Ecosystem Restoration Management Plan
MIP Year 11-15, Oct. 2014 – Sept. 2019
OIP Year 8-12, Oct. 2014 – Sept. 2019
MUs: Opaeula Lower I

Overall MIP Management Goals:

- Form a stable, native-dominated matrix of plant communities which support stable populations of IP taxa.
- Control weed threats to support stable populations of IP taxa.

Background Information

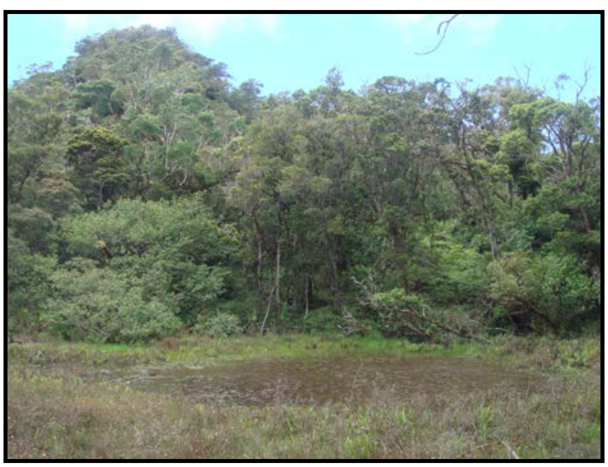
Location: Northern Koolau mountain range
Land Owner: Kamehameha Schools, US Army lease and license agreement
Land Managers:Oahu Army Natural Resource Management Program (OANRP)
Acreage: 15.9 acres
Elevation Range: 1920 ft - 2260 ft
Description: Lower Opaeula Management Unit (MU) is located in the northern Koolau Mountain Range, on the island of Oahu. Encompassing 15.9 acres of predominantly native habitat, the MU is bounded by Opaeula Stream to the north and Helemano Stream to the south. The MU mainly consists of a bowl which surrounds two ponds, the ridge immediately to the south of the bowl, running between Puu Curta and Puu Melicope, and a narrow finger extending south of the ridge into the Helemano drainage. This finger fence was added to protect rare resources. Although the historic Peahinaia trail runs to Lower Opaeula, it is overgrown, and OANRP access is via helicopter at the highest point in the MU, Puu Curta. The plant community is classified as a montane wet forest, and comprised of a mixture of native and introduced species. This MU contains rare taxa included in both the Makua and Oahu Implementation Plans. It is somewhat unique in the mid-elevation, uluhe-dominated Koolaus, as it includes stands of tall native trees. While some early management took place between 2000 and 2003, efforts were halted until the fence was constructed in 2011.

Native Vegetation Types at Opaeula Lower I

Koolau Vegetation Types
Wet forest
Canopy includes: *Acacia koa, Metrosideros* spp., *Syzygium sandwicense, Cheirodendron* spp., *Cibotium* spp, *Ilex anomala*, *Psychotria* spp., and *Melicope* spp. Understory includes: *Dicranopteris linearis, Freycinetia arborea, Alyxia stellata, Dianella sandwicense, Melicope* spp., *Psychotria* spp., *Cibotium chamissoi*, *Machaerina angustifolia*, and *Broussaisia arguta*.
NOTE: For MU monitoring purposes vegetation type is mapped based on theoretical pre-disturbance vegetation. Alien species are not noted.

Wet Forest Vegetation Type at Lower Opaeula I

Typical vegetation in the forested bowl



Left: Frogpond, the larger of the two ponds in Lower Opaeula
Right: *Gardenia mannii* on Puu Melicope

View of north facing slope from Puu Curta facing west, showcasing taller stature *A. koa*

MIP/OIP Rare Resources at Opaeula Lower I

Organism Type	Species	Pop. Ref. Code	Population Units	Management Designation	Wild/ Reintroduction
Plant	*Cyrtandra dentata*	OPA-F	Opaeula	MFS	Wild
Plant	*Gardenia mannii*	OPA-B, OPA-T, PAA-K	Lower Peahinaia	MFS/T1 GSC/T1	Wild
Plant	*Melicope lydgatei*	OPA-D*, E*, F, M, PAA-L	Kawaiiki and Opaeula	T1**	Wild
Plant	*Myrsine judii*	PAA-H	Kaukonahua to Kamananui-Koloa	T2	Wild
Plant	*Phyllostegia hirsuta*	OPA-G*	Helemano and Opaeula	GSC/T1	extirpated
Animal	*Achatinella sowerbyana*	OPA-N*	Opaeula	T2	extirpated
Insect	*Drosophila substenoptera*	OPA-A	Opaeula		Wild

MFS= Manage for Stability GSC= Genetic Storage Collection *= Population Dead T1 = Tier 1 T2=Tier 2

T1** due to the lack of fire threat for OIP species that occur outside of KTA or SBW, *Melicope lydgatei will no longer be managed as a MFS/T1*

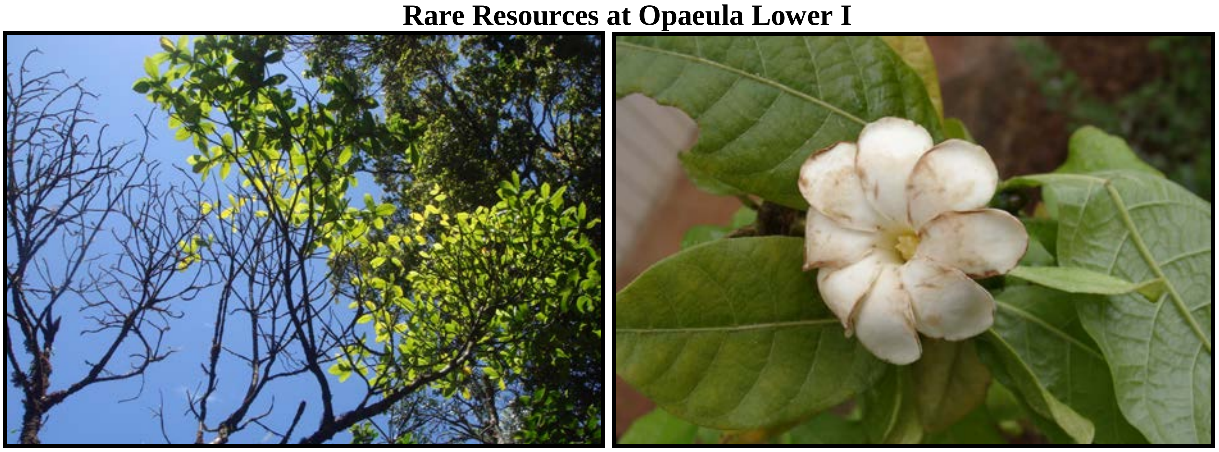
Other Rare Taxa at Opaeula Lower I

Organism Type	**Species**	**Status**
Plant	*Cyanea lancelota*	endangered
Plant	*Exocarpos gaudichaudii*	none
Plant	*Joinvillea ascendens* subsp. *ascendens*	candidate
Plant	*Stenogyne kaalae* subsp. *sherffii*	Endangered, outplanted in 2013 with OPEP
Insect	*Drosophila craddockae*	none
Insect	*Drosophila oahuensis*	none

Locations of rare resources at Opaeula Lower I

Map removed to protect rare resources

Rare Resources at Opaeula Lower I



Gardenia mannii

Melicope lydgatei

Stenogyne kaalae subsp. *sherffii*

Cyrtandra dentata

MU Threats to MIP/OIP MFS Taxa

Threat	Taxa Affected	Localized Control Sufficient?	MU scale Control required?	Control Method Available?
Rats	All	Unknown	Unknown	Yes
Pigs	All	No	Yes	Yes, majority of MU fenced
Weeds	All	Yes	No	Yes
Fire	*N/A*	No	No	Yes, but fire unlikely in this MU
Slugs	*Cyrtandra dentata,*	Yes	No	Yes, Sluggo is available for local control if area has been surveyed by an experienced malacologist to determine whether rare snails are present
Ants	Unknown, possibly *Drosphila substenoptera*	Unknown	Unknown	Some available, depends on species
Crane flies (Libnotes sp)	*Drosphila substenoptera*	Unknown	Unknown	Unknown, not likely
Yellowjackets (*Vespula pensylvanica)*	*Drosophila substenoptera*	No	Yes	Yes, but probably impractical at site

Management History

- Initial management began with the use of snares in the area in 1999. OANRP ran the snare groups until May 2001, but removed them due to the area being accessed by hunters.
- Funding for a portion of the MU fence from DLNR was awarded to the Koolau Mountain Watershed Partnership in 2001
- Weed control efforts occurred from 2002 and 2003, however they were discontinued as OANRP staff observed severe pig damage in freshly weeded areas.
- In November 2010 A 20 year license agreement was obtained from Kamehameha Schools to conduct Natural resource management on KS lands leased by the US Army.
- Initial line clearing for fence construction occured in June 2011. Fence construction completed in December 2011. Ungulate control was resumed and the unit declared ungulate free in early 2012.
- In April 2012, tree fall on fence was observed by staff on a routine fence check and ungulate sign was detected within the fence. Snare groups were promptly set. Seven pigs were removed from the unit and in June the unit was declared ungulate free once more.
- Ecosystem weed control resumes in April 2012.
- In April 2013, a population of *Stenogyne kaalae* subsp. *sherffii* was outplanted in the fence with staff members of the Oahu division of the Plant Extinction Prevention Program of Hawaii.
- In May 2013. OANRP staff installed plots to conduct a study of different weed control regimes on *Clidemia hirta* to determine best control strategy.
- In December 2013, a single *D. substenoptera* was observed at Lower Opaeula MU, the first record of the species in the Koolau range since 1972

Ungulate Control

Identified Ungulate Threats: Pigs

Threat Level: High

Primary Objective:

- Maintain fence as ungulate free.

Monitoring Strategy:

- Conduct quarterly fence checks.
- Note any pig sign while conducting day to day actions within fenced MU.
- Document any pig sign during other management activities.

Management Strategy:

- Initiate snaring program if any pig activity is detected within fence.

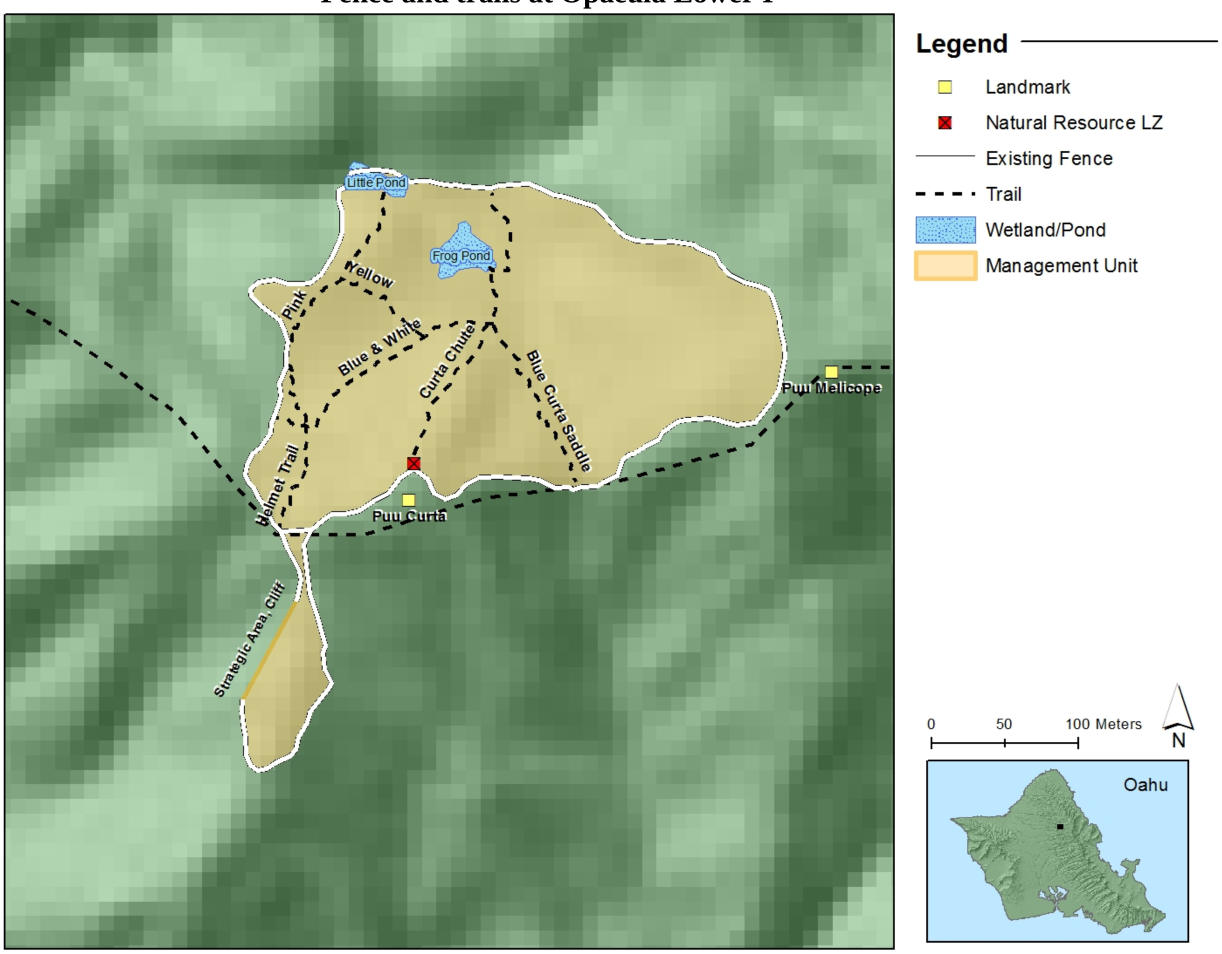
Fence Completion:

- Fence was completed in December 2011.

Maintenance Issues:

- Tree falls are the biggest maintenance issue for the MU. There are many very large old trees in the area. Since completion of the fence, one tree has already fallen on the fence. In another area a portion of the ground under the fence sloughed away creating an opening. During periods following heavy rains, a portion of the fence bordering the smaller pond is sometimes under water, and this may promote corrosion. However, the section is short (approximately 10m) and would easily be replaced since it is built with panels.

Fence and trails at Opaeula Lower I



Weed Control
Weed Control actions are divided into 4 subcategories:
1) Vegetation Monitoring
2) Surveys
3) Incipient Taxa Control (Incipient Control Area - ICAs)
4) Ecosystem Management Weed Control (Weed Control Areas - WCAs)

These designations facilitate different aspects of MIP/OIP requirements.

