.

Recommendation 5: The succineid snail (*Succinea konaensis*) occurs under fallen, dead trees. If dead trees are to be moved at the Mid-Level Support Facility area, they should be placed outside the disturbance area. It may be preferred to have a qualified biologist present to search for and remove individual snails and relocate them with the dead trees.



Jesse Eiben checking Wēkiu bug traps on Puʻu Hauʻoki in April 2009.

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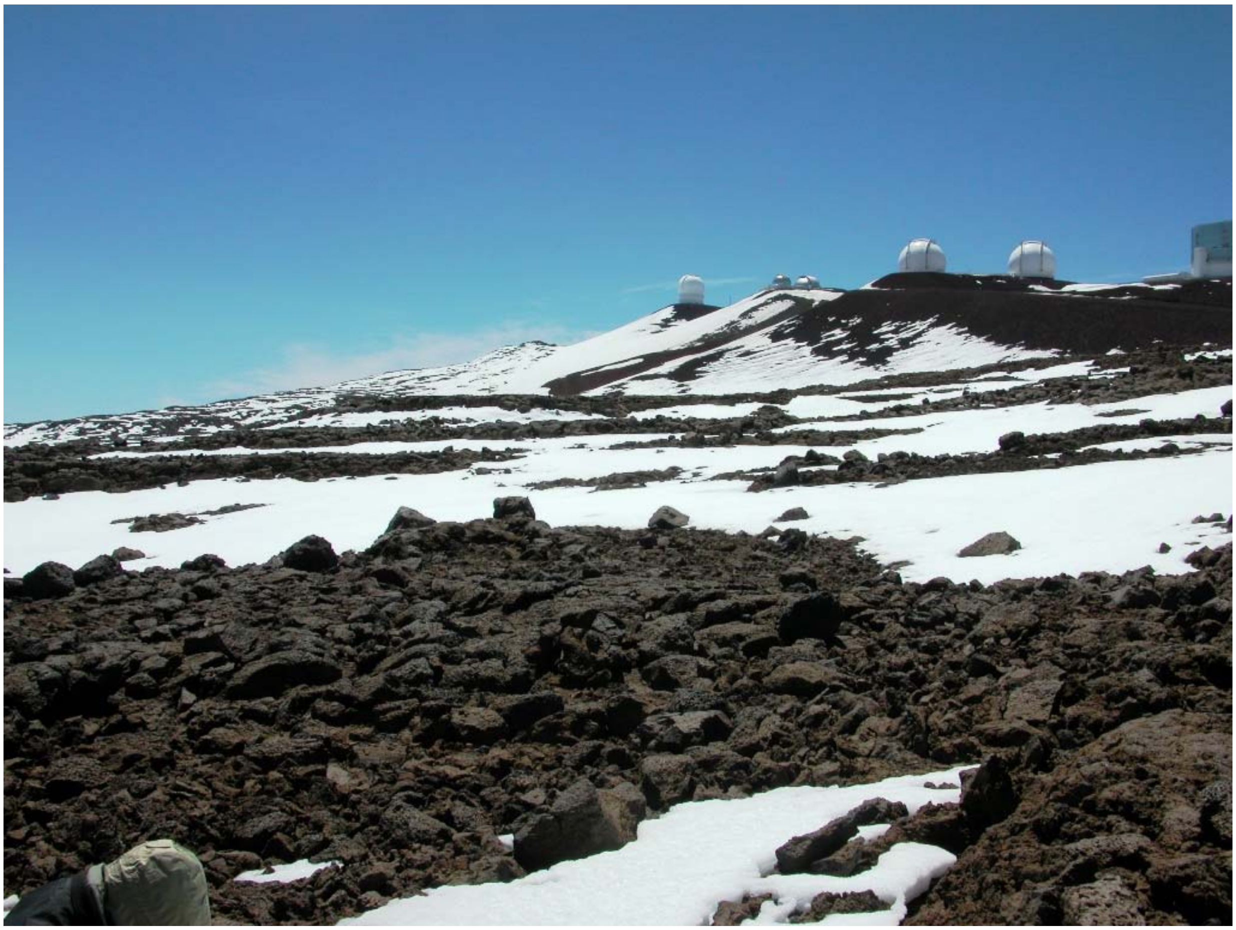

Looking towards the summit observatories from Area E in April 2009.

APPENDIX A

Results of the Thirty Meter Telescope Proposed Site Evaluation for the
Wekiu Bug (*Nysius wekiuicola*): Fall 2008.

Technical Report prepared by Jesse Eiben, M.S.

Results of the Thirty Meter Telescope Proposed Site Evaluation for the Wekiu Bug (*Nysius wekiuicola*): Fall 2008

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Summary
A four day sampling regime with the use of 45 baited attractant live traps designed for monitoring the presence and absence of the Wekiu bug (*Nysius wekiuicola* Ashlock and Gagné) was used to create part of the biological assessment of a proposed site for the Thirty Meter Telescope on Maunakea, Hawaii. Three Wekiu bugs were captured and counted before being released at the end of the sampling period on September 28, 2008. No Wekiu bugs were found in the area purported to be directly physically impacted by any possible telescope construction activity. The fall season is not the best time to look for the presence or absence of the Wekiu bug anywhere in its range, so there can be only limited conclusions drawn from this sampling period. However, there is broad accord among scientists that the type of rock substrate in the Northern Plateau is not known to regularly harbor large numbers of Wekiu bugs.

Introduction
As part of a project by Pacific Analytics, LLC for the Thirty Meter Telescope Project, I have been contracted to sample for the Wekiu bug in areas selected as possible sites for Project construction on the Northern Plateau of Maunakea. This project is different from, yet is informed by, scientific research I am conducting for my PhD in entomology at the University of Hawaii at Manoa involving the life history and population genetics of the Wekiu bug.

The Wekiu bug, *Nysius wekiuicola* Ashlock and Gagné, on the Island of Hawaii has been the focus of much attention in its native range on and near the summit of Hawaii's tallest mountain, Maunakea. Since the bug's formal description in 1983 by Ashlock and Gagné, the bug's habitat and life history has been of great interest to scientists, conservationists, and the public as a whole. The specialized life history allowing the Wekiu bug to survive the extremes of temperature, solar radiation, and water and food availability make this insect a true marvel of adaptation. Due to its limited range, specialized habitat requirements, isolated populations, and habitat destruction, the Wekiu bug was is currently a candidate for listing priority 8 under the Endangered Species Act (Endangered, 2006). Explorations of the summit area over the past 10 years by entomologists representing the Bishop Museum, Pacific Analytics, LLC, and the University of Hawaii at Manoa have greatly enhanced our knowledge of the types of areas Wekiu bugs inhabit, their behaviors and life history (Pacific Analytics, 2006, Englund et al. 2007, Eiben, unpublished).