Vegetation Monitoring

<u>MU Vegetation Monitoring</u>

As defined by the MIP, the major vegetation cover goals are as follows:

Primary Management Objective:

- Assess if the percent cover for both the non-native understory and canopy is 50% or less across the entire management unit (Makua Implementation Team et al. 2003).
- If non-native species cover is not below the 50% threshold, determine if this value is decreasing significantly toward that goal based on repeated monitoring of the MU.

Secondary Management Objective:

- Assess if the percent cover for both the native understory and canopy is 50% or more across the entire management unit (Makua Implementation Team et al. 2003).
- If native species cover is not below the 50% threshold, determine if this value is increased significantly toward that goal based on repeated monitoring of the MU.

Current vegetation monitoring techniques used by OANRP are designed for MUs larger than Opaeula Lower I. NRS are therefore developing a methodology that will accurately detect changes in vegetation composition for an MU of this size. Methodology is expected to be developed within the next two years.

<u>Weed Control Monitoring</u>

The following are weed control objectives/questions which will be monitored in the MU.

1. Document effect of weed control in areas dominated by *P. cattleianum*.
    - Install photopoints at various locations through the MU and take photos annually.
2. When climax stands of *Clidemia hirta* are controlled, what is the vegetation response? NRS are interested in the following responses: the recovery of native species eighteen months after weeding, the establishment of other weed species, and the re-establishment of *C. hirta*. NRS want to discover the best interval between weeding events to minimize effort and weedy recruitment and maximize native recovery.
    - To answer these questions, a new monitoring protocol was established and is documented in Appendix 1-2 of the 2013 Year End Report: Monitoring Protocol 1.4 – Evaluate Non-Native Vegetation Control Methods – Pilot study to identify the most effective weed control re-treatment interval for *Clidemia hirta* for Opaeula Lower MU. An overview on the methods is included below.
    - In May 2013, four small ground plots were installed. This informal trial will compare the efficacy of different treatment schedules on *Clidemia*, specifically, how *Clidemia* vegetation cover and native species richness compare between 4 plots with different weeding regimes. The different weeding regimes or treatments are:
        - Plot 1 - no control
        - Plot 2 - weeded at time = 0 months
        - Plot 3 - weeded at times = 0 months and 6 months
        - Plot 4 - weeded at times = 0 months and 12 months.

- The plots will have photo points taken upon installation, six, 12, and 18 months, and vegetation cover data will be taken 18 months. The results of this study will guide future weeding efforts in the MU and may alter the proposed weeding intervals set forth in this plan.

- In addition to the four plots, 50 small (less than six inches) individual *Clidemia hirta* were located and tagged. These 50 keiki will be monitored quarterly to determine how long individuals take to reach maturity. At the 12 month reading, none of the tagged keiki had matured, the 18 month interval monitoring is due to be conducted after this year's reporting deadline.

Surveys

Army Training: The army conducts aerial training above Lower Opaeula I.
Other Potential Sources of Introduction: OANRP staff, rats, birds, and wind.
Survey Locations: LZ, Camp Site
Management Objective:

- Prevent the establishment of any new invasive alien plant or animal species through regular surveys at LZ.

Monitoring Strategy:

- Note unusual, significant, or incipient alien taxa during the course of regular field work and quarterly surveys of LZ.

Management Strategy:

- Novel alien taxa found will be researched and evaluated for distribution and life history. If taxa are found which pose a major threat, control will begin and will be tracked via ICAs.

Surveys are designed to be the first line of defense in locating and identifying potential new weed species. Currently the only avenues for human introduced incipient species are the landing zone at Puu Curta and the drop zone at the campsite. Quarterly monitoring of the Puu Curta LZ and the campsite will be conducted and the aforementioned protocols will be adhered to in the event of a discovery of a novel species.

Incipient Taxa Control (ICAs)

Management Objective:

- As feasible, implement regular control of high priority species identified as incipient invasive aliens in the MU with the goal of eradication within 10 years.
- Conduct seed dormancy trials for all high priority incipients by 2016.

Management Strategies:

- Visit ICAs at stated re-visitation intervals. Control all mature plants at ICAs and prevent any immature or seedling plants from reaching maturity.
- If unsuccessful in preventing immature plants from maturing, increase ICA re-visitation interval.

ICAs are drawn around each discrete infestation of an incipient invasive weed. ICAs are designed to facilitate data gathering and control. For each ICA, the management goal is to achieve complete eradication of the invasive taxa. Frequent visitation is often necessary to achieve eradication. Seed bed life/dormancy and life cycle information is important in determining when eradication may be reached; much of this information needs to be researched and parameters for determining eradication defined. Staff will compile this information for each ICA species.

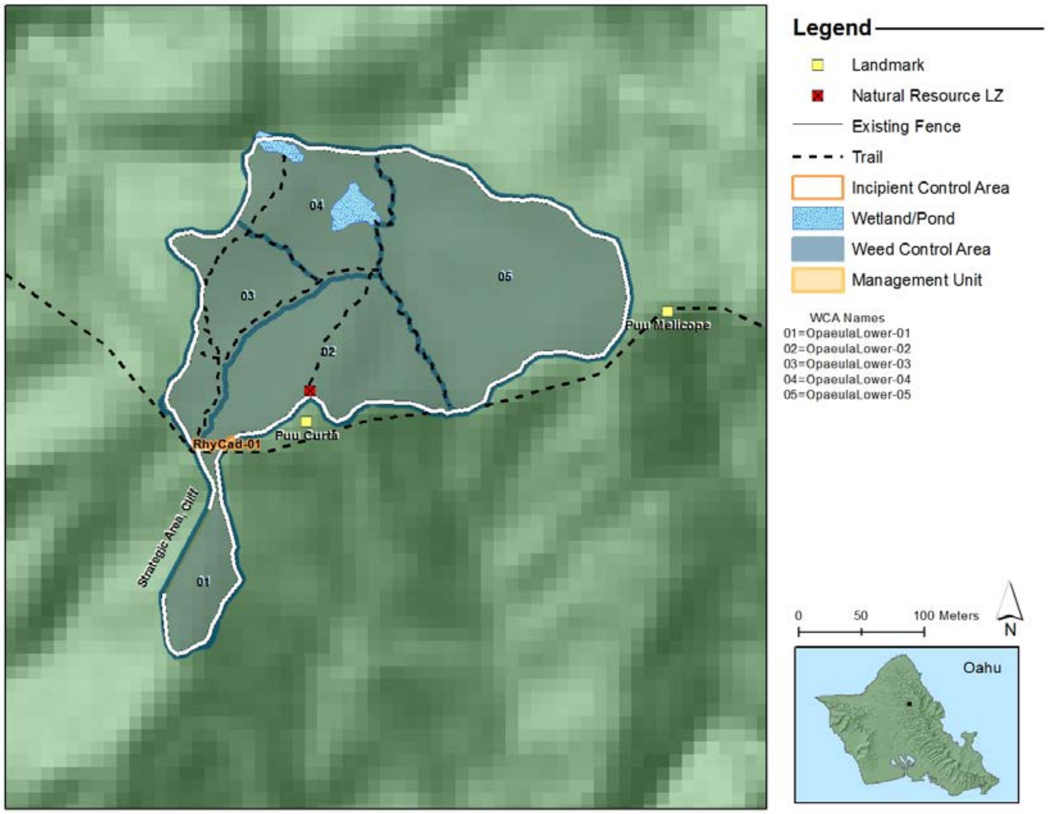
The table below summarizes invasive taxa at Opaeula Lower. Note that this MU was not described in the original MIP, and therefore is not included in Appendix 3.1 of the MIP, which lists significant alien species and ranks their potential invasiveness and distribution. This table supplements Appendix 3.1 by identifying target species for Opaeula Lower. While the list is by no means exhaustive, it provides a good starting point for discussing which taxa should be targeted for eradication in the MU. Three management designations are possible: Incipient (small populations, eradicable); Control Locally (significant threat posed, may or may not be widespread, control feasible at WCA level); and Widespread (common weed, may or may not pose significant threat, control feasible at WCA level).

Only one incipient, *Rhyncospora caduca*, has been identified by OANRP in the MU. OANRP will continue to monitor and consider control on possible incipients when appropriate. While not classified as incipient for this MU, the other taxa described in the table below are targeted during regular weed control sweeps. OANRP will continue to control *R. caduca* in order to remove all matures within WCAs. Return visits will be scheduled in order to prevent immature individuals from reaching maturity.

Summary of Target Taxa

Taxa	Management Designation	Notes	No. of ICAs
Angiopteris evecta	Control Locally	Scattered immature individuals along streamlets in the middle of the MU, mostly in OpaeulaLower-03	0
Citharexylum caudatum	Widespread	Scattered throughout the MU. Widespread along the Poamoho road, this taxa has bird-dispersed fruit. It can form dense stands, and has flexible habitat requirements. It is a priority for control whenever found.	0
Clidemia hirta	Widespread	Widespread and often forming dense patches throughout the MU.	0
Lantana camara	Widespread	One large patch at campsite in OpaeulaLower-04; also scattered throughout the MU.	0
Paspalum conjugatum	Widespread	Concentrated around the campsite and ponds in OpaeulaLower-04, but also scattered throughout the MU.	0
Psidium cattleianum	Widespread	Widespread and often forming dense patches throughout the MU. The flat bowls in the center of the MU contain some particularly dense stands of *P. cattleianum*. Control must be conducted carefully, to ensure that cleared areas aren't taken over by grass, but are managed for native taxa regeneration.	0
Psidium guajava	Widespread	Widespread throughout the MU.	0
Rhynchospora caduca	Incipient	One population has been found along the southern fenceline in OpaeulaLower-03. It is widespread along the Poamoho road and Mid LZ, making it very likely that this species was introduced via management, and will show up elsewhere in the MU.	1
Setaria palmifolia	Control Locally	One population treated at campsite in OpaeulaLower-04. It is unclear if this is widespread in nearby drainages, but within the exclosure, this is the only known site. It is a priority for control.	0
Sphaeropteris cooperii	Control Locally	Scattered individuals in the middle of the MU, especially in OpaeulaLower-03. Lower Opaeula is perfect habitat for *S. cooperii*, and many immature plants have already been removed from the MU. Few large, mature individuals have been found. Due to its documented invasive capability, it is a priority for control.	0
Urochloa maxima	Control Locally	One population treated at campsite in OpaeulaLower-04. While the habitat here is a little wet for this grass, its habitat-altering characteristics make it a control priority.	0
Unknown Palm	Control Locally	At least two palm trees are known from the eastern slopes of the MU. They are non-native, but have yet to be identified. If possible, they should be identified, and removed.	0

Weed Control Areas (WCAs) & Incipient Control Areas (ICAs) at Opaeula Lower I



Legend
Landmark
Natural Resource LZ
Existing Fence
Trail
Incipient Control Area
Wetland/Pond
Weed Control Area
Management Unit
WCA Names
01=OpaeulaLower-01
02=OpaeulaLower-02
03=OpaeulaLower-03
04=OpaeulaLower-04
05=OpaeulaLower-05
0
50
100 Meters
N
Oahu
01
02
03
04
05
Puu Malicope
Puu Curtis
RhyCad-01
Strategic Area, Cliff

Incipient and Weed Control Areas

Ecosystem Management Weed Control (WCAs)

<u>MIP Goals:</u>

- Within 2m of rare taxa: 0% alien vegetation cover except where causes harm.
- Within 50m of rare taxa: 25% or less alien vegetation cover
- Throughout the remainder of the MU: 50% or less alien vegetation cover

<u>Management Objectives</u>:

- Focus weeding around *Gardenia manii*, *Cyrtandra dentata,* and *Drosophila substenoptera* populations to enlarge and improve habitat.
- Maintain 50% or less alien vegetation cover in the understory across the MU.
- Reach 50% or less alien canopy cover across the MU in the next 5 years.
- In WCAs within 50m of rare taxa, work towards achieving 25% or less alien vegetation cover in understory and canopy.

<u>Management Strategy:</u>

- Modify weeding efforts if population monitoring indicates weed control efforts are not contributing to stable population growth of IP taxa.

Early OANRP weed control efforts at Lower Opaeula were focused on reducing alien vegetation encroachment around *C. dentata, G. mannii,* and *M. lydgatei* rare plant populations. These efforts were not effective at removing woody weeds, as ungulates were not excluded from the MU at the time and the weeded areas provided open space for the pigs to till.
The major weed threats in the MU are *P. cattleianum* and *C. hirta*. Both of these species have the potential to form dense monotypic stands, and are a dominant presence in other areas of the Koolau Mountains. Weed control in Lower Opaeula will focus on conducting ground sweeps across all portions of the MU, targeting *P. cattleianum* and other weeds (listed in the Summary Target Taxa table above). The entire MU has been divided into Weed Control Areas (WCAs) to assist in tracking and scheduling control efforts. WCAs will be weeded on a rotational basis given the difficulty of access, terrain, and staff resources. The WCAs that are most accessible, have the gentlest terrain, the most rare resources, and the fewest weeds will be prioritized for control.

In general, weed sweeps involve all staff lining up and walking in a phalanx across a WCA, treating every target weed seen. The goal of a sweep is to survey and achieve complete coverage of a WCA. In more weed-dense areas, control involves working in a smaller designated area, removing all weeds, and in the case of dense C. hirta stands, stacking the slash into piles in or out of the fence. In areas with steep terrain or dense native understories, methods will be modified to use "spotters" with binoculars that will direct other staff to target weeds seen. This will ensure more effective weed sweeps that minimize disturbance to native vegetation.

WCAs: OpaeulaLower-01 (Melicope Finger Fence)

<u>Veg Type</u>: Wet Montane

<u>OIP Goal</u>: 50% or less alien cover.

<u>Targets</u>: All woody species, particularly *P. cattleianum, C. hirta,* and *C. caudatum.*

<u>Notes</u>: This is the southernmost WCA and encloses a *M. lydgatei* rare plant population. The majority of this WCA is dominated by *Dicranopteris linearis*, with a *Metrosideros polymorpha* and *Acacia koa* overstory. Most of the weeds (*C. hirta* and *C. caudatum*) are concentrated at the southern end of the WCA near the stream bottom and low lying areas. Weed sweeps will concentrate on *C. hirta* removal around rare taxa locations and native forest patches. Eventually, efforts may be expanded across the WCA as time allows.

WCA: OpaeulaLower-02 (Puu Curta Slopes)
Veg Type: Wet Montane
OIP Goal: 50% or less alien cover.
Targets: All woody species, particularly *P. cattleianum* and *C. hirta.*
Notes: Rare taxa in this WCA include *M. lydgatei* and *E. gaudichaudii*. This WCA encompasses northern slopes of Puu Curta and the vegetation is predominantly native, with a thick *D. linearis* understory. Weed sweeps will focus on *P. cattleianum* and *C. hirta*, which are concentrated in a bowl around the Blue Curta Trail in the lower part of the WCA. This WCA also contains the main landing zone for the MU, as well as a *R. caduca* ICA along the southwest fenceline. Weed sweeps will utilize spotters with binoculars to direct targeted weed control to minimize damage to *D. linearis*.