The objectives for this study are to provide presence and absence data of the Wekiu bug in a subset of its range on and near the summit of Maunakea as part of the biological assessment of a potential site for a new observatory in the Astronomy Precinct being prepared by Pacific Analytics, LLC.

Materials and Methods

<u>Study Area:</u>

The area of Maunakea being sampled for Wekiu bugs is known as Area E on the Northern Plateau of the mountain. In practical terms, the area encompasses a part of the west and northwest zone of the Astronomy Precinct on the summit of Maunakea. Specific locations for wekiu bug live-trap placements were haphazardly selected in Area E, along the 4-wheel drive road to Area E, around the Batch Plant, and in two control locations not in the expected construction disturbance areas where Wekiu bugs have been found multiple times in 2007 and 2008 (Eiben, unpublished).

Trapping Methods:

A live pitfall trap design very similar to those described by Englund et al. (2002) and Pacific Analytics (2002) was used to attract Wekiu bugs. The modifications in design are as follows. Two 10oz clear plastic cups were used for each trap. The upper cup was punctured with one small hole in the bottom center through which a small absorbent wick made of tissue (Kimtech Science) was pushed. A small amount of water was poured into the bottom of the lower reservoir cup. The attractant shrimp paste was placed in the upper cup contacting the wick, on a few small pieces of rock in the cup, smeared on the side of the cup, and on a cap rock. The traps were dug into the available ground substrate attempting to achieve a depth where moisture was present in the ash layer. The lip of the cup was not necessarily placed flush with ash layer, and there was no wire mesh surround to provide structure surrounding the cups. This cup design has been successful for attracting and capturing Wekiu bugs during 2007 and 2008 (Eiben, unpublished). Most sites selected for sampling used a pair of traps within 16.4 feet of each other in different microhabitat types (ex. large rock jumble vs. ash layer near the surface) to attempt to sample the true diversity of the habitat (see Tables 1 and 2). The traps were checked daily and bugs captured were removed for the duration of the sampling period to prevent recounts. Bugs were held for up to three days in captivity with food and water sources.

Results

No Wekiu bugs were observed while hiking through the trapping areas, nor were any Wekiu bugs observed while emplacing the traps. Forty-five traps were placed for three or four days from September 25-28. Three Wekiu bugs were captured in two locations over the sampling period (see Table 1, Table 2, and Figure 1). One adult female and one 5th instar nymph Wekiu bug were captured in the control area near the SE base of Puu Hau Oki on September 26, 2008. One 5th instar nymph Wekiu bug was found in the control area on the E base area of Puu Poliahu on September 28, 2008. All three Wekiu bugs found in the traps were alive and were released alive in good condition where they were captured on September 28, 2008.

Discussion

Though the sampling effort (number of traps) for Wekiu bugs during this sampling period was quite intense given the area surveyed, there can be little information drawn from the lack of bugs found in Area E. During the fall season, the number of Wekiu bugs found on Maunakea throughout its range are much less than during other times of the year. The reason for this is unknown. Wekiu bugs are found in much higher numbers during the late spring and early summer, and these areas are correlated to lasting snow pack (Englund et al. 2007). The duration and availability of moisture sources may indeed be a limiting factor for the year-round distribution of the Wekiu bug within its range. The spring sampling period of Area E should be much more informative for determining the presence or absence of the Wekiu bug in the possible construction zone for the Project.

Acknowledgements

I would like to thank Greg Brenner of Pacific Analytics, LLC for his help in the field and valuable insights about the Wekiu bug and its habitat. Betsy Gagné at DLNR has proven

instrumental in obtaining permits for all work relating to the genus Nysius in Hawaii. The support of Stephanie Nagata at OMKM is crucial to all work involving the Wekiu bug and is always most helpful.

Table 1. Detail of baited shrimp trap locations and wekiu bug captures during September, 2008

Site Description	Trap Name	Paired traps	GPS Coordinates (NAD83)	Wekiu Bug Captures			
				25-Sep-08	26-Sep-08	27-Sep-08	28-Sep-08
Site 1 footprint	TMT1A	Yes	19°49'57.22"N 155°28'52.93"W	Install	0	0	0
Site 1 footprint	TMT1B	Yes		Install	0	0	0
Site 1 footprint	TMT2A	Yes	19°49'57.90"N 155°28'53.69"W	Install	0	0	0
Site 1 footprint	TMT2B	Yes		Install	0	0	0
Site 1 footprint	TMT3A	Yes	19°49'56.35"N 155°28'53.65"W	Install	0	0	0
Site 1 footprint	TMT3B	Yes		Install	0	0	0
Site 1 footprint	TMT4A	Yes	19°49'55.42"N 155°28'53.08"W	Install	0	0	0
Site 1 footprint	TMT4B	Yes		Install	0	0	0
Site 1 footprint	TMT5A	Yes	19°49'53.80"N 155°28'52.97"W	Install	0	0	0
Site 1 footprint	TMT5B	Yes		Install	0	0	0
Road	TMT6A	Yes	19°49'52.46"N 155°28'53.04"W	Install	0	0	0
Road	TMT6B	Yes		Install	0	0	0
Road	TMT7A	Yes	19°49'51.67"N 155°28'50.74"W	Install	0	0	0
Road	TMT7B	Yes		Install	0	0	0
Site area	TMT8A	Yes	19°49'52.10"N 155°28'49.69"W	Install	0	0	0
Site area	TMT8B	Yes		Install	0	0	0
Site area	TMT9A	Yes	19°49'52.68"N 155°28'48.22"W	Install	0	0	0
Site area	TMT9B	Yes		Install	0	0	0
Site 2 footprint	TMT10A	Yes	19°49'41.02"N 155°28'46.45"W	Install	0	0	0
Site 2 footprint	TMT10B	Yes		Install	0	0	0
Site 2 footprint	TMT11A	Yes	19°49'41.84"N 155°28'45.01"W	Install	0	0	0
Site 2 footprint	TMT11B	Yes		Install	0	0	0
Site 2 footprint	TMT12A	Yes	19°49'43.10"N 155°28'44.08"W	Install	0	0	0
Site 2 footprint	TMT12B	Yes		Install	0	0	0