WCA: OpaeulaLower-03 (West Side)
Veg Type: Wet Montane
OIP Goal: 25% or less alien cover around rare plants, 50% or less alien cover elsewhere.
Targets: *S. cooperi*. *A. evecta.* All woody species, particularly *P. cattleianum, C. caudatum,* and *C. hirta.*
Notes: The flatter areas of this WCA contain large stands of nearly monotypic *P. cattleianum* and *C. hirta* which are targeted for removal. Immature *S. cooperi* and *A. evecta* have also been observed in the WCA and will be controlled during weed sweeps. This WCA has an abundance of native species in some areas, including *M. polymorpha, A. platyphylum,* and *C. platyphyllum* in the canopy, and *W. oahuensis, P. hathewayi,* and *Cibotium* species in the understory. Rare plants in this WCA include *C. dentata, G. mannii,* and a *S. kaalae sherffii* reintroduction. Photopoints to document changes in vegetation after weeding have been set throughout the WCA, especially where large patches of *P. cattleianum* and *C.hirta* are being removed. Common native tree and understory outplanting may occur in these cleared areas depending on whether or not native recruitment occurs.

WCA: OpaeulaLower-04 (North-West Corner and Ponds)
Veg Type: Wet Montane
OIP Goal: 50% or less alien cover.
Targets: All woody species, particularly *P. cattleianum, P. guajava, C. spinosum,* and *C. hirta. P. conjugatum, U.maxima,* and *L. camara* will be targeted at the camp site and around the ponds.
Notes: This WCA is easy to access and weed sweeps can be conducted over the entire area to focus on *P. cattleianum* and *C. hirta*. Other weeds including *P. conjugatum, S. palmifolia, U. maxima,* and *L. camara* will be targeted at the camp site. The open areas directly adjacent to the pond that are subject to a cycle of ebb and flood will not be prioritized as they are easily invaded by grasses, however grass control will be a priority at the forested edges of the pond. The western half of the WCA contains high amounts of native vegetation, including *W. oahuensis, A. stellata, F. arborea,* and *Antidesma sp,* and a *G. mannii* rare plant population. A photopoint to document changes in vegetation after weeding has been established near the main pond.

WCA: OpaeulaLower-05 (Puu Melicope Slopes)
Veg Type: Wet Montane
OIP Goal: 25% or less alien cover around rare plants, 50% or less alien cover elsewhere.
Targets: All woody species, particularly *P. cattleianum, P. guajava, C. caudatum,* and *C. hirta.*
Notes: This WCA contains a high percentage of native vegetation, including *D. linearis, M. polymorpha, A. koa,* and *F. arborea*. There is a *M. lydgatei* rare plant population on the southern fenceline and populations of *G. mannii* and *Drosophila substenoptera* at the far East corner of the WCA.. Weed control will be concentrated around the rare taxa and native forest patches. This WCA may be extended eastward beyond the fence in order to improve habitat for *D. substenoptera* as the management actions for the species are still being determined. Spotters with binoculars will be utilized to direct

targeted weed control to minimize damage to *D. linearis* on slopes. There are two large non-native palms in this WCA that need to be identified and controlled.

Rodent Control

Species: *Rattus rattus* (Black rat), *Rattus exulans* (Polynesian rat), *Mus musculus* (House mouse)
Threat level: Threaten *G. manii, and C. dentata*, threat level unknown to other rare plant taxa. High threat in regards to *Achatinella sowerbyana* (extirpated).
Current control method: Many available, No active control method currently employed.
Seasonality: A population spike occurs in the fall within other MUs were rat populations are tracked. It is not known if this population spike occurs in Opaeula Lower I.
Number of control grids: None
Acceptable Level of Activity: Currently there are no known populations of *Achatinella sowerbyana* or any other *Achatinella spp.* in the MU. Rats have predated airlayers on *G. mannii* and *C. dentata,* but this predation can be avoided with the use of cages around the air layers. No control program has been planned as the threat level to rare plants has not been fully assessed. If rats are shown to be preying upon IP plant taxa besides airlayers (ie *G. manii* fruit or outplantings), localized control will be conducted to achieve the desired resource response.
Monitoring Objective:

- Monitor IP taxa to determine impacts by rodents.

Monitoring Strategies:

- Use direct observation and game cameras to determine rodent impacts.
- Use tracking tunnel data, trap data, and rare plant monitoring to guide further rodent control.

Management Objective:

- Reduce rodent impacts on rare taxa (as determined by monitoring).

Management Strategy:

- Implement rodent control around rare plant populations during two periods: when out planting occurs and when outplants mature and are producing fruit.

Ant Control

Species: No collections to date, however *Solenopsis papuana* has been observed.
Threat level: Low, may be higher for *D.substenoptera.*
Control level: Only for new incipient species.
Seasonality: Varies by species, but nest expansion observed in late summer, early fall at other sites.
Number of sites: No surveys for ants have been conducted at Opaeula Lower I. However, *Solenopsis papuana* has been observed on sponges used in surveying for *Drosophila.* Suggested sites to survey in the future are the Landing Zone and the campsite.
Acceptable Level of Activity: Unknown
Primary Objectives:

- Determine what ant species are present and monitor these sites over time.

Monitoring Strategy:

- Sample ants at human entry points at the LZ and campsite. Use samples to track changes in existing ant densities and to alert OANRP staff to any new introductions. Ants are unlikely to be a problem here due to wet conditions.

Management Strategy:

- If incipient species are found and deemed to be a high threat and/or easily eradicated locally (<0.5 acre infestation) begin control with AMDRO. If *S. papuana* is found to be impacting *Drosophila*, control methods will be determined and implemented.

Yellowjacket Control

Threat: *Vespula pensylvanica* (western yellowjacket)
Threat level: Unknown, perhaps High for *D.substenoptera*.
Control level: MU level.
Seasonality: Year-Round, abundance peaking in August–October.
Number of sites: None yet, proposed bait network of about 30 heptyl butyrate traps.
Acceptable Level of *V. pensylvanica* Activity: Unknown

Primary Objective:

- Determine the population and threat level *V. pensylvanica* poses in the MU.

Secondary Objectives:

- Map spatial distribution and seasonal abundance changes of *V. pensylvanica* in the MU.
- Determine if *V. pensylvanica* is having an impact on *Drosophila* spp. in the MU.

Management Strategies:

- By end of 2015, conduct a distribution and abundance survey for *V. pensylvanica* in areas of the MU where *Drosophila* are known to be or potentially present.
- If needed, develop a control technique and strategy for *V. pensylvanica*.

Monitoring Objectives:

- Monitor for unusually high summer/fall outbreaks and apply control if necessary.

The arrival of *Vespula pensylvanica*, a generalist predator on other invertebrates and scavenger, was followed shortly by major declines of many of the large sized endemic picture-wing *Drosophila* species. They are also known to have serious impacts on native *Hylaeus* bees, both through direct predation and by excluding bees from flowers. The endangered *Drosophila* species found at Lower Opaeula, *D. substenoptera*, may be particularly vulnerable to predation because they often stand conspicuously with their wings held to the side even when not actively displaying. In relatively dense forests such as Opaeula, *V. pensylvanica* may occur in high abundance but still be inconspicuous by keeping primarily to the canopy. Wasps are strongly attracted to the non-toxic chemical lure heptyl butyrate, which can be used to quantitatively monitor populations over time. If they turn out to be highly abundant at the MU, particularly in the late summer and fall when populations typically undergo booms, then control may be warranted. Work at Hawaii Volcanoes National Park has demonstrated successful control using poisoned meat baits.

Slug Control

Species: Slugs (multiple species assumed present but no collections to date).
Threat level: High.
Current control method: Localized.
Seasonality: Wet season (September-May).
Number of MFS species affected: *Cyrtandra dentata*.
Acceptable Level of Activity: No control program planned currently and threshold not determined for threats.
Primary Objective:

- Reduce slug population to levels where germination and survivorship of rare plant taxa are impeded.

Monitoring Objective:

- Determine presence and species composition of slugs
- Determine monitoring methods for *C. dentata*

Monitoring Strategies:

- During annual plant monitoring, record whether slug damage is present (chewed leaf margins, slime trails on vegetation).
- Determine slug species present and estimate baseline densities using traps baited with beer.
- Annual census monitoring of slug densities during wet season.
- If Sluggo is deployed, monitor efficacy via beer traps.

Management Strategy:

- If slug numbers are high enough to damage native plants, survey areas for the presence of rare snails. If no rare snails are present, begin slug control using Sluggo at the label rate.

Fire Control

Threat Level: Low

Available Tools: Visual Markers, Helicopter Drops, Wildland Fire Crew.

Management Objective:

- To prevent fire from burning any portion of the MU at any time.

Preventative Actions**:** None needed

Old military helmet found in a draw not far from the Peahinaia trail

Action Table

Action Type	Actions	MIP Year 11 Oct 2014-Sept 2015				MIP Year 12 Oct 2015-Sept 2016				MIP Year 13 Oct 2016-Sept 2017				MIP Year 14 Oct 2017-Sept 2018				MIP Year 15 Oct 2018-Sept 2019			
		4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
General Monitoring	Develop monitoring protocols for smaller MU's in the next two years. From then on, monitor vegetation at determined interval.	X	X	X	X	X	X	X	X												
	Install photopoints, take 1x year.	X				X				X				X				X			
	Conduct trial on Clihir to determine optimal interval for weeding climax stands at this MU. Trial includes 4 plots: 1 control, 3 others to be weeded at varying intervals. Trial to run for 1-2 years. At 3 months after installation, need to determine whether to weed one plot then, or wait till 6 months. Trial installed May 2013	X	X	X	X	X	X	X													
General Survey	OS-KLOA-02: Survey Frogpond Campsite (by fence) whenever used, not to exceed once per quarter. If not used, do not need to survey.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	LZ-KLOA-033: Survey Puu Curta LZ whenever used, not to exceed once per quarter. If not used, do not need to survey.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ICA	LowerOpaeula-RhyCad-01: Monitor/control Rhycad at fenceline site quarterly/every 6 months. Dig out plants and remove from field, along with any potentially viable fruit.	X		X		X		X		X		X		X		X		X		X	
OpaeulaLower-01	Sweep entire subunit for canopy weeds and sparse understory weeds, working slowly towards removing all Clihir, once every 3-5 years. Prioritize rare taxa locations and native forest patches.													X	X	X	X				

Action Type	Actions	MIP Year 11 Oct 2014- Sept 2015				MIP Year 12 Oct 2015- Sept 2016				MIP Year 13 Oct 2016- Sept 2017				MIP Year 14 Oct 2017- Sept 2018				MIP Year 15 Oct 2018- Sept 2019			
		4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
OpaeulaLower-02	Control weeds along fencelines and trails, as needed.				X				X				X				X				X
	Conduct control in weedy gulch to east of Blue Curta Saddle trail. Target understory control, and gradual removal of canopy.			X	X			X	X			X	X			X	X			X	X
	Sweep entire WCA for canopy weeds and sparse understory weeds, once every 5 years. Use spotters with binoculars to guide control and minimize damage to uluhe.					X	X	X	X												
OpaeulaLower-03	Control weeds around reintroductions (SteKaaShe) every 6 months. Target all weedy taxa; always control SphCoo, AngEve, CitCau if seen.	X		X		X				X		X		X		X		X		X	
	Control grasses (mostly PasCon) in forested areas, every 6 months or as needed.	X		X		X		X		X		X		X		X		X		X	
	Sweep WCA once a year, targeting AngEve, SphCoo, CitCau in particular, and focusing on controlling Clihir and sparse canopy weeds in native forest patches and around rare taxa.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
OpaeulaLower-04	Control weeds along fencelines and trails, as needed.				X				X				X				X				X
	Control grasses (mostly PasCon) in forested areas, every 6 months or as needed. Ignore areas directly around Frog Pond and Little Pond	X		X		X		X		X		X		X		X		X		X	
	Control SetPal and UroMax around Frog Pond and camp quarterly.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Action Type	Actions	MIP Year 11 Oct 2014- Sept 2015				MIP Year 12 Oct 2015- Sept 2016				MIP Year 13 Oct 2016- Sept 2017				MIP Year 14 Oct 2017- Sept 2018				MIP Year 15 Oct 2018- Sept 2019			
		4	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**
	Sweep WCA once a year, targeting AngEve, SphCoo, CitCau in particular, and focusing on controlling Clihir and sparse canopy weeds in native forest patches and around rare taxa.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Control weeds along fencelines and trails, as needed.				X				X				X				X				X
OpaeulaLower-05	Conduct control in weedy gulch to east of Blue Curta Saddle trail. Target understory control, and gradual removal of canopy.			X	X			X	X			X	X			X	X			X	X
	Sweep entire WCA for canopy weeds and sparse understory weeds, once every 3-5 years. Use spotters with binoculars to guide control and minimize damage to uluhe.									X	X	X	X								
Ungulate Control	Monitor fence integrity quarterly	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Rodent Control	Monitor rare plant taxa for signs of rodent damage	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Implement localized rodent control if determined to be necessary for the protection of rare plants	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ant Control	Conduct surveys for ants at 2 human entry points (Puu Curta LZ, campsite)				X				X				X				X				X
Yellowjacket Control	Survey yellowjacket population levels (continue if determined to be a threat)																				X
	Monitor rare plants for signs of slug damage		X				X				X				X				X		
Slug Control	Deploy slug bait around susceptible plant population(s) at TBD interval																				

Hatching=Quarter Scheduled

Ecosystem Restoration Management Plan
OIP Year 7-11, Oct. 2013 - Sept. 2017
MU: Opaeula

Overall OIP Management Goals:

- Ensure the plant communities within the MU form a stable, native-dominated matrix which will be able to support stable populations of the OIP rare species.
- Control ungulate, rodent, invertebrate, and weed threats to support stable populations of IP taxa. Implement control methods by 2014.

Background Information

Location: Northern Leeward Koolau Mountains; Opaeula summit
Land Owner: Kamehameha Schools, US Army lease and license agreement
Land Manager: Oahu Army Natural Resources
Acreage: 122.4 acres
Elevation range: 2,600-2,800 ft.
Description: The Opaeula MU is characterized by windswept summit vegetation with gentle terrain leading into moderate slopes, winding drainages and small flat bog areas. There are two main drainage systems in Opaeula. The southern drainage contains the headwaters to the Opaeula stream. This drainage is larger, but shallow with gradual slopes. In contrast, the northern drainage is deep, with steep slopes and several waterfalls as it travels further off of the summit. The fence crosses both drainages on the western boundary and follows the summit trail to the north on the eastern boundary.

The 2008 OIP places the Opaeula and Helemano areas into the same Management Unit (MU). This management plan focuses on the Opaeula portion of the MU.

Native Vegetation Types

Koolau Vegetation Types
Wet forest
Canopy includes: *Metrosideros* spp., *Cheirodendron* spp., *Cibotium* spp, *Ilex anomala*, *Myrsine sandwicensis*, *Pritchardia martii*, and *Perrottetia sandwicensis*. Understory: Typically covered by a variety of ferns and moss; may include *Dicranopteris linearis*, *Melicope* spp., *Cibotium chamissoi*, *Machaerina angustifolia*, *Nertera granadensis, Kadua centranthoides*, *Nothoperanema rubiginosa*,, *Sadleria sp.* and *Broussaisia arguta*.
NOTE: For MU monitoring purposes vegetation type is mapped based on theoretical pre-disturbance vegetation. Alien species are not noted.

Wet Forest Vegetation Types and Views of Opaeula

Western fence line looking north at the cabin

Main Opaeula drainage

Gentle sloping topography looking west

Small waterfall in the Northern drainage

Rare Resources

Organism Type	Species	Pop. Ref. Code	Population Unit	Management Designation	Wild/ Reintroduction
Snail	*Achatinella sowerbyana*	OPA-A-R	GU-C Opaeula/ Helemano	MFS/T2	Wild
Snail	*Achatinella lila*	OPA-A,B	Opaeula	MFS/T2	Wild
Plant	*Euphorbia rockii*	OPA-D	Opaeula	MFS/T2	Wild
Plant	*Cyanea koolauensis*	OPA-O	Opaeula	MFS/T1	Wild
Plant	*Cyrtandra viridiflora*	OPA-B,E,F,G,H,I,J, K,L,N,O,T,U, X,Z	Opaeula	MFS/T2	Wild
Plant	*Myrsine juddii*	OPA-C	Opaeula	GS/T2	Wild
Plant	*Sanicula purpurea*	OPA-E	Opaeula	MFS/T2	Reintroduction
Plant	*Viola oahuensis*	OPA-A,B,D,F,L,O, M,P,S,T,V	Opaeula	MFS/T2	Wild

MFS= Manage for Stability
GSC= Genetic Storage Collection
MRS = Manage Reintroduction for Genetic Storage
*= Population Dead
†=Reintroduction not yet done
T1 = Tier 1
T2 = Tier 2

Other Rare Taxa in the Opaeula MU:

Organism Type	Species	Federal Status	Notes
Plant	*Cyanea lanceolata*	Endangered	OPA-B,X
Plant	*Joinvillea ascendens* subsp. *ascendens*	Species of Concern	OPA-G,I,O
Plant	*Lobelia gaudichaudii*		OPA-A,B,C,D,H,I,J
Plant	*Myrsine fosbergii*		GS/T3 OPA-A
Plant	*Zanthoxylum oahuensis*	Endangered	OPA-B

Rare Resources at Opaeula

Cyrtandra viridiflora

Achatinella sowerbyana

Cyanea st. johnii

Locations of Rare Resources at Opaeula

Map removed to protect rare resources

MU Threats to OIP MFS Taxa

Threat	Taxa Affected	Localized Control Sufficient?	MU scale Control required?	Control Method Available?
Pigs	All	No	Yes	Yes
Euglandina rosea	*Achatinella spp.*	Unknown	Unknown	No, limited to hand-removal and physical barriers
Slugs	*C. koolauensis*	Yes	No	Yes
Ants	Possibly rare plants and snails	Unknown	Unknown	Some available, depends on species
Weeds	All	Yes	Yes	Yes
Fire	N/A	N/A	No (very low threat)	Yes
Rats	All	Unknown	Yes	Currently being developed

Management History:

- 1995 OANRP staff began survey work in Opaeula MU
- 2000 OANRP staff started survey work in adjacent Helemano MU
- 2001 Opaeula fence construction complete, Koolau Mountain Watershed Partnership formed.
- 2005 *Setaria palmifolia* control initiated, Helemano fence line cleared.

Ungulate Control

Identified Ungulate Threats: Pigs
Threat Level: High

Primary Objectives:
- Maintain MU fence as ungulate free.

Strategy:
- Maintain the fenced area as ungulate-free by maintaining fence and using fence transects to monitor for sign.

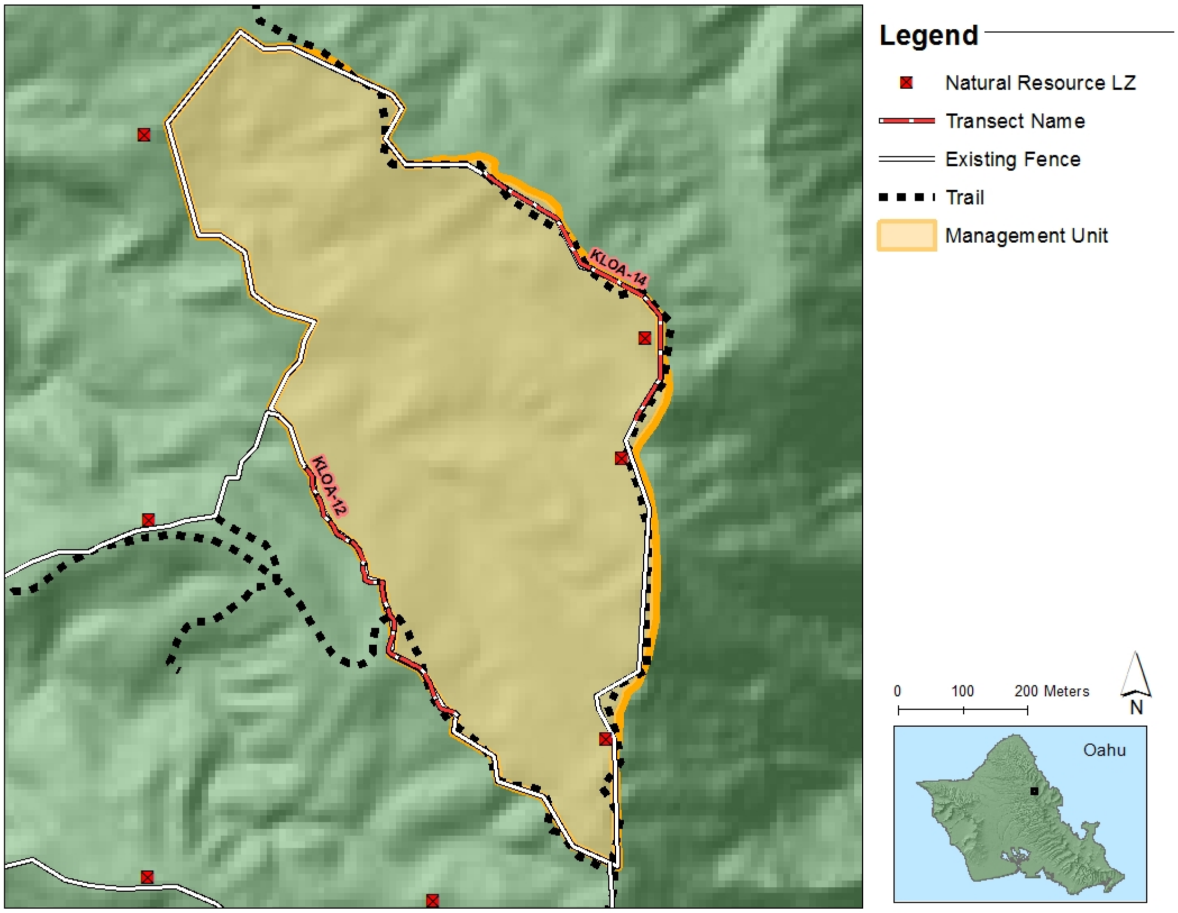
Monitoring Objectives:
- Conduct fence checks and read transects semi-annually.
- Monitor for pig sign while conducting other management actions in the fence.
- Monitor hypalons to ensure the fence stays secure.

Management Responses:
- If any pig activity is detected in the fence area, implement snaring program.

Maintenance Issues:
There is a perimeter fence around the MU. The MU fence is relatively small (122 acres). The major threats to the perimeter fence include landslides, weathering and vandalism. There are two major gulch crossings. One stream crossing was strategically placed at the base of a large waterfall to avoid weather related issues. The second had to be blocked using a chlorosulfonated polyethylene synethetic rubber (Hypalon™) that restricts animal movement but allows water to flow under and can rise and fall with stream flow. There have been no incidences of vandalism in the past. Special emphasis will be placed on checking the fence after extreme weather events. Monitoring for ungulate sign will occur during the course of other field activities. The fence line will be kept clear of vegetation (especially grasses) to facilitate semi-annual monitoring.

Sections of the fence that are exposed to constant wind erosion have not fared well over time and are in need of replacement. Some of these sections have been replaced already but the rest will be replaced this year.

Ungulate Management and Survey Locations at Opaeula



Opaeula fence

Weed Control

Weed Control actions are divided into 4 subcategories:

1) Vegetation Monitoring
2) Surveys
3) Incipient Taxa Control (Incipient Control Area - ICAs)
4) Ecosystem Management Weed Control (Weed Control Areas - WCAs)

These designations facilitate different aspects of OIP requirements.

Vegetation Monitoring

Objectives:

- Develop vegetation monitoring protocol for Opaeula MU.
- Conduct vegetation monitoring for Opaeula MU every three years.
- Produce vegetation map every three years for comparative analysis of weeding efforts.

MU Vegetation Monitoring

Due to the relatively intact condition of the Northern Koolau summit region, Vegetation monitoring protocols used in other MUs may not be feasible in Opaeula MU. Current monitoring practices would increase traffic through the MU and may negatively impact the area by introducing weedy species normally found in the fence corridors to the interior. Possible alternatives to transect monitoring are aerial monitoring surveys, remote vegetation mapping, or a combination of both. Utilizing new technologies and methodologies to develop vegetation monitoring protocols is a priority for this MU.

Vegetation Monitoring Response:

- Produce, refine and modify the vegetation map in conjunction with MU vegetation monitoring efforts.
- Analyze vegetation monitoring data to determine efficacy of weeding efforts in the MU.

Surveys

Army Training: None.

Other Potential Sources of Introduction: NRS, pigs, hikers

Survey Locations: Landing zones, camp sites, fence lines, high potential traffic areas.

Management Objective:

- Prevent establishment of any new invasive alien plant or animal species through regular surveys along fences and trails, on landing zones, around camp sites and in other high-traffic areas.

Monitoring Objectives:

- Annually survey fence lines and main access trails to Camp Sites and LZs.
- Annually survey LZs and Camp sites.

Management Responses:

- Research and evaluate any significant alien taxa found for distribution and life history. If found to pose a major threat, begin control and track via Incipient Control Areas (ICAs).

Surveys are designed to be the first line of defense in locating and identifying new potential weed species. Landing zones, camp sites, fence lines, and other highly trafficked areas are inventoried regularly; Army LZs are surveyed annually and all other sites are surveyed quarterly or as they are used. Only currently used LZs and campsites are surveyed. No weed transects have been established along fences or other high-traffic areas such as trails and staging areas. NRS will consider whether such transects are a valuable tool at Opaeula. See the Ungulate Management and Survey Locations on Opaeula map above.

Incipient Taxa Control (ICAs)

<u>Management Objectives</u>:

- As feasible, control high priority species identified as incipient and invasive in the MU.
- Conduct seed dormancy trials for all high priority incipient weed species.
- Identify potential paths of contamination and develop strategies to decontaminate gear when working in densely infested incipient areas.

<u>Monitoring Objective:</u>

- Visit ICAs at predetermined intervals and control all target plants.

<u>Management Responses:</u>

- If unsuccessful in preventing immature plants from maturing, increase ICA revisit interval.

ICAs are drawn around each discrete infestation of an incipient invasive weed. ICAs are designed to facilitate data collection and control. For each ICA, the management goal is to achieve complete eradication of the invasive taxa. Frequent visits are often necessary to achieve eradication. Seed bed life/dormancy and life cycle information is important in determining when eradication may be reached; much of this information needs to be researched and parameters for determining eradication defined. NRS will compile this information for each ICA species.

The table below summarizes target invasive taxa at Opaeula. While the list is by no means exhaustive, it provides a good starting point for discussing which taxa should be targeted for eradication. ICAs are not designated for every species in the table below; however, occurrences of all species in the table should be noted by field staff. All current ICAs are mapped. Three management designations are possible: Incipient (small populations, eradicable), Control Locally (significant threat posed, may or may not be widespread, control feasible at WCA level), and Widespread (common weed, may or may not pose significant threat, control feasible at WCA level).