Table 2. Detail of baited shrimp trap locations and wekiu bug captures during September, 2008

Site Description	Trap Name	Paired traps	GPS Coordinates (NAD83)	Wekiu Bug Captures 25-Sep-08	26-Sep-08	27-Sep-08	28-Sep-08
Site 2 footprint	TMT13A	Yes	19°49'43.61"N 155°28'45.84"W	Install	0	0	0
Site 2 footprint	TMT13B	Yes		Install	0	0	0
Site 2 footprint	TMT14A	Yes	19°49'46.49"N 155°28'47.39"W	Install	0	0	0
Site 2 footprint	TMT14B	Yes		Install	0	0	0
Site Area	TMT15A	Yes	19°49'43.79"N 155°28'51.78"W	Install	0	0	0
Site Area	TMT15B	Yes		Install	0	0	0
Site Area	TMT16A	Yes	19°49'45.55"N 155°28'53.47"W	Install	0	0	0
Site Area	TMT16B	Yes		Install	0	0	0
Road	TMT road1	No	19°49'28.63"N 155°28'40.01"W	N/A	Install	0	0
Road	TMT road2	No	19°49'32.48"N 155°28'41.26"W	N/A	Install	0	0
Road	TMT road3	No	19°49'38.27"N 155°28'44.31"W	N/A	Install	0	0
Road	TMT road4	No	19°49'43.75"N 155°28'48.79"W	N/A	Install	0	0
Batch plant	TMTbatch1A	Yes	19°49'12.65"N 155°28'27.44"W	N/A	Install	0	0
Batch plant	TMT batch1B	Yes		N/A	Install	0	0
Batch plant	TMT batch2A	Yes	19°49'12.72"N 155°28'29.82"W	N/A	Install	0	0
Batch plant	TMT batch2B	Yes		N/A	Install	0	0
Batch plant	TMT batch3	No	19°49'11.04"N 155°28'30.52"W	N/A	Install	0	0
Non-construction	TMT Pol contA	Yes	19°49'26.54"N 155°28'48.36"W	N/A	Install	0	1*
Non-construction	TMT Pol contB	Yes		N/A	Install	0	0
Non-construction	TMT Oki contA	Yes	19°49'25.72"N 155°28'31.66"W	Install	2**	0	0
Non-construction	TMT Oki contB	Yes		Install	0	0	0

*one fifth instar nymph captured
**one adult female and one fifth instar nymph captured

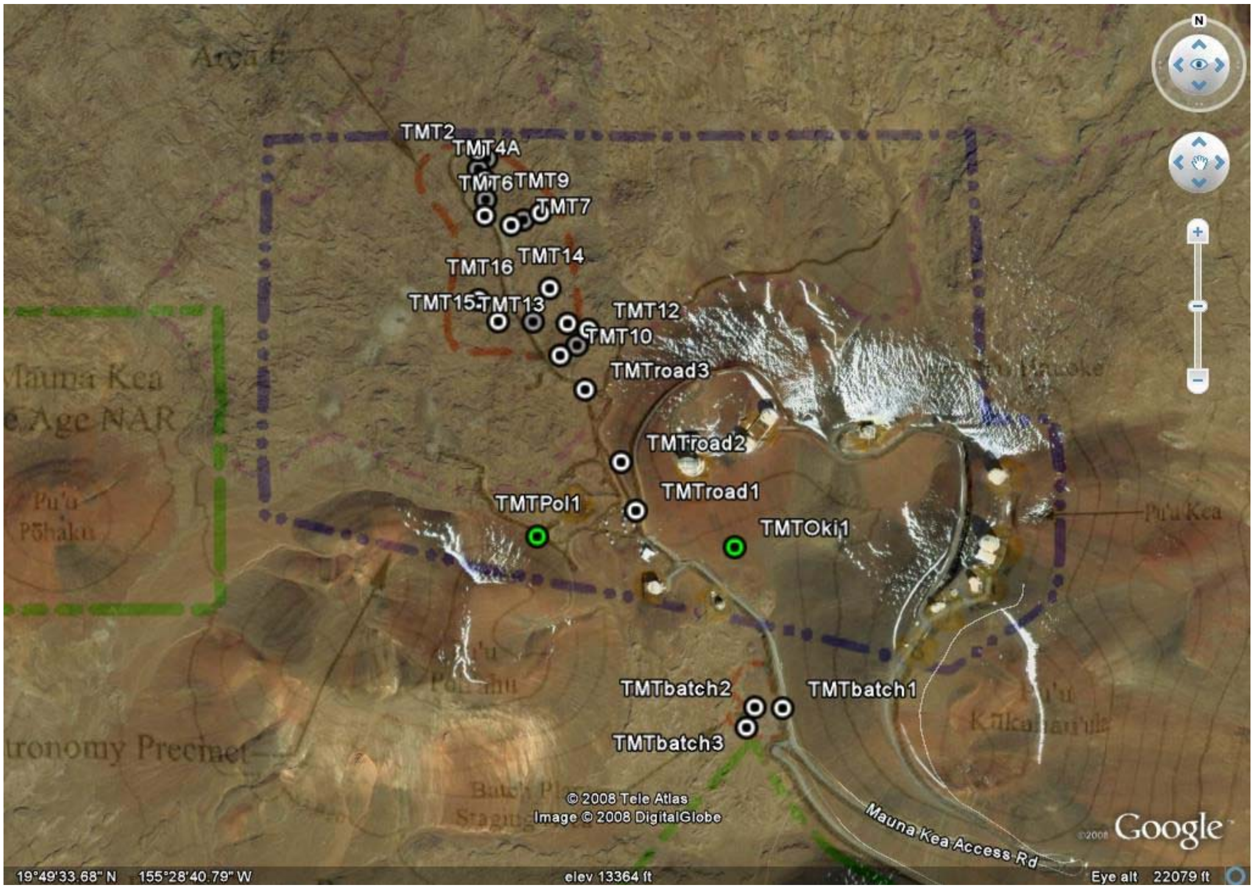

Figure 1. Overview map of study site sample locations within the Astronomy Precinct on Maunakea, Hawaii

*Astronomy Precinct outlined in purple

**Green dots indicate Wekiu bug capture locations

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APPENDIX B

Results of the Thirty Meter Telescope Proposed Site Evaluation for the
Wekiu Bug (*Nysius wekiuicola*): Spring 2009.