Summary of Potential ICA Target Taxa

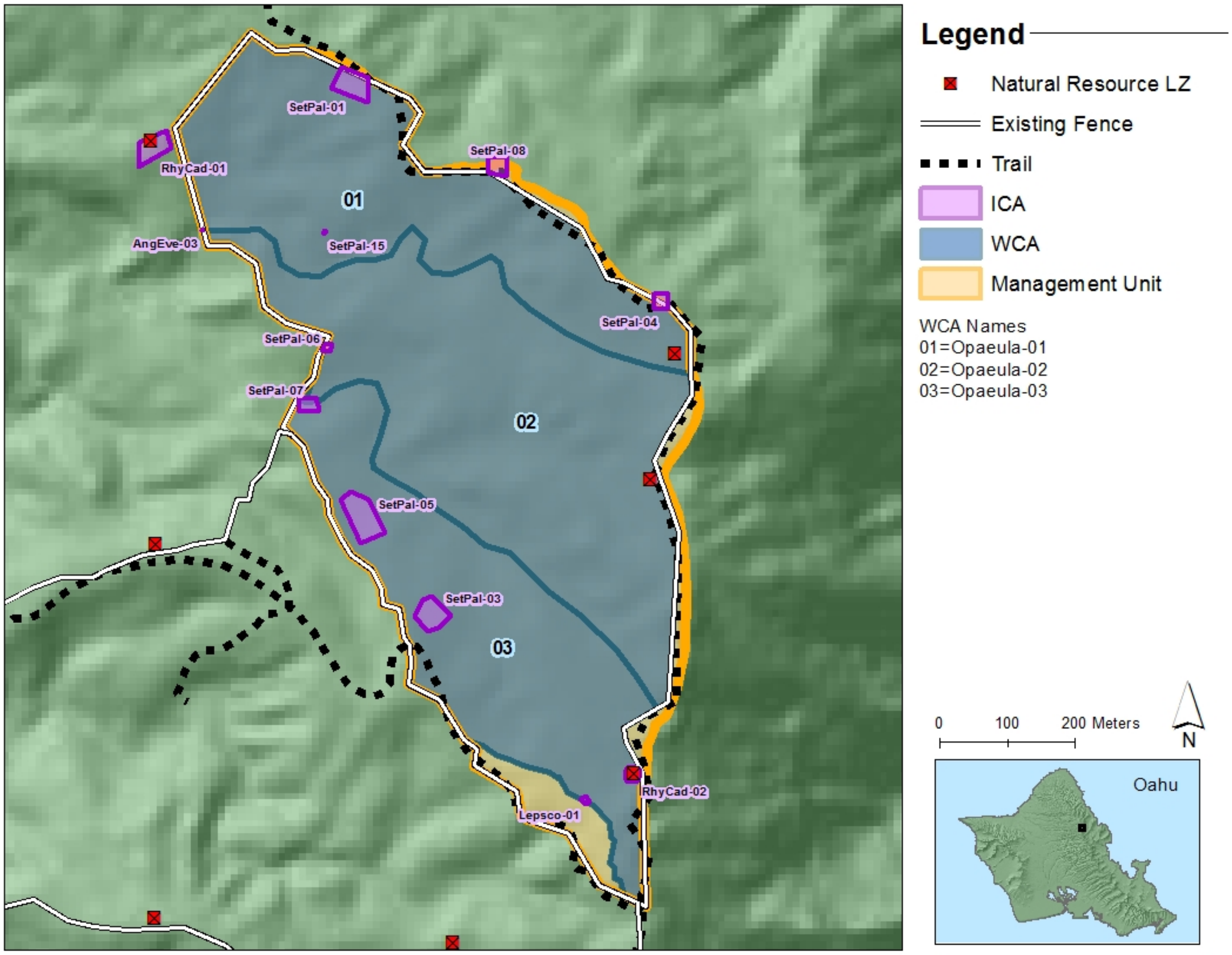
Taxa	Management Designation	Notes	No. of ICAs
Angiopteris evecta	Incipient	No plants known from within MU but two mature individuals found and controlled along west fence line exterior, northern drainage. Invasiveness in similar habitats creates potential for invasiveness in MU. Survey to determine if recruitment is taking place. Control is a high priority. Control any plants found outside the MU, if near the fence.	1
Erigeron karvinskianus	Control locally	Established populations along summit create potential for invasiveness. Much of the windward cliff habitat just east of the MU fence has been invaded by *E. karvinskianus*. It poses a threat to rare taxa found in this area, particularly *Lobelia gaudichaudii*. Eradication not feasible. Emphasize control around rare taxa. Prevent *E. karvinskianus* from crossing onto the leeward side. Control of one small population on east fence line; high priority due to wind dispersed seeds and location.	0
Clidemia hirta	Widespread	*C. hirta* is a well established part of the Koolau vegetation type. NRS do not currently target it for control, except in the vicinity of rare taxa.	0
Pterolepis glomerata	Widespread	This Melastome is ubiquitous across the Koolaus. It thrives in disturbed areas, particularly pig wallows. NRS do not currently target it for control.	0
Psidium cattleianum	Widespread	Individual plants scattered across Opaeula. Primary target of WCA sweeps.	0
Schefflera actinophylla	Control locally	One individual outside of the southern fence line, high priority for control. Established populations on the windward side of the summit create potential for invasiveness. If found, control as part of WCA sweeps. Consider creating ICAs if mature plants are found. Control plants outside the MU, if near the fence.	0
Setaria palmifolia	Control locally	Several stable populations known in low lying stream areas and fence lines. It appears that the eastern section of the MU does not have *S. palmifolia*, while the western section does. This taxon is likely moving via NRS activities and waterways. ICAs are drawn both in and out of the subunit. Control techniques need to be evaluated due to proximity to waterways. Improved NRS decontamination practices need implementation to minimize seed dispersal. NRS will target plants along trails and fences.	10
Sphaeropteris cooperii	Control locally	No plants found in MU, but a large numbers of plants observed south along the Koolau summit. If found, target during WCA sweeps	0
Spondias dulcis	Incipient	Few Individual plants are known from inside and outside the MU. If found, control as part of WCA sweeps.	

Opaeula ICA target taxa

Setaria palmifolia *Angiopteris evecta*

Erigeron karvinskianus *Schefflera actinophylla*

Incipient and Weed Control Areas at Opaeula MU



Ecosystem Management Weed Control (WCAs)

<u>OIP Goals:</u>

- Within 2m of rare taxa: 0% alien vegetation cover
- Within 50m of rare taxa: 25% or less alien vegetation cover
- Throughout the remainder of the MU: 50% or less alien vegetation cover

<u>Management Objectives</u>:

- Maintain 50% or less alien vegetation cover in the understory across the MU.
- Reach 50% or less alien canopy cover across the MU in the next 5 years.
- In WCAs within 50m of rare taxa, work towards achieving 25% or less alien vegetation cover in understory and canopy.

<u>Management Responses:</u>

- Increase/expand weeding efforts if MU vegetation monitoring (conducted every 3 years) indicates that goals are not being met.

WCAs are weeded on a rotational basis given the difficulty of access, terrain, and limited staff resources. Use aerial and ground surveys to guide control efforts for *P. cattleianum*, *S. palmifolia*, and other target weeds.

WCA: Opaeula-01

Vegetation Type: Wet Montane
OIP Goal: 25% or less alien cover (rare taxa in WCA).
Target: *P. cattleianum*, tree weeds
Notes: OIP rare plants: Cyacal and Viooah present. Area predominantly native. To minimize impact to area, sweeps are done via Spot-and-treat method: spotting from open ridges with binoculars and directing other staff to plants for treatment.

WCA: Opaeula-02

Vegetation Type: Wet Montane
OIP Goal: 25% or less alien cover (rare taxa in WCA).
Target: *P. cattleianum*, tree weeds
Notes: Many steep areas make complete sweep coverage unfeasible. Weed control will be conducted so as not to compromise staff safety. To minimize impact to area, sweeps are done via Spot-and-treat method: spotting from open ridges with binoculars and directing other staff to plants for treatment.

WCA: Opaeula-03

Vegetation Type: Wet Montane
OIP Goal: 25% or less alien cover (rare taxa in WCA).
Target: *P. cattleianum*, tree weeds
Notes: OIP rare plants: *Euphorbia rockii* and *Viola Oahuensis*. To minimize impact to area, sweeps are done via Spot-and-treat method: spotting from open ridges with binoculars and directing other staff to plants for treatment.

Rodent Control

Species: *Rattus rattus* (Black rat), *Rattus exulans* (Polynesian rat), *Mus musculus* (House mouse)
Threat Level: Medium - High
Available tools for rodent control: Snap traps, Goodnature® A24 automatic traps
Current control method: , Goodnature® A24 automatic traps
Seasonality: Year-round at tree snail locations
Number of control grids: Three

Primary Objectives:
To maintain rodent populations at a level that facilitates stabilized or increasing tree snail (*A. sowerbyana*) populations. Like *A. sowerbyana*, rare plant populations (e.g. *Cyanea* spp., *Cyrtandra viridiflora, Euphorbia rockii*) are scattered throughout the MU. Rodent control should be implemented around rare plant populations if predation is noted and rats are deemed a significant threat to the population.

Management Objectives:

To protect the ecosystem as a whole, MU-wide rodent control is desirable; however, this is not feasible with the current methods of rat control because of steep terrain and dense vegetation.

The management objectives are:

- To maintain localized rodent control around *A. sowerbyana* populations.
  - Rodent control currently consists of Victor® snap traps housed in wooden boxes around trees containing tree snails. The grids have historically been maintained every 4 to 6 weeks by OANRP NRS.
  - Goodnature® A24 automatic traps will also be installed in October 2013.
  - ***The State of Hawaii Oahu Snail Extinction Prevention Program (OSEPP) Coordinator will resume maintenance of all rat control grids starting November 2013, including the snap traps and A24s.***
- To implement localized rodent control if determined necessary for the stability of rare plant populations.

Monitoring Objectives:

- Monitor changes in the rat population via tracking tunnels or trapping data.
- Monitor rare resources via census counts, sampling, incidental observations, etc. to detect rat predation and ensure efficacy of rat control.
- Monitor changes of other ecosystem parameters such as arthropod diversity/abundance, seedling diversity/abundance, and plant composition in various vegetation types.

Rat Control Actions:

Year	Action	Quarter
OIP YEAR 7-11: Oct. 2013 - Sept. 2017	• OANRP will not conduct rat control for Tier 2 and Tier 3 species; instead OSEPP will maintain grids until further notice	• 1-4

Slug Control

Species: **Slugs** (multiple species assumed present but no collections to date)
Threat level: Unknown (no collections)
Control level: Localized
Seasonality: Higher in the wet season (September-May), but may need control year-round
Sites: *Cyanea koolauensis* population

Management Objective:

- If monitoring shows slugs are present and observations show that plants are damaged, apply Sluggo molluscicide monthly if no rare snails are present in the vicinity

Monitoring Objectives:

- Determine slug species present and estimate baseline densities using traps baited with beer
- Annual census monitoring of slug densities during wet season.
- Annual census monitoring of *C. koolauensis* seedling recruitment following fruiting events.

Ant Control

Species: *Solenopsis papuana*, *Paratrechina vaga*
Threat level: Low
Control level: Localized
Seasonality: Varies by species, but nest expansion observed in late summer, early fall
Number of sites: 3 (Opaeula cabin, Poamoho monument, Poamoho trail LZ)
Acceptable Level of Ant Activity: Current level acceptable

Management Objective:

- If incipient species are found and deemed to be high threat and/or easily eradicated locally (<0.5 acre infestation) begin control using a bait containing Hydramethylnon (Amdro, Maxforce or Seige).

Monitoring Objective:

- Continue to sample ants at human entry points a minimum of once a year. Use samples to track changes in existing ant densities and to alert NRS to any new introductions.

Ants have been documented to pose threats to a variety of resources, including native arthropods, plants (via farming of Hemipterian pests), and birds. Ants have been rare in these areas, for example, ants are only found one out of every three baiting attempts and in low numbers. Thus, ants are unlikely to pose a serious threat. Surveys were conducted using a standardized sampling method (see Appendix Invasive Ant Monitoring Protocol this document). *Solenopsis papuana* were found at high elevations (>2000 ft.) along the Helemano fence on a single occasion in 2011. No other ants were found. *Pheidole megacephala* was found at the Lychee Landing Zone, however this LZ is no longer used for flights to Opaeula. The Poamoho trail LZ which is currently in use has not had ants during the last three sampling attempts. The same was true for the Poamoho monument. Opaelua cabin is known to have *Solenopsis papuana*, *Paratrechina vaga* but has not been surveyed since 2011.

All areas should be surveyed using the Invasive Ant Monitoring Protocol http://manoa.hawaii.edu/hpicesu/DPW/2010_YER/027.pdf. If densities are high, then treatment should begin using Hydramethylnon (Amdro, Maxforce or Seige) to prevent movement of ants to higher elevations.

Fire Control

Due to the very low threat from fire, no actions are proposed at this time.

Cyanea lanceolata

Action Table

Action Type	Actions	OIP Year 7 Oct 2013-Sept2014				OIP Year 8 Oct 2014-Sept2015				OIP Year 9 Oct 2015-Sept2016				OIP Year 10 Oct 2016-Sept2017				OIP Year 11 Oct 2017-Sept2018			
		4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
Vegetation Monitoring	Conduct baseline vegetation monitoring across MU																				
	Conduct MU vegetation monitoring every 3 years																				
General Survey	LZ-KLOA-030: Survey Peahinaia summit LZ whenever used, not to exceed once per quarter. If not used, do not need to survey.																				
	LZ-KLOA-042: Survey Weatherport/Opaeula Cabin LZ whenever used, not to exceed once per quarter. If not used, do not need to survey.																				
	LZ-KLOA-065: Survey Peahinaia Notch LZ whenever used, not to exceed once per quarter. If not used, do not need to survey.																				
	LZ-KLOA-115: Survey 290 LZ whenever used, not to exceed once per quarter. If not used, do not need to survey.																				
	WT-KLOA-14: Survey transect on eastern Opaeula fence annually.																				
	WT-KLOA-12: Survey transect on western Opaeula fence annually.																				
ICA	KLOA-AngEve-03: Monitor/control AngEve in Opaeula stream along fence every 6 months to a year; during weed transect surveys. Foliar spray of G4 works well; to reduce non-target drift, cut off large fronds of mature plants and treat when new croziers appear.																				
	KLOA-LepSco-05: Monitor/control Lepsco at crossover annually; during weed transect surveys. Collect/remove any fruit found and remove from field.																				

Action Type	Actions	OIP Year 7 Oct 2013-Sept2014				OIP Year 8 Oct 2014-Sept2015				OIP Year 9 Oct 2015-Sept2016				OIP Year 10 Oct 2016-Sept2017				OIP Year 11 Oct 2017-Sept2018			
		4	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**
	KLOA-RhyCad-01: Monitor/control Rhycad at Shelter LZ quarterly. Dig out plants and remove from field, along with any potentially viable fruit.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	KLOA-RhyCad-02: Monitor/control Rhycad on Peahinaia Summit LZ quarterly. Dig out plants and remove from field, along with any potentially viable fruit.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	KLOA-SetPal-01: Monitor/control Setpal on northern fence line every 6 months/year. Dig out plant and remove from field, along with any potentially viable fruit. Flag locations of mature plants with pink to facilitate follow-up.	X		X		X		X		X		X		X		X		X		X	
	KLOA-SetPal-03: Monitor/control Setpal at KLOA-12-st260 quarterly. Dig out plant and remove from field, along with any potentially viable fruit. Flag locations of mature plants with pink to facilitate follow-up.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	KLOA-SetPal-04: Monitor/control Setpal at KLOA-14-st290 bait grid every 6 months/year. Dig out plant and remove from field, along with any potentially viable fruit. Flag locations of mature plants with pink to facilitate follow-up.	X		X		X		X		X		X		X		X		X		X	
	KLOA-SetPal-05: Monitor/control Setpal at KLOA-12-st370 annually. Dig out plant and remove from field, along with any potentially viable fruit. Flag locations of mature plants with pink to facilitate follow-up.			X				X				X				X				X	
	KLOA-SetPal-06: Monitor/control Setpal at goosehead every 6 months/year. Dig out plant and remove from field, along with any potentially viable fruit. Flag locations of mature plants with pink to facilitate follow-up.	X		X		X		X		X		X		X		X		X		X	

Action Type	Actions	OIP Year 7 Oct 2013-Sept2014				OIP Year 8 Oct 2014-Sept2015				OIP Year 9 Oct 2015-Sept2016				OIP Year 10 Oct 2016-Sept2017				OIP Year 11 Oct 2017-Sept2018			
		4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
	KLOA-SetPal-07: Monitor/control Setpal at hypalon annually. Dig out plant and remove from field, along with any potentially viable fruit. Flag locations of mature plants with pink to facilitate follow-up.																				
	KLOA-SetPal-08: Monitor/control Setpal at Shaka bait grid annually. Dig out plant and remove from field, along with any potentially viable fruit. Flag locations of mature plants with pink to facilitate follow-up.																				
	KLOA-SetPal-14: Monitor/control Setpal at Hypalon Bowl quarterly. Walk through site. Dig out plant and remove from field, along with any potentially viable fruit. Flag locations of mature plants with pink to facilitate follow-up.																				
	KLOA-SetPal-15: Monitor/control Setpal at WCA Opaeula-01 site quarterly. Dig out plant and remove from field, along with any potentially viable fruit. Flag locations of mature plants with pink to facilitate follow-up.																				
	KLOA-SpoDul-01: Monitor/control SpoDul in WCA Opaeula-02 annually. If locate any reproductive material (flowers especially), collect and submit to Bishop Museum. ID on this species not yet confirmed.																				
General WCA	Conduct aerial surveys, as needed, to guide weed control efforts in WCAs.																				
Opaeula-01 (Northern Opaeula)	Conduct weed sweeps for Psicat and any other weedy trees. Sweep entire WCA in a year. Re-sweep every 3-7 years.																				
Opaeula-02 (Central Opaeula/ Goosehead Ridge)	Conduct weed sweeps for Psicat and any other weedy trees. Sweep entire WCA in a year. Re-sweep every 3-5 years.																				