Technical Report prepared by Jesse Eiben, M.S.

Results of the Thirty Meter Telescope Proposed Site Evaluation for the Wekiu Bug (*Nysius wekiuicola*): Spring 2009

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Summary
A four day sampling regime with the use of 24 baited attractant live traps designed for monitoring the presence and absence of the Wekiu bug (*Nysius wekiuicola* Ashlock and Gagné) was used to create part of the biological assessment of a proposed site for the Thirty Meter Telescope on Maunakea, Hawaii. A total of 146 wekiu bugs were observed and/or captured between April 20 and 23, 2009. In the past, Wekiu bugs have often been captured in greater numbers during late March, April and May than during the summer and fall (Eiben pers. obs.). This cycle of Wekiu bug activity was confirmed during the two sampling periods for the proposed TMT site. Wekiu bugs were found in areas impacted previously by construction and in areas that are considered unaltered habitat. No Wekiu bugs were found in the area of the proposed construction footprint of the Project construction, however there were many Wekiu bugs found along the currently closed unpaved 4-wheel drive road north of the SMA array. This road may be impacted by Project construction, and Wekiu bug habitat and populations will need to be taken into consideration in the event of the road reopening. There is still broad accord among scientists that the type of rock substrate in the Northern Plateau is not known to regularly harbor large numbers of Wekiu bugs, and this was confirmed during the spring 2009 sampling session.

Introduction
As part of a project by Pacific Analytics, LLC for the Thirty Meter Telescope, I have been contracted to sample for the Wekiu bug in areas selected as possible sites for telescope facility construction on the Northern Plateau of Maunakea. This project is different from, yet is informed by, scientific research I am conducting for my PhD in entomology at the University of Hawaii at Manoa involving the life history and population genetics of the Wekiu bug.

The Wekiu bug, *Nysius wekiuicola* Ashlock and Gagné, on the Island of Hawaii has been the focus of much attention in its native range on and near the summit of Hawaii's tallest mountain, Maunakea. Since the bug's formal description in 1983 by Ashlock and Gagné, the bug's habitat and life history has been of great interest to scientists, conservationists, and the public as a whole. The specialized life history allowing the Wekiu bug to survive the extremes of temperature, solar radiation, and water and food availability make this insect a true marvel of adaptation. Due to its limited range, specialized habitat requirements, isolated populations, and habitat destruction, the Wekiu bug is currently a candidate for listing priority 8 under the Endangered Species Act (Endangered, 2006). Explorations of the summit area over the past 10 years by entomologists representing the Bishop Museum, Pacific Analytics, LLC, and the University of Hawaii at Manoa have greatly enhanced our knowledge of the types of areas Wekiu bugs inhabit, their behaviors and life history (Pacific Analytics, 2006, Englund et al. 2007, Eiben, unpub.).

The objectives for this study are to provide presence and absence data of the Wekiu bug in a subset of its range on and near the summit of Maunakea as part of the biological assessment of a potential site for a new telescope facility in the Astronomy Precinct being prepared by Pacific Analytics, LLC.

Materials and Methods

Study Area:

The area of Maunakea being sampled for Wekiu bugs is known as Area E on the Northern Plateau of the mountain. In practical terms, the area encompasses a part of the west and northwest zone of the Astronomy Precinct on the summit of Maunakea. Specific locations for Wekiu bug live-trap placements were haphazardly selected in Area E in the proposed footprint sites of the TMT Project, along the 4-wheel drive road to Area E, around the Batch Plant, and in two control locations not in the expected construction disturbance areas where Wekiu bugs have been found multiple times in 2007 and 2008 (Eiben, unpublished).

Trapping Methods:

A live pitfall trap design very similar to those described by Englund et al. (2002) and Pacific Analytics (2002) was used to attract Wekiu bugs. The modifications in design are as follows. Two 10oz clear plastic cups were used for each trap. The upper cup was punctured with one small hole in the bottom center through which a small absorbent wick made of tissue (Kimtech Science) was pushed. A small amount of water was poured into the bottom of the lower reservoir cup. The attractant shrimp paste was placed in the upper cup contacting the wick, on a few small pieces of rock in the cup, smeared on the side of the cup, and on a cap rock. The traps were dug into the available ground substrate attempting to achieve a depth where moisture was present in the ash layer. The lip of the cup was not necessarily placed flush with ash layer, and there was no wire mesh surround to provide structure surrounding the cups. This cup design has been successful for attracting and capturing Wekiu bugs during 2007 and 2008 (Eiben, unpublished). Most sites selected for sampling used a pair of traps within 5 meters of each other in different microhabitat types (ex. large rock jumble vs. ash layer near the surface) to attempt to sample the true diversity of the habitat (see Table 1). The traps were checked daily and bugs captured were removed for the duration of the sampling period to prevent recounts. Bugs were held for up to three days in captivity with food and water sources.

Results

A total of 146 Wekiu bugs were observed in the baited traps and in the immediate vicinity of the traps. Twenty four traps were placed for three full days starting on April 20 and removed on April 23. No Wekiu bugs were captured or observed in the area known as Area E on the Northern Plateau (12 traps), nor near the Batch Plant area (2 traps), 41 Wekiu bugs were found in 6 traps along the dirt road that is currently closed adjacent to the SMA array, and 105 Wekiu bugs were captured in four traps in two control locations not in areas with any planned direct impacts by construction activities of the Project (see Table 1, and Figure 1). Five nymph, 102 adult male, and 39 adult female Wekiu bugs were captured in total. Twenty seven live Wekiu bugs captured in the two “Poi Bowl, Pu’u Hau ‘Oki” control trap sites were collected and moved to the University of Hawaii lab colony by myself, Jesse Eiben, as per my permit allowances for the life history study of the Wekiu bug. There was an 85 percent survivorship rate of Wekiu bugs trapped in this sampling period with eighteen Wekiu bugs found dead in the traps, and four Wekiu bugs dying in captivity.

Discussion

The sampling effort during the spring sampling session was less intense (24 traps vs. 45 traps) than the fall sampling period because the spring is typically the active season for adult Wekiu bugs. As expected, we observed much higher trapping rates than in the fall of 2008 when Wekiu bugs are scarce and/or not attracted to traps. The weather at the summit during the sampling period of April 20-23, 2009 was quite cold and windy with the daytime high air temperature hovering only slightly above freezing at 34-41ºF and wind gusts up to 94 mph with ~45mph constant wind speeds. The lower trap catches on April 22 could be correlated to the overcast sky the previous day. Wekiu bugs were less likely to be active during the time between the traps were checked because they were simply too cold to be attracted and move in high numbers toward the baited traps on April 21st. Important to note is the complete lack of any recent wind deposited insect food sources for the Wekiu bugs. Virtually no by-catch of other insects was found in the traps, and the snow-covered areas of the mountain observed were bereft of insects.