Action Type	Actions	OIP Year 7 Oct 2013-Sept2014				OIP Year 8 Oct 2014-Sept2015				OIP Year 9 Oct 2015-Sept2016				OIP Year 10 Oct 2016-Sept2017				OIP Year 11 Oct 2017-Sept2018			
		4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
Opaeula-03 (Southern Opaeula)	Conduct weed sweeps for Psicat and any other weedy trees. Sweep entire WCA in a year. Re-sweep every 3-5 years.																				
Ungulate Control	Check MU fence for breaches (quarterly)																				
	Monitor fence quarterly																				
	Add and replace sections of fence 2015-2016																				
Rodent Control	None																				
Ant Control	Conduct surveys for ants annually at 3 sites Opaeula cabin, Poamoho monument, Poamoho trail LZ																				
	Control ants, if necessary																				
Predatory Snail Control	None																				
Slug Control	Monitor slug activity at *C. koolauensis* rare plant population annually																				
	If slugs found to damage plants apply Sluggo once monthly through, at least, the wet season																				

2

Date Written: 26 Feb 2009
Dates Updated: 16 Nov 2014

Ecosystem Restoration Management Plan
MIP Year 11-15, Oct. 2014 – Sept. 2019
MU: Palikea Subunit 1 and Palikea NoMU

Overall MIP Management Goals:

- Form a stable, native-dominated matrix of plant communities which support stable populations of IP taxa.
- Control ungulate, rodent, arthropod, slug, snail, fire, and weed threats to support stable populations of IP taxa.

Background Information

Location: Southern Waianae Mountains
Land Owner: State of Hawaii
Land Manager: State of Hawaii/OANRP
Acreage: 24.9 acres
Elevation Range: 1900ft. -3100 ft.
Description: Palikea MU is located at the southern end of the former Honouliuli Preserve. It is now a State of Hawaii Forest Reserve. The managed area includes the summit ridge and windward slopes of the southern parts of Palawai gulch. The western edge of the MU ends abruptly in cliffs which sweep down into Halona and Nanakuli on the leeward side of the mountains. The eastern edge is partially ringed by a series of cliffs. The crestline is the most native of the MU, while the southern corner is predominantly non-native overstory and understory. The MU includes several small ridges, one long major ridge, steep gulches, one large and shallow gulch, and one flat bowls. The MU is named after the Puu Palikea, the tallest peak in the area, located on the eastern edge of the exclosure. Access to Palikea is via Makakilo and Palehua to the south, and is facilitated by an agreement with the Gill and Olsen groups. Staff drive up the gated Palehua road, park at Mauna Kapu, and hike into Palikea along the summit crest trail.

This plan is the first major revision to the original Palikea ERMUP. Please reference the original plan for additional information: available at http://manoa.hawaii.edu/hpicesu/dpw_ermp.htm and also located on the OANRP internal server (V/Ecosystem Restoration MU Plan/Palikea/2009).

Native Vegetation Types

Waianae Vegetation Types
Mesic mixed forest
Canopy includes: *Acacia koa*, *Metrosideros polymorpha*, *Nestegis sandwicensis*, *Diospyros* spp., *Pouteria sandwicensis*, *Charpentiera* spp., *Pisonia* spp.,*Psychotria* spp., *Antidesma platyphylum*, *Bobea* spp. and *Santalum freycinetianum*. Understory includes: *Alyxia oliviformis*, *Bidens torta*, *Coprosma* spp., and *Microlepia strigosa*
Mesic-Wet forest
Canopy includes: *Metrosideros polymorpha* . Typical to see *Cheirodendron trigynum* ,*Cibotium* spp., *Melicope* spp., *Antidesma platyphyllum*, and *Ilex anomala*. Understory includes: *Cibotium chamissoi*, *Broussasia arguta*, *Dianella sandwicensis*, *Dubautia* spp. Less common subcanopy components of this zone include *Clermontia* and *Cyanea* spp.
NOTE: For MU monitoring purposes vegetation type is mapped based on theoretical pre-disturbance vegetation. Alien species are not noted.
NOTE: For MU monitoring purposes, vegetation types were subdivided using topography (gulch, mid-slope, ridge). Topography influences vegetation composition to a degree. Combining vegetation type and topography is useful for guiding management in certain instances.

Primary Vegetation Types at Palikea

Mesic-Wet Summit Crest

Mesic Gulch

Uluhe dominated flats – not a separate vegetation type, but an anomalous feature in Palikea

Views of Palikea

View to the north, from a gulch towards the summit ridge.

View to the south, from northern fenceline.

MIP/OIP Rare Resources:

Organism Type	Species	Pop. Ref. Code	Population Unit	Management Designation	Wild/ Reintroduction
Plant	*Cyanea grimesiana* subsp. *obatae*	PAK-A, B	Palikea	MFS	Wild and Reintroduction
Plant	*Cyanea superba* subsp. *superba*	N/A	N/A	None	Reintroduction
Plant	*Phyllostegia hirsuta*	PAK-A	Palikea	MFS	Reintroduction
Snail	*Achatinella mustelina*	PAK-A, B,C, D, E, F, G, H, I, J, K, L, M, N, P	ESU-F	MFS	N/A
Bird	*Chasiempis ibidis*	N/A	N/A	None	N/A
Fly	*Drosophila montgomeryi*	PAK-A	Palikea	MFS	Wild
Fly	*Drosophila substenoptera*	PAK-A	Palikea	MFS	Wild

MFS= Manage for Stability *= Population Dead
GSC= Genetic Storage Collection †=Reintroduction not yet done

Other Rare Taxa at Palikea MU:

Organism Type	Species	Status
Plant	*Cyanea calycina*	Endangered
Plant	*Exocarpos gaudichaudii*	Species of Concern
Plant	*Lobelia yuccoides*	Species of Concern
Plant	*Nothocestrum longifolium*	Species of Concern
Plant	*Phyllostegia parviflora var. lydgatei* (reintroduction)	Endangered
Plant	*Platydesma cornuta var. decurrens*	Endangered
Plant	*Pritchardia sp. A* (reintroduction)	Species of Concern
Plant	*Silene perlmanii* (reintroduction)	Endangered
Plant	*Schiedea hookeri* (reintroduction)	Endangered
Plant	*Solanum sandwicense* (reintroduction)	Endangered
Plant	*Urera kaalae* (reintroduction)	Endangered
Snail	*Achatinella concavospira*	Endangered
Snail	*Auriculella ambusta*	Species of Concern
Snail	*Laminella sanguinea*	Species of Concern
Fly	*Drosophila aglaia*	Endangered
Fly	*Drosophila craddockae*	Species of Concern
Fly	*Drosophila hemipeza*	Endangered
Fly	*Drosophila tarphytrichia*	Endangered
Bird	*Asio flammeus sandwichensis*	State Endangered
Bird	*Vestiaria coccinea*	State Endangered

Rare Resources at Palikea

Drosophila hemipeza

Chasiempis ibidis

Cyanea grimesiana obatae

Bagging *C. grimesiana obatae* for fruit collection

Laminella sanguinea

Lobelia yuccoides

Locations of Rare Resources at Palikea

Map removed to protect rare resources

MU Threats to MIP/OIP MFS Taxa:

Threat	Taxa Affected	Localized Control Sufficient?	MU scale Control required?	Control Method Notes
Pigs	All	No	Yes	MU fenced
Rats	All	Unknown	Yes	MU-wide trap out grid installed in 2010
Predatory snails	*Achatinella mustelina*	Unknown	Unknown	Limited to hand-removal and physical barriers
Slugs	*Cyanea grimesiana* subsp. *obatae*	Yes	No	Sluggo application once per month
Ants	Potential threat to *Drosophila* spp.	Unknown	Unknown	Control possible, but non-target impacts to native insects need to be determined
Vespula pensylvanica	Potential threat to *Drosophila* spp.	No	Yes	Experimental toxicants available
Jackson's Chameleon	*Achatinella mustelina*, *Drosophila* spp.	Unknown	No	Hand capture
Weeds	All	Yes	Yes	See WCA section
Fire	All	No	Yes	See Fire section

Management History

The Nature Conservancy of Hawaii (TNC) pioneered management at the Palikea MU during its tenure as steward of the Honouliuli Preserve. Naturally, TNC did not focus only on MIP taxa (as does OANRP), but rather managed all taxa found within Honouliuli. Thus, several plant populations listed in the two Rare Resources tables above include reintroductions which do not fall under the auspices of the MIP; these reintroductions are of *C. superba*, *U. kaalae*, *S. sandwicense*, and *P. parviflora*. TNC also conducted more wide scale elepaio management in Palikea than OANRP currently does.

- 1993: TNC begins management at Honouliuli Preserve. Work at Palikea began shortly thereafter. Surveys detect numerous rare taxa.
- 1997: Rare *Drosophila* species found (*D. aglaia*, *D. hemipeza*, *D. montgomeryi*, and *D. tarphytrichia*).
- 1999: Small fence constructed around wild *C. grimesiana* population, PAK-A with assistance from OANRP staff
- 2000-2006: Restoration work concentrated in small TNC fence. Work includes weed removal, catchment construction, and re-vegetation with common and rare species.
- 2003-04: First TNC reintroductions of *C. grimesiana* planted into the small TNC fence.
- 2004: OANRP begins consistent rodent control efforts at Palikea to protect *A. mustelina*. Rat control areas expand over time as more snail populations are found.
- 2008: 25 acre MU fence completed. The MU fence was closed in December 2007, but strategic sections at the summit portion of the fence were found to be insecure and additional fencing was completed in August 2008. Fence skirting in vulnerable (loose) soil was completed in September 2008. NRS was able to eradicate pigs from the fence prior to the completion of fence improvements; all ungulates were removed by May 2008.
- 2000-2006: TNC Snaring outside fence reduces pig population to unknown level.
- 2007: TNC ends most field work in Honouliuli. Some baiting continues at Palikea.
- 2009: OANRP Snaring program re-initiated outside the fence to protect newly discovered snail populations and unfenced MIP plant taxa.
- 2009: TNC ends all management of Honouliuli.
- 2009: State of Hawaii takes over management from Campbell Estate
- 2009: Arthropod sampling conducted inside and outside a proposed rat control grid by UH researchers
- 2010: Rat control grid established by OANRP
- 2011: State of Hawaii takes over land management control as Honouliuli Forest Reserve. OANRP signed MOU with the State of Hawaii for OANRP management of natural resources on State lands related to OIP and MIP.
- 2011: OANRP Snaring outside MU fence is halted due to change in land holding
- 2012: Snail exclosure fence constructed within northwest corner of MU. Project is funded by U.S. Fish and Wildlife Service with logistics handled by OANRP.
- 2012: OANRP restoration efforts initiated inside snail enclosure.
- MU fence extended approximately 100m below snail exclosure fence and around the campsite LZ
- 2013: Endangered snails moved from the management unit to inside snail exclosure fence
- 2013: Outplanting of common native plants begins in management unit and snail exclosure fence.
- 2014: Palikea placed under DOFAW management

Ungulate Control

Identified Ungulate Threats: Pigs
Threat Level: High

Primary Objective:

- Maintain the entire MU as ungulate-free.

Strategy:

- Maintain the MU fence as pig free by maintaining the fence, retrofitting older fence sections with skirting, and trimming overhanging and fallen trees.

Monitoring Objectives:

- Conduct fence checks Monitor for pig sign while conducting other management actions in the fence.

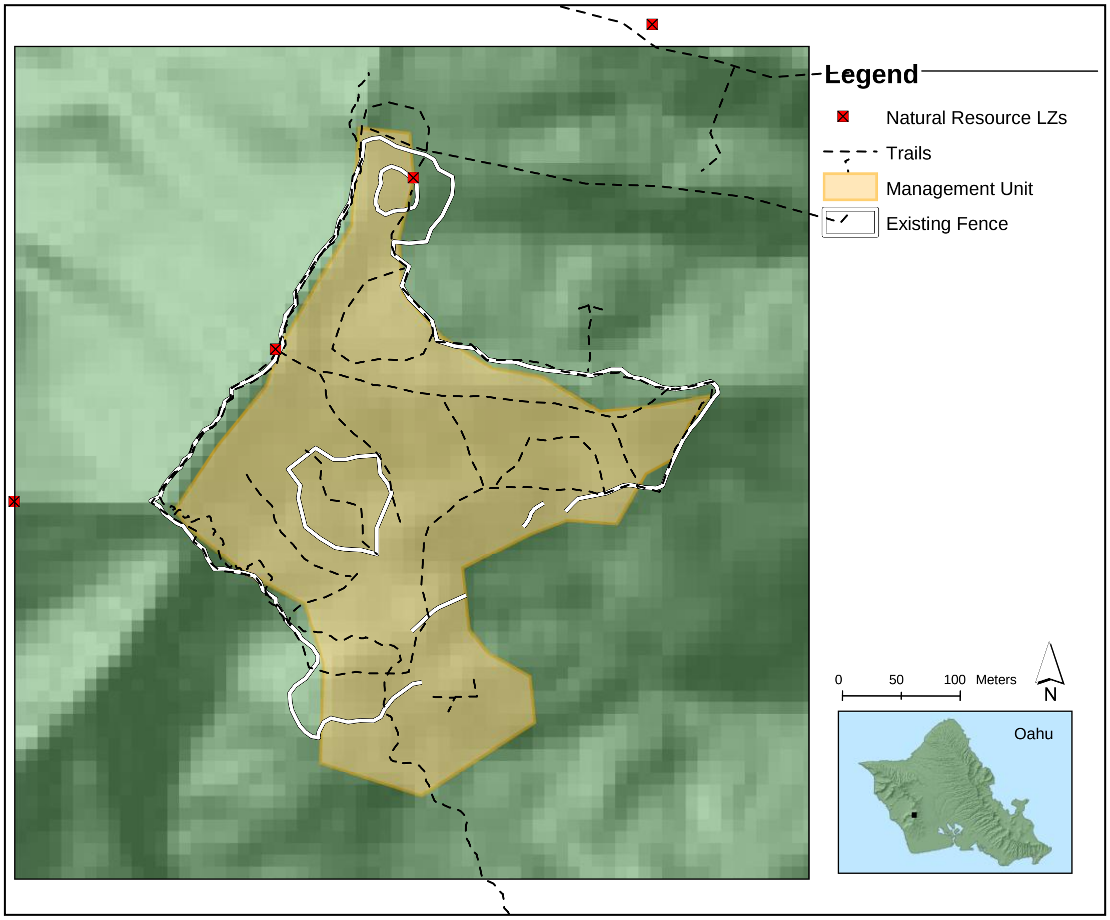
Management Responses:

- If any pig activity is detected within the fenced unit, implement hunting and/or snaring program.