Wekiu bugs were captured in places characterized as having large areas with an assemblage of different sized rock cinder scoria in a depth of approximately 2-10 inches before the ash layer was reached. This mixed rock tephra is found on the slopes of cinder cones. The areas where Wekiu bugs are found show a constant state of flux, with the scoria slowly moving down slope by the force of gravity and undergoing frost-heaves that continually 'sift' dust and ash down in depth thereby creating a natural and very slow sorting of rock scoria with larger rocks nearer the surface and smaller cinders being closer to the ash layer. This habitat type is apparently highly suitable for supporting populations of Wekiu bugs. There are many interconnected reasons why Wekiu bugs are associated with specific type of habitat. Wekiu bugs can use this depth of different sized cinder to thermoregulate by moving through the innumerable crevices that the assortment of rocks create. These crevices also provide paths for escape from predators (most likely the endemic lycosid spider). Temperature and humidity data show the incredible variation found in these few inches of rock, with humidity and temperature being oppositely correlated. Near the ash layer, the temperature is cool with high humidity, and at the surface where Wekiu bugs can bask in the sun, the temperature can be very high (up to 114º F) with extremely low humidity (10 percent) (Eiben unpublished). These microhabitats are necessary for the Wekiu bug physiologically, but can also create areas that hold and preserve prey items on which Wekiu bugs feed. As insects drop from the wind column and sift through the scoria, they can become protected from the intense desiccating conditions found at the surface. Of the traps that attracted Wekiu bugs, some traps were placed in areas with very little depth of this type of cinder tephra, however, since the effective range of these traps is unknown, the bugs could be attracted from adjacent deep cinder zones.

It has previously been shown that Wekiu bugs are found in much higher numbers during the late spring and early summer, and these areas are correlated to lasting snow pack (Englund et al. 2007). During this trapping session and others (Eiben, unpublished), it is apparent that Wekiu bugs are often found in areas that have no current adjacent snow pack (along the dirt road north of SMA, and at the lower trap sites on Pu'u Poliahu and Pu'u Hau 'Oki). The duration and availability of moisture sources may indeed be a limiting factor for the year-round distribution of the Wekiu bug within its range. When discussing insect populations and habitats, it essential to be cognizant that the individual organism does not seek out and use habitat on a very large scale. Population growth in an area will be at the whim of the food and climate (microclimate) available. This is especially true on Maunakea, where weather events can drastically change the time and duration of activity possible and availability of fresh prey items for Wekiu bugs.

Acknowledgements

I would like to thank Greg Brenner of Pacific Analytics, LLC for his help in the field and valuable insights about the Wekiu bug and its habitat. Betsy Gagné at DLNR has proven instrumental in obtaining permits for all work relating to the genus Nysius in Hawaii. The support of Stephanie Nagata at OMKM is crucial to all work involving the Wekiu bug and is always most helpful.

Table 1. Detail of baited shrimp trap locations and wekiu bug captures during April, 2009

Site Description	Trap Name	Paired traps	GPS Coordinates (NAD83)	Wekiu Bug Captures 20-Apr-09	21-Apr-09	22-Apr-09	23-Apr-09	TOTALS
SMA Access Road	STMTR1-A	No	N19 49.482 W155 28.648	Install	9	0	3	= 12
SMA Access Road	STMTR1-B	No	N19 49.481 W155 28.653	Install	3	0	7	= 10
SMA Access Road	STMTR2-A	No	N19 49.505 W155 28.659	Install	2	0	5	= 7
SMA Access Road	STMTR2-B	No	N19 49.503 W155 28.656	Install	1	1	2	= 4
SMA Access Road	STMTR3-A	No	N19 49.549 W155 28.679	Install	1	0	6	= 7
SMA Access Road	STMTR3-B	No	N19 49.549 W155 28.686	Install	0	0	1	= 1
Site 1 Footprint	STMTF1-A	Yes	N19 49.968 W155 28.880	Install	0	0	0	0
Site 1 Footprint	STMTF1-A			Install	0	0	0	0
Site 1 Footprint	STMTF1-B	Yes	N19 49.975 W155 28.895	Install	0	0	0	0
Site 1 Footprint	STMTF1-B			Install	0	0	0	0
Site 1 Footprint	STMTF1-C	Yes	N19 49.932 W155 28.898	Install	0	0	0	0
Site 1 Footprint	STMTF1-C			Install	0	0	0	0
Site 2 Footprint	STMTF2-A	Yes	N19 49.903 W155 28.887	Install	0	0	0	0
Site 2 Footprint	STMTF2-A			Install	0	0	0	0
Site 2 Footprint	STMTF2-B	Yes	N19 49.908 W155 28.853	Install	0	0	0	0
Site 2 Footprint	STMTF2-B			Install	0	0	0	0
Site 2 Footprint	STMTF2-C	Yes	N19 49.885 W155 28.849	Install	0	0	0	0
Site 2 Footprint	STMTF2-C			Install	0	0	0	0
Batch Plant	STMTbatch	Yes	N19 49.175 W155 28.492	Install	0	0	0	0
Batch Plant	STMTbatch			Install	0	0	0	0
Non-Construction	STMTPol-A	Yes	N19 49.448 W155 28.802	Install - 1	14	6	21	= 42
Non-Construction	STMTPol-B			Install	2	0	1	= 3
Non-Construction	STMTPoi-A	Yes	N19 49.429 W155 28.517	Install	6	13	16	= 35
Non-Construction	STMTPoi-B			Install	3	5	17	= 25