Maintenance

There are three fences in Palikea Subunit 1: the MU perimeter fence, the *C. grimesiana* subsp. *obatae* PU fence (TNC fence), and the snail enclosure fence. The MU fence is relatively small (25 acres) and takes advantage of cliffs to strategically protect the area. The major threats to the fence include fallen trees and vandalism; there are no major gulch crossings. No incidences of vandalism have been observed, but since the fence is accessible to the public, there is the potential for vandalism to take place. Special emphasis will be placed on checking the fence after extreme weather events. Monitoring for ungulate sign will occur during the course of other field activities. The *C. grimesiana* subsp. *obatae* fence is very small (1.3 acres), and provides additional protection to both wild and reintroduced *C. grimesiana* subsp. *obatae*. The fence is GPS mapped and tagged at ten meter intervals to aid in monitoring fence sections in need of repair. The snail enclosure fence is a predator-proof fence to protect endangered snails from pigs, rats, mice, Jackson's chameleons and invasive carnivorous snails. The enclosure fence is maintained for electronics and material repair by the OANRP snail specialist.

Palikea Fenced Areas



Weed Control

Weed Control actions are divided into four subcategories:

1) Vegetation monitoring
2) Surveys
3) Incipient Control Areas
4) Weed Control Areas

These designations facilitate different aspects of MIP/OIP requirements.

Vegetation Monitoring

Please see appendix: Palikea MU vegetation monitoring, for a full description of monitoring history and results.

Surveys

Army Training: No
Other Potential Sources of Introduction: NRS, pigs, public hikers
Survey Locations: roads, landing zones, camp sites, fencelines, high potential traffic areas

Management Objective:

- Prevent the establishment of any new invasive alien plant or animal species through regular surveys along roads, landing zones, camp sites, fencelines, trails, and other high traffic areas (as applicable)

Monitoring Objectives:

- Survey roads annually
- Survey transect and camp site for weeds
- Quarterly surveys of LZs (if used)
- Note unusual, significant, or incipient alien taxa during the course of regular field work

Management Responses:

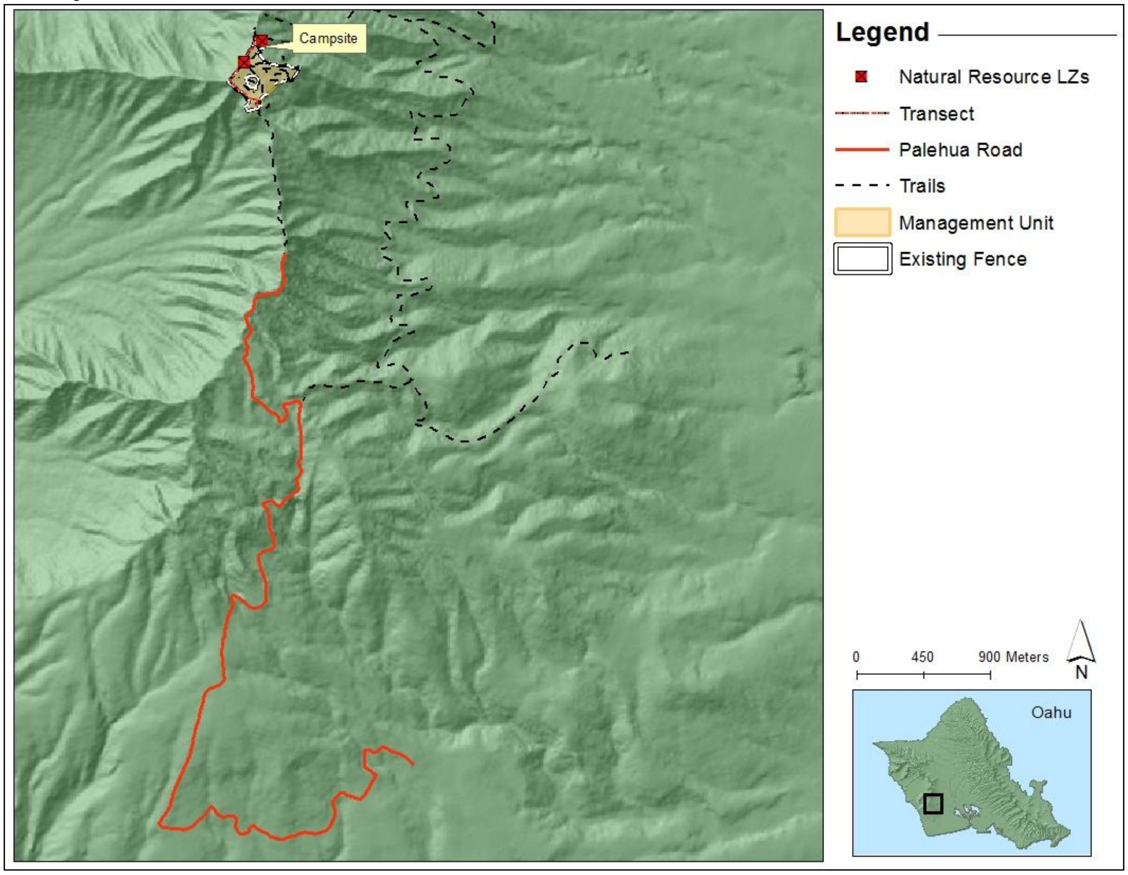
- Any significant alien taxa found will be researched and evaluated for distribution and life history. If found to pose a major threat, control will begin and will be tracked via ICAs.

Sanitation Issues:

Due to the widespread presence of *Ehrharta stipoides*, special care needs to be taken to clean shoes and gear upon departure from the MU. Seeds from *E. stipoides* have long awns and are easily transported via canvas, fabric, and Velcro. Staff should inspect and clean gear upon leaving the MU, sweep out vehicles daily, and ensure that camping gear is clean. Contractors working in Palikea need to follow the same guidelines. If possible, sanitation should be addressed in contract documents. There is anecdotal evidence suggesting *E. stipoides* has been spread from Palikea to Kahanahaiki via personnel in the past, which only emphasizes the importance of this issue.

Surveys are designed to be the first line of defense in locating and identifying potential new weed species. Roads, landing zones, camp sites, fencelines, and other highly trafficked areas are inventoried regularly. At Palikea, LZs, the campsite, one transect, and the access road are currently surveyed. NRS conducted the first road survey in January 2009. Since no Army training takes place at Palikea, NRS will conduct Palehua road surveys biannually.

Survey Locations at Palikea



Incipient Taxa Control (ICAs)

Management Objectives:

- As feasible, eradicate high priority species identified as incipient invasive aliens in the MU by 2019.

Monitoring Objectives:

- Visit ICAs at stated re-visitation intervals. Control all mature plants at ICAs and kill any immature or seedling plants to prevent them from reaching maturity. Survey Palikea trail, from gate around west (ridge) side of exclosure, ending at camp; annually.

Management Responses:

- If unsuccessful in preventing immature plants from maturing, increase ICA revisitation interval.

ICAs are drawn around each discrete infestation of an incipient invasive weed. They are designed to facilitate data gathering and control. For each ICA, the management goal is to achieve complete eradication of the invasive taxa. Frequent visitation is often necessary to achieve eradication. Seed bed life/dormancy and life cycle information is important in determining when eradication may be reached; much of this information needs to be researched and parameters for determining eradication defined. NRS will compile this information for each ICA species.

The table below summarizes target weed taxa at Palikea. Appendix 3.1 of the MIP lists significant alien species and ranks their potential invasiveness and distribution. Each species is given a weed management code: 0 = not reported from MU, 1 = incipient (goal: eradicate), 2 = control locally. OANRP supplemented and updated Appendix 3.1 with additional target species identified during field work. In many cases, the weed management code assigned by the MIP has been revised to reflect field observations. If no code is listed in the 'original' column, the species was not evaluated by the IP, but was added later by OANRP. While the list is by no means exhaustive, it provides a good starting point for discussing which taxa should be targeted for eradication, immediate control throughout the MU, or control within active WCAs. ICAs are not designated for every species in the table below; however, occurrences of all species in the table should be noted by field staff. All current ICAs are mapped.

Summary of Potential ICA Target Taxa

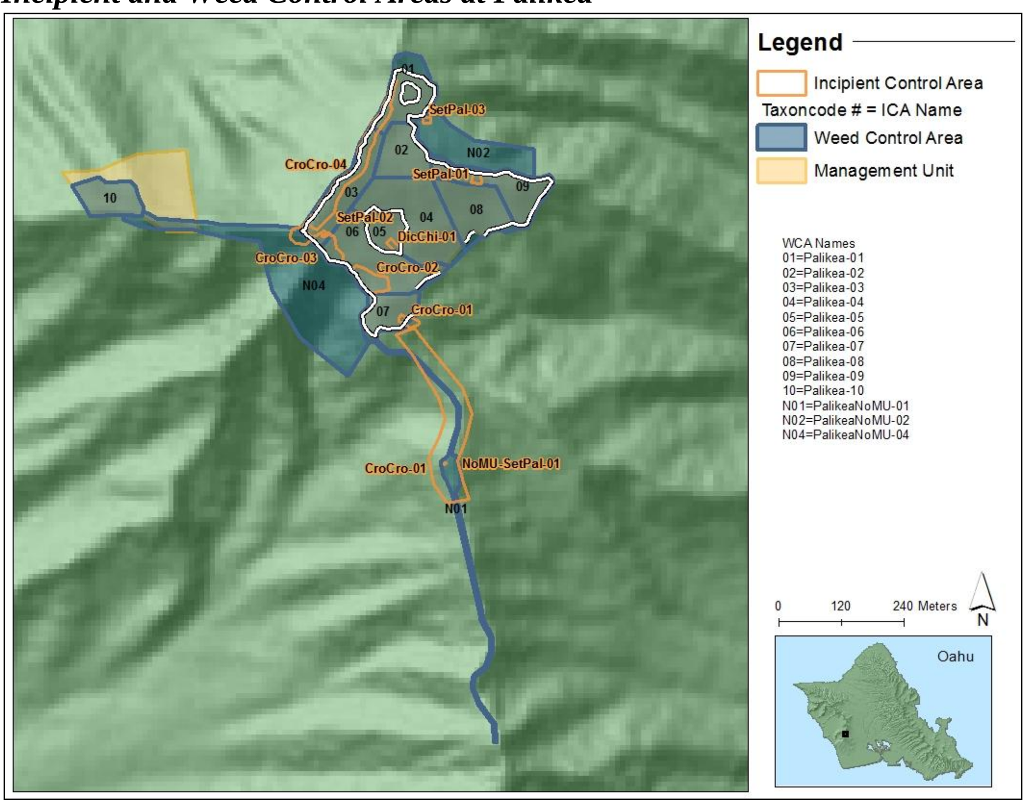
Taxa	MIP weed man. code		Notes	No. of ICAs
	Original	Revised		
Acacia mearnsii	1	0	None within MU; large infestation along trail. No control currently planned outside of the MU. Erosion a major potential side effect.	0
Angiopteris evecta	0	1	Staff has found three locations with immature plants both within the MU fence and in gulches below the campsite LZ. No mature plants have been found at any of the known sites, or during the course of field work elsewhere in the MU. Therefore, it appears that there must be some source population located outside the MU, and that staff can expect more immature plants to appear across the MU in future. While ICAs were initially created for this taxon, based on the likelihood of plants showing up anywhere, not just at known location, it was decided to control this species as part of WCA management, instead of ICA efforts.	0
Araucaria columnaris	0	1	There is a stand of *Araucaria* both inside and outside the fence in the southern part of the MU exclosure, and another smaller stand above the TNC exclosure. Currently, the population appears stable, although a few immature plants have been seen and removed. *Araucaria*'s potential for invasiveness has been observed elsewhere. This taxon will eventually be targeted for control in the WCAs in which in occurs, but is not currently a high priority.	0
Casuarina glauca	2	1	While there are few to no plants found within MU, there is a large population outside MU along the access trail. This taxon has a low rate of spread. Any plants found within MU will be targeted in WCA sweeps.	0
Crocosmia x crocosmiiflora	2	1	Several infestation sites were known prior to fence construction. After the fence was completed, NRS noted plants scattered further along the fence corridor, suggesting that staff activity is a dispersal vector. Four ICAs have been drawn in the MU, and one outside. Control is conducted primarily with volunteer groups, and has been successful at reducing overall numbers of plants. Staff supplement volunteer efforts by working on steep slopes in the ICAs. Control technique: manual removal of bulbs. Herbicide not required. Vegetative reproduction dominant, with seed produced occasionally.	5
Cryptomeria japonica		0	There is a large population of *Cryptomeria* in and to the south of the TNC exclosure. While the population appears stable, a few immature plants have been seen. This taxon is well-documented as an ecological pest in other areas of Hawaii, although native species persist beneath it at Palikea. Gradual removal of this weedy tree has begun in WCAs. No aggressive control actions are planned at this time. This taxon is susceptible to IPA and drilling control methods.	0