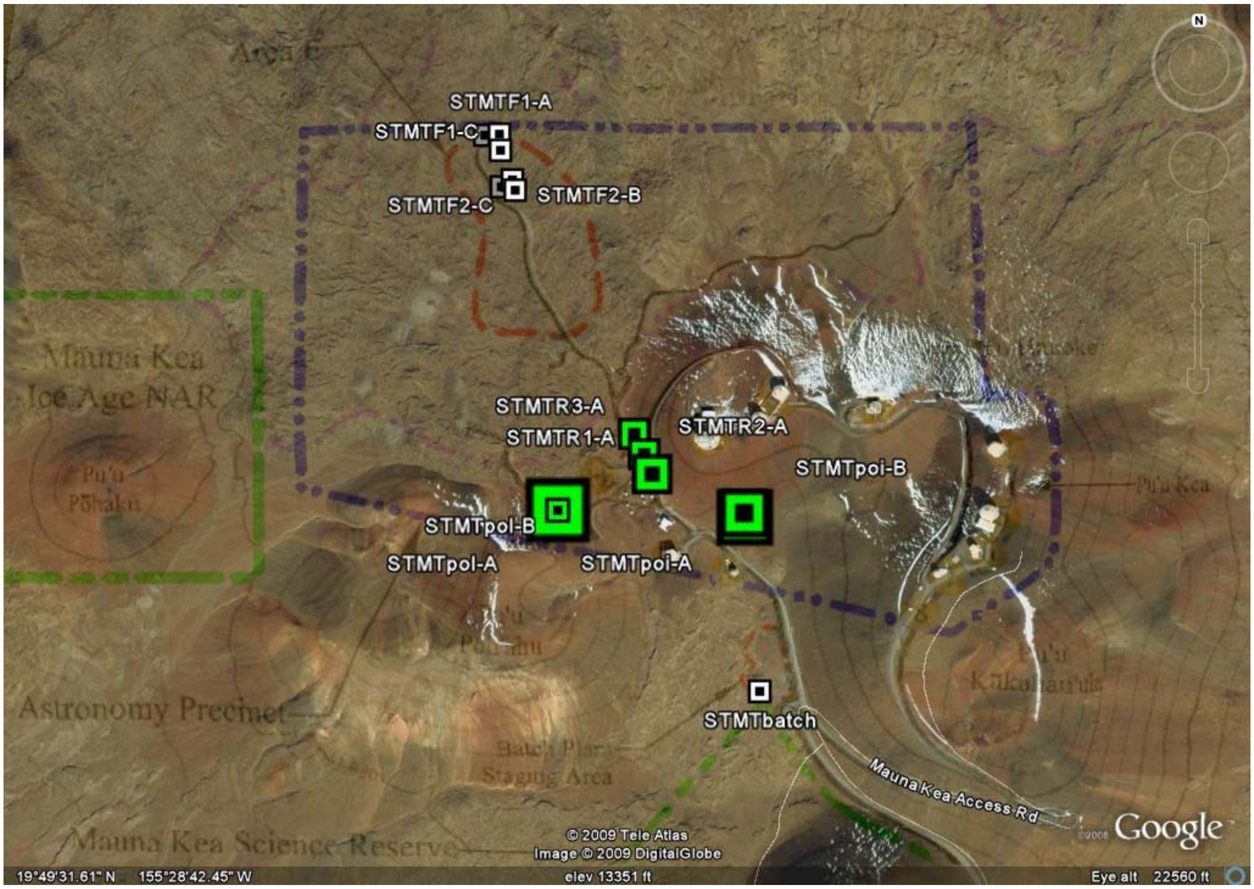

Figure 1. Overview map of study site sample locations within the Astronomy Precinct on Maunakea, Hawaii

*Astronomy Precinct outlined in purple

**Green squares indicate Wekiu bug capture locations, size correlated to trap captures

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APPENDIX C

MAUNAKEA REPORT
The lichens and bryophytes in the proposed Thirty Meter Telescope sites
at the summit of Maunakea, Hawaii

Technical Report prepared by Clifford Smith, Emeritus Professor in Botany,
University of Hawaii at Manoa.

MAUNAKEA REPORT
The lichens and bryophytes in the proposed Thirty Meter Telescope sites at the summit of Maunakea, Hawaii.

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INTRODUCTION

The summit area of Maunakea is barren land of massive cinder cones above andesite lava flows that erupted during the last period of glaciation; the lava flows erupting below the glacier cooled without crystallizing creating a particularly dense rock (Anon xxxx). The average daytime maximum air temperature is 50.1ºF and the low 24.8ºF; it freezes almost every night of the year (NOAA 2008). Such fluctuations are often referred to as 'summer every day, winter every night.' The average annual rainfall is 74 inches/year principally from November through April with little rain during June and July. Snow accumulates during the winter months sufficient for skiing but accumulation records have not been kept. UV radiation is intense; records from the Mauna Loa Observatory at 11,135 foot elevation are much higher than at sea level and will be higher still on the summit area of Maunakea (Bodhaine et al. 1997). Winds at the summit can reach 100 mph sufficient to abrade vegetation from rock surfaces (Anon xxxx).

In a general botanical survey of the summit area above 12,992 feet, Smith et al. (1982) recorded one species of algae, no hornworts or liverworts, possibly 12 species of moss, possibly 25 species of lichen, one fern and five flowering plants. All species occurred in very low abundance though there were very small, highly protected pockets where the lichens and mosses were common.

This survey was confined to a much smaller 40-acre area of the North Plateau.

STUDY SITE

The study site was the area being considered for the Thirty Meter Telescope just below the summit of Maunakea, Island of Hawaii. The area surveyed is called Area E, a 34-acre zone near the 13N Site located on the North Plateau of the Mauna Kea Science Reserve (MKSR).

METHODOLOGY

We spent two days in the area walking through the whole site recording all lichens and bryophytes observed. We search all four principal habitat types and spent some extra time investigating the small caves taking particular care not to disturb anything that looked of archaeological significance. We replaced all rocks that were picked up for examination as precisely as possible. We did disturb some of the rocks on the ground as we slide into the caves. We walked as much as possible on the large rocks and flows to prevent disturbance as well as for safety reasons.

The undersurface of 25 rocks of varying size were examined for lichens in rubble habitats. Counts were made of lichens present on the undersurface of rocks in the rubble areas to quantify abundance in these areas.

We removed small samples of all species found. Voucher specimens will be deposited in the B. P. Bishop Museum in Honolulu, Hawaii. Larger specimens were collected of species of whose identity we were uncertain so they could be sent to other lichen experts for confirmation of their identity.

HABITAT DESCRIPTION

Substrate types

- Pahoehoe.- About 50% of the habitat was of this type. The general topography was essentially flat and smooth with many folds. The edges of the folds were steep and rounded. There were several areas where the flow had shattered, fallen away creating small cliff-like faces. In several areas particularly at the head of small draws that typically radiated away from the mountain top in a northerly direction, small caves were found which ranged from about one foot to almost six feet deep.
- Aa.- No aa was found in the study area.
- Ash.- Small areas of ash was found in about 10% of the area.
- Rubble of shattered stones - This environment constituted about 40% of the habitat. Because lichens can grow on the undersurface of rocks we counted the number of rocks on their undersurface. We selected three different situations; stones with somewhat embedded in ash, stones where ash subsurface stones rested on ash, stones where there was no evident between or below the stones. Twenty five stones were overturned and examined for lichens and then replaced in their original position, Stones of various sizes were examined. Lichens were found only in the group where ash was not evident. In all but one instance the only lichen found was *Lecanora polytropa* and none of the thalli were fertile.

Rock surface

There are two apparent rock types in the study area a dense bluish coloured rock that breaks with a smooth surface with very few cracks or bubble cavities and a brown rock with a rougher surface and numerous bubble cavities. Both are andesite rock formed under the ancient summit glacier. The rocks are acidic and low in calcium.

Topography

The overall topography is approximately 10º slope with a sharp decline to a lower plateau on the eastern side. The slope increases at the northern edge of the study.

- Site 1 has less andesite rock, at least there is less exposed smooth, blue rock, there are also several small ‘draws’ leading down the mountain. They do not appear to be drainage channels. They are important habitat because it is at the head of these draws that one finds good lichen habitat on the rock face and in the small caves underneath.
- Site 2 has large areas of andesite rock with many clean faces of the smooth, blue andesite rock. The draws are much wider here and do not support as good lichen communities.

Temperature

The average monthly temperatures at the summit range from -5 to 13ºC (NOAA 2008).

Average Maximum Temperature (1971-2000).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Av.
(ºF)	42.0	42.5	40.3	41.4	47.5	49.3	50.9	49.9	50.5	48.3	45.1	42.7	46.0
(ºC)	5.6	5.8	4.6	5.2	8.6	9.6	10.5	9.9	10.3	9.1	7.3	5.9	7.8
Average Minimum Temperature													
(ºF)	26.3	26.1	24.9	26.2	29.0	29.4	30.3	30.9	31.3	29.5	27.8	27.6	28.4
(ºC)	-3.2	-3.3	-3.9	-3.2	-1.7	-1.4	-0.9	-0.6	-0.4	-1.4	-2.3	-2.4	-2.0

There is a notable, as yet unmeasured, difference in the temperature of exposed (hot) and shaded (cold) areas of rock faces. The difference is quite abrupt particularly where the aspect of the rock face changes abruptly.

Rainfall (NOAA 2008)

Average Precipitation (1971-2000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Av.
(in.)	0.85	0.15	1.07	0.48	0.97	0.12	0.20	0.75	0.62	0.53	1.26	0.42	7.41
(mm)	216	38	272	122	246	30	51	190	157	135	320	107	1882

SPECIES LIST

Lichens

Acarospora c.f. depressa.
Small light brown areoles (<3 mm diam.). Not fertile.
On the underside of a 15 × 7 cm piece or rubble.
Probably much more common lower down.

Candelariella cf. vitellina
Orange crust rarely more than 1 cm diam. of compact rounded areoles or isolated apothecia. Not fertile.
On consolidated ash or *Grimmia* tussocks in well-sheltered situations exposed to light but not in positions where it is exposed to full sunlight for long periods.
A cosmopolitan species on siliceous and non-calcareous rock.
The size and clumped, almost erect, nature of the areoles and their separation from the apothecia might suggest that this is a different species. However, the K- staining reaction clearly excludes the possibility that it is a species of *Caloplaca*. The somewhat unusual growth form may be a

consequence of the unfavorable environment where the squamules rarely divide but continue to grow.

Lecanora polytropa
Thallus of small, often indistinct areoles to somewhat continuous yellow-green crusts with frequent apothecia. The apothecia sessile, the margin the same color as the thallus, the disc paler with a somewhat greasy appearance, often partly or completely grayish to black, frequently completely overlapping the areole.
On rock in cracks or on *Grimmia* tussocks in open situations and at the mouth of overhangs. It is also found on the undersurface of rocks in the rubble areas.
A cosmopolitan species on siliceous rock.
The most widely distributed species in the study area.

Lecanora sp.
One small (1 cm diam.) thallus of compact white squamules most covered with large apothecia with concolorous margins and 1 mm diam., light buff discs.
On a small rock chip among consolidated ash amongst Grimmia.

Lepraria ?incana
A thin crust of small gray to blue-gray granules with a delicate intervening web of white hyphae.
In deep shade of small caves. Generally on the floor but toward the cave mouth also on the roof. The species prefers shaded habitats and is not tolerant of direct rainfall. It requires the very humid conditions found in the protected caves and can absorbed moisture when the relative humidity is higher than 70 percent.
Cosmopolitan.
Confirmation awaiting chemistry.

Pseudephebe minuscula
Colonies up to 5 cm diam., black, richly branched, prostrate, closely appressed to the rock face, thread-like, wiry. Not fertile.
On exposed, N-facing, vertical or almost so, rock faces. It was only found on the smooth rock face of exposed andesite rock. Common on sheer north-facing rocks at the head of the small draws and occasionally more open areas.
Arctic-alpine, circumboreal.

Rhizocarpon geographicum
An immediately recognizable species of small yellow areoles surrounded by a black hypothallus, with occasional apothecia in the middle or to the edge of the areoles.
On exposed, N-facing, vertical or almost so, rock faces. It was only found on the smooth rock face of exposed andesite rock.
Cosmopolitan. Arctic-alpine, montane in the tropics.
Not common.

Rhizocarpon sp.
Small colonies (1-2 cm diam.) of brown, shiny areoles <0.5 mm diam., interspersed with a black hypothallus.
On exposed, N-facing, vertical or almost so, rock faces. It was only found on the smooth rock face of exposed andesite rock.
Reminiscent of *R. hochstetteri* but no apothecia were found.

Umbilicaria aprina
Small (1-2 cm diam.), gray to black thalli generally closely appressed to the rock face but with ascending edges where crowded, the upper surface with large white crystals particularly along ridges. Attached at one point only (umbilicate). Not fertile.
On exposed, N-facing, vertical or almost so, rock faces. It was only found on the smooth rock face of exposed andesite rock.
Abundant in a few areas. Also known in greater abundance and size particularly where protected from continuous insolation in the summit area down to at least 3660m.
Found on high tropical mountain in Africa and also in Scandinavia and Greenland.
The thalli are attached along cracks or in a few small gas pockets on the rock surface.

Umbilicaria hirsuta
Very similar to *U. aprina* but the upper surface is brown and there are no crystals on the upper surface.
Only one colony was found mixed in with *U. aprina*
A cosmopolitan species found in greater abundance at lower elevations.

Lichen Abundance Estimates:

Counts of lichens present on the undersurface of 25 rocks in the rubble areas.
Embedded rocks. No lichens in two separate situations.
Rocks over ash. *Lecanora polytropa* under two rocks in one sample, 0 in the other.
Rocks not over apparent ash. *Lecanora polytropa* under ten or 12 rocks in the two samples as well as being on rocks under the rocks examined. *Acarospora sp*. under one rock.

Bryophytes

Grimmia ?pulvinatum
Small tussocks of grayish moss with black leaves and a fine white terminal hair.
On consolidated ash in well-sheltered situations exposed to light but not in positions where it is exposed to full sunlight for long periods.

Pohlia cruda
Small tussocks of green moss often with an orange tinge.
On consolidated ash in well-sheltered situations exposed to light but not in positions where it is exposed to full sunlight for long periods.

GENERAL COMMENTS

- The lichens and bryophytes are confined to protected habitats almost always on the north-facing sides of rocks or the head of small collapsed lava tubes.
- There is an extremely low cover (<1 percent) and diversity of lichens (10 species out of a currently known 612 species in the islands) and bryophytes (2 species out of a currently known 273 species in the islands) in the area. In sheltered, amenable habitats, lichens are locally common.
- The distribution of the different lichens is thought to reflect their ability to tolerate UV irradiation, overall light intensity and the availability of water, both liquid and gaseous.
- There is a marked difference in the distribution of the various lichens. The dark to black species (*Rhizocarpon ?hochstetteri, Pseudephebe miniscula, Umbilicaria aprina and U. hirsuta*) are found on the open face of northern facing rocks, (*Candelariella vitellina, Lecanora polytropa* and *Lecanora sp.*) at the base of northern facing rocks and (*Lepraria ?incana*) on the roof of the small lava tubes or deeper inside the tube). The presence of the dark species in the most exposed inhabited areas is in keeping with McEvoy, M., Gauslaa, Y. & Solhaug, K.A. (2007) finding that melanic pigments play a photoprotective role in light acclimation. The other species do not have such protection though the apothecia and areoles of *L. polytropa* are often light to dark grey in more exposed situations. *Lepraria* species frequently grow in protected shaded and humid habitats.
- Concise determinations of some species is not possible under the time constraints of this study even though fruiting bodies may be present. Species growing in such severe habitats, particularly those growing on rocks, produce spores only during favorable conditions. The only sure way of finding good specimens would be to conduct monthly collections for at least one year.
- None of the plants show evidence of feeding and there do not appear to be any obligate herbivores present. Therefore, the plants present do not appear to be necessary to support any herbivore trophic level.
- None of the lichen species present contain cyanobacteria so if nitrogen fixation is taking place up there none of it comes from lichens. Lichens on lava flows down below contribute to the nitrogen budget particularly the very common *Stereocaulon vulcani*.

RECOMMENDATIONS

- Site E2, the upper, more southerly footprint site being considered for Project construction is the preferred site from a cryptogamic point of view. The number of species is lower and the abundance of those present is lower. There is less sheltered habitat present.
- There is a greater abundance of lichens at the same elevation adjacent to the proposed sites where there are mounds of rocks rather than the solid flows present in the proposed sites.

CONCLUSIONS

- There is a very low diversity and cover of plants in the study area.
- All of the species are found at somewhat lower elevations at least on the southern side of the mountain. None of the species are unique to Hawaii.
- Lichens and bryophytes are generally confined to the northerly aspect of rocks or under overhangs and even then the abundance of species is much higher in those facing north.
- The vascular plants appear to be confined to the western side of the larger pahoehoe flows.
- It was gratifying to note that much of the rubbish that was seen in the 1982 Survey of the summit area had been removed.

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Respectfully submitted,

Clifford W. Smith

Mauna Loa Observatory (11,135 ft)													
Average Max. Temperature (ºF)	49.8	49.6	50.2	51.8	53.9	57.2	56.4	56.3	55.8	54.7	52.6	50.6	53.2
Average Min. Temperature (ºF)	33.3	32.9	33.2	34.6	36.6	39.4	38.8	38.9	38.5	37.8	36.2	34.3	36.2
Average Total Precipitation (in.)	2.39	1.53	1.73	1.28	1.01	0.49	1.16	1.49	1.34	1.14	1.74	1.98	17.30
Average Total SnowFall (in.)	0.0	1.0	0.3	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3.7
Average Snow Depth (in.)	0	0	0	0	0	0	0	0	0	0	0	0	0

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Abstract

A UV spectroradiometer was installed at Mauna Loa Observatory (MLO), Hawaii, in July 1995. This instrument, based on a commercially available double monochromator, uses a diffuser mounted as a horizontal receptor inside a quartz dome and views the whole sky. The instrument scans over the 290–450 nm spectral range with a band pass of about 1 nm for each 5° of solar zenith angle (SZA). The UV irradiances measured at MLO are much more intense than at low-altitude midlatitude locations. For observations at SZA 45° the erythemally weighted UV irradiances can exceed 21 $\mu W\ cm^{-2}$, which is approximately 15–20% greater than that seen at Lauder, New Zealand, for similar ozone amounts. The difference is primarily due to the higher altitude at MLO (3.4 km). For overhead Sun conditions at MLO the largest value of erythemal UV was 51.3 ± 3.1 $\mu W\ cm^{-2}$, which to our knowledge is the highest recorded any-where at the Earth's surface. UV irradiance is strongly correlated (inversely) with Dobson spectrophotometer total ozone measurements at MLO, with higher correlations at shorter wavelengths. The radiative amplification factor (RAF) for erythema at MLO is about 1.33 ± 0.2 at SZA 45°.

McEvoy, M., Gauslaa, Y. & Solhaug, K.A. (2007). Changes in pools of depsidones and melanins, and their function, during growth and acclimation under contrasting natural light in the lichen Lobaria pulmonaria. New Phytologist **175(2)**: 271-282.

Abstract

["In conclusion, the highly responsive melanic pigments play a photoprotective role in light acclimation, whereas the constant amount of depsidones across a wide spectrum of growth ranges and irradiances is consistent with herbivore defense functions."]