Dicliptera chinensis	1	1	*Dicliptera chinensis* inside old TNC exclosure is controlled quarterly. This weed is glyphosate resistant. Pick and remove from field any potentially viable fruit or roots.	1
Ehrharta stipoides	2	2	This species is widespread both in and outside of MU, and vegetation monitoring suggests it covers a greater area now than in 2008. Control is needed to check the spread of this species. This grass is a WCA control priority. Focus will be on keeping *E. stipoides* off the access and rat trails, as well as preventing movement to other MU's by cleaning gear after each trip to Palikea	0
Ficus macrophylla	1	1	One large tree was known from the northern part of the MU. It was successfully controlled by drilling holes around the base with a gas-powered drill and filling them with glyphosate.	0
Fraxinus uhdei	0	1	One mature tree was found during monitoring. The tree was killed and no new seedlings found.	0
Juniperus bermudiana	1	0	This species is not known from this MU.	0
Melaleuca quinquenervia	2	1	Few to no trees are found within the MU. If any are seen, they will be a priority for control in WCA sweeps. This species is a host for the Puccinia rust. There is a large infestation along access trail.	0
Montanoa hibiscifolia	1	0	None seen within MU. If seen, control is a high priority.	0
Schefflera actinophylla	1	0	One plant was found in the MU during vegetation monitoring. This bird-dispersed species is a high priority for control, and is a target during WCA sweeps.	0
Setaria palmifolia	2	1	There are three locations of this invasive grass within the MU, and a fourth on the access trail.ICAs have been created around each. Control technique: handpull and remove plant material, or spray with glyphosate. Efforts have been effective, with few plants found at any of the sites in the last year.	4
Sphaeropteris cooperi	1	2	During monitoring and other field activities, many plants have been found scattered across the MU. Large infestations are known just outside MU to the west and north.. There is zero tolerance for this species, which is a priority during WCA sweeps. The plants are killed when weeding WCA's	0
Toona ciliata	1	0	None known within Palikea MU. If any are found, they will be a high priority for control in WCA sweeps.	0
Trema orientalis	0	1	Some trees were seen at the eastern edge of the MU fence on the middle ridge, in an area with very steep terrain. There is zero tolerance for this wind-dispersed species inside the MU, and it is a priority target during WCA sweeps.	0

Incipient species at Palikea

C. crocosmiiflora flower and corm

Incipient and Weed Control Areas at Palikea



Ecosystem Management Weed Control (WCAs)

MIP Goals:

- Within 2m of rare taxa: 0% alien vegetation cover
- Within 50m of rare taxa: 25% or less alien vegetation cover
- Throughout the remainder of the MU: 50% or less alien vegetation cover

Management Objectives:

- Maintain 50% or less alien vegetation cover in both the understory and canopy across the MU.
- In WCAs within 50m of rare taxa, work towards achieving 25% or less alien vegetation cover in understory and canopy.

Management Responses:

- Increase/expand weeding efforts if MU vegetation monitoring (conducted every 3 years) indicates that goals are not being met. Please see Appendix: Palikea MU vegetation monitoring for discussion

Weed Control Summary

In order to meet management objectives for Palikea MU, a number of general and specific actions are recommended. More aggressive weed control across the MU is necessary. Partial canopy removal/thinning for *Morella faya*, *S. terebinthifolius*, and *Cryptomeria japonica* is recommended, as these are among the more frequently occurring and more easily managed canopy weeds, and have infrequent recruitment. However, caution should be applied to not open too much canopy, as this may promote growth of understory weeds, especially *C. hirta* and *R. rosifolius*. Incision Point Application (IPA) herbicide delivery technique is recommended for *Cryptomeria japonica* and *Araucaria columnaris* across the entire MU, as these weeds occur relatively infrequently in the canopy, and may be a more achievable target for elimination. *Passiflora suberosa* should be targeted during WCA efforts, especially in the canopy. *Sphaeropteris cooperi* has been found sporadically throughout the MU over the years and is a target species to be controlled during weed sweeps through all WCA areas. *Ehrharta stipoides* is a prominent weedy grass that needs more attention as it is spreading along trails and is seen throughout the interior of the MU. Common native outplantings will be conducted in addition to weeding efforts to aid in native understory recovery.

Vegetation monitoring at Palikea indicates that management objectives of having < 50% non-native understory and canopy and > 50% native understory and canopy cover were only met with respect to the non-native understory. This indicates that continued weed control is needed at Palikea. Areas near rare taxa will continue to be prioritized, especially along the southern fenceline near camp, and the H-line around the common outplanting area. Where *A. mustelina* are present, NRS will seek to avoid unintentional negative impact by being cognizant of snail presence and avoiding chemical control of grass in and around of preferred snail trees.

In the central portion of the MU and along the southern fenceline, control strategies will focus on sweeping through the understory for *C. hirta* and *R. rosifolius*, while controlling weedy grasses along trails and fencelines. Gradually removing canopy weeds such as *Morella faya*, and *S. terebinthifolius*, while simultaneously targeting *P. cattleianum* stands for more aggressive, clear-cut style control will be the strategy used throughout the MU. Large numbers of *A. koa* seedlings have been observed recruiting thickly in the cleared *P. cattleianum* areas. Additionally, common reintroductions will be used to complement weeding efforts.

In the northeastern part of the MU, gulch portion of the MU the gulches are weedier and more varied than the rest of the MU. Work here centers around rare taxa and weeding is prioritized within the *C. grimesiana* fence around wild and reintroduced plants. Control of the canopy tree *Cryptomeria japonica* will be a priority, as well as understory weeds *C. hirta, R. rosifolius*, and weedy grasses.

WCA: Palikea-01 (Campsite corner)
Vegetation Type: Mesic-Wet Forest (ridge)
MIP Goal: Less than 25% non-native cover given presence of MIP taxa (snails). Monitoring shows that for this vegetation type, native cover is at 50%.
Targets: All weeds, focusing on *M. faya*, *P. cattleianum*, *C. hirta*, *R. rosifolius*, and grasses.
Notes: This WCA includes a native dominated forest patch home to *A. mustelina*, *A. concavospira* and *L. sanguinea*, enclosed by a predator-proof snail exclosure. There are few weeds and many common outplantings have been added inside the exclosure. See Appendix 1-6, Snail Exclosure Restoration summaries for further details on this process. The exclosure is slated for continued gradual removal of *S. terebinthifolius*, as it is present in the middle of the exclosure fence. Much of the WCA is bordered by the fenceline, and the more native areas of the WCA are concentrated above and around the snail exclosure fence. NRS will target *E. stipoides*, other grasses, and *S. terebinthifolius* along fencelines and trails. Follow up treatment of *B. appendiculatum*, *R. rosifolius*, *C.hirta*, *P. suberosa*, and other understory weeds will be required. Currently, *R. rosifolius* and *P. suberosa* are present in thick patches above the snail jail towards the fenceline and weeding efforts will be prioritized at this location until the area is cleared of these weeds . The understory adjacent to the fenceline below the campsite LZ is dense with weedy grasses and immature *P. cattleianum*, and should be sprayed regularly.

WCA: Palikea-02 (Uluhe flats/H line)
Vegetation Type: Mesic Mixed Forest (uluhe dominated flats)
MIP Goal: 50% or less alien cover (no rare taxa in WCA). Monitoring data for this vegetation type is highly variable; however, the 50% alien cover goal has been met for the MU as a whole.
Targets: All weeds, focusing on *S. terebinthifolius*, *P. cattleianum*, *S. cooperi*, and shrubs.
Notes: Much of this WCA is covered with *Dicranopteris linearis*, however, the areas around the flats include high densities of *S. terebinthifolius*, *C. hirta* and *P. cattleianum*. Targeting these regions would help to improve overall habitat quality while providing connectivity between the surrounding WCAs, most of which are 50% or greater native cover. *S. cooperi* has been found in this region; this taxa should be targeted in particular. In the *S. terebinthifolius* and *P. cattleianum* dominated areas, common native outplantings are underway in order to speed rehabilitation and provide habitat enhancement for populations of endangered *Drosophila*. Native canopy replacement is needed as the *M. polymorpha* will not quickly replace removed non-native trees. Common native species slated for outplanting include: *C. longifolia, C. trigynum*, *K. affinis. A. platyphyllum, M. polymorpha* and *Drosophila* host trees *U. glabra and U. kaalae*. *U. glabra* will be planted in the winter of 2014 for habitat improvements for *Drosophila*.

WCA: Palikea-03 (Crestline)
Vegetation Type: Mesic-Wet Forest (ridge)
MIP Goal: 25% or less alien cover (rare taxa in WCA). Monitoring shows that this vegetation type is already at 50% native cover.
Targets: All weeds, focusing on *M. faya*, *S. terebinthifolius*, *P. cattleianum*, *E. stipoides*, other grasses.
Rare Taxa: *A. mustelina*

Notes: This region is steep, including much of the summit area in the MU. Some portions of the WCA include cliffs. Fortunately, most of the understory is dominated by native species, however, *M. faya* forms a significant part of the canopy. Control of this species will be staggered so as to minimize changes in the light regime. Early results from IPA (incision point application) herbicide trials show promise for controlling *M. faya.* The area along the fenceline will be sprayed regularly for *E. stipoides* and other grasses; keeping *E. stipoides* from moving away from the fenceline and into the MU is a priority. There is a large population of *A. mustelina* on the southern end of the WCA; NRS will seek to avoid negative impacts to the population by exercising caution when working around snail trees. In open areas, NRS will consider using common native species seed sow or plantings to reduce habitat for *E. stipoides*. Past attempts to transplant *Dicranopteris linearis* into bare ground areas have been unsuccessful. Appropriate species for future plantings include *R. albescens* and *D. sandwicensis*. *Melinus minutiflora* control will be focused around Puu Palikea and surrounding snail habitat, followed by common native seed sow using *Bidens torta and Carex wahuensis*, as the weedy grasses are persistent and spreading down gulch.

WCA: Palikea-04 (Mid-Gulch)
Veg Type: Mesic Forest (gulch)/ Mesic-Wet Forest (Slope)
MIP Goal: 25% or less alien cover (rare taxa in WCA). This WCA spans two vegetation types. Monitoring shows that the mesic-wet vegetation type is already at 50% native cover, while the mesic gulch forest type is much more variable in cover (80-100% alien).
Targets: All weeds, focusing on *S. cooperi, M. faya, S. terebinthifolius, P. cattleianum, E. stipoides, M. minutiflora* and other grasses.
Notes: This WCA is large and stretches from the eastern edge of the MU, along the *C. grimesiana* fence, to the steep, cliff areas on the western edge of the MU. It encompasses a mesic gulch bordered by two ridges. The mesic forest vegetation type is the most degraded type in Palikea. It is dominated by *S. terebinthifolius*, has low species diversity, low native cover, and very high percent bare ground. The bare ground is due to dense shading by *S. terebinthifolius*. On the western end of the WCA, *P. cattleianum* provides most of the canopy, although vegetation is somewhat mixed in the understory with natives and weeds. Despite the weedy character of the WCA, *A. mustelina*, *A. concavospira*, *L. sanguinea*, and *C. ibidis* are all present. Care needs to be taken to avoid significant negative impacts to these rare taxa and their habitat. Control work will focus on gradual removal of *S. terebinthifolius* canopy; this will open up light gaps which will need to be monitored for weedy grasses, etc. The ridges bordering the gulch include more native vegetation elements. These ridges will be swept, and *M. faya*, the primary weed, will be targeted gradually. The mixed *P. cattleianum* patches on the west of the area will be swept and weeded gradually. Native canopy outplantings (e.g. *Pisonia* sp., *U. glabra*) will likely be needed to assist in recovery after any large removals of *S. terebinthifolius*.

WCA: Palikea-05 (CyaGri Fence)
Veg Type: Mesic Forest (gulch)
MIP Goal: 25% or less alien cover (rare taxa in WCA). Monitoring shows that for this vegetation type, percent native cover is highly variable.
Targets: All weeds, focusing on understory species.
Notes: This WCA encompasses the small TNC fence. Approximately an acre, the fence protects both wild and reintroduced *C. grimesiana*, as well as other rare species reintroductions planted by TNC. This area has been protected from pigs since 1999; since then, native ferns have thrived. Weed control has been ongoing at this site for many years. Portions of the WCA are still dominated by weeds, and the canopy throughout the WCA is made up of *Cryptomeria japonica*. *C. japonica* has not been observed recruiting aggressively in the WCA, however *C. grimesiana* seedling recruitment beneath this overstory has also been limited. NRS have begun to remove selected trees and will continue to do so in the coming year with the aim of increasing *C. grimesiana* seedling recruitment, and to eventually promote a native canopy in this area. NRS is hopeful that native fern recruitment seen within the TNC fence will be

echoed elsewhere in Palikea. Planting common native species such as *Pipturus albidus, Hedyotis terminalis,* and *D. sandwicensis* may help to jumpstart forest restoration in the weedier portions of this WCA. Continued control of weedy grasses along the perimeter of the TNC fence will be a priority as *M. minutiflora* seems to be spreading lower into the gulch and upslope away from the fence into other WCA's. Common outplantings in the predominantly grassy areas will help to control the spread of *M. minutiflora* .

WCA: Palikea-06 (Tsugi Gulch)

Veg Type: Mesic Forest (gulch)/ Wet-Mesic Forest
MIP Goal: 25% or less alien cover (rare taxa in WCA). This WCA spans two vegetation types. Monitoring shows that the mesic-wet vegetation type is already at 50% native cover, while the mesic gulch forest type is much more variable in cover (80-100% alien).
Targets: All weeds, focusing on C. *japonica*, *M. faya, S. terebinthifolius, P. cattleianum, C. hirta, B. appendiculatum, S. cooperi, E. stipoides*, and grasses.
Rare Taxa: *A. mustelina* and *Chasiempis ibidis* in WCA.
Notes: Much of this WCA is dominated by *Cryptomeria japonica* and *P. cattleianum* canopy. The area is heavily shaded, with a very open understory and lots of bare ground. This WCA directly abuts the *C. grimesiana* fence. Gradually native ferns should colonize much of the bare ground in the WCA, as they did in the TNC fence. In a novel control method conducted this year, select mature *C. japonica* trees were treated by drilling and injecting herbicide, as well as IPA, and are starting to die. Gradual removal of this dominant overstory trees, as well as *R. rosifolius* in the understory, will be a focus. The large gulch extending from the south portion of the TNC fence up towards the crestline will be a focus of weeding and restoration efforts. Weed control efforts will focus on understory species, grasses, and some *P. cattleianum* canopy control. Gradual removal of *P. cattleianum* will be implemented. Common native species will be outplanted here to help provide native understory replacements for *P. cattleianum* and *C. japonica*.

WCA: Palikea-07 (Norfolks, South Corner)

Veg Type: Mesic Mixed Forest (slope, ridge)
MIP Goal: 25% or less alien cover (rare taxa in WCA). Monitoring data for this vegetation type is highly variable; however, the 50% alien cover goal has been met for the MU as a whole.
Targets: All weeds, focusing on *Araucaria columnaris*, *M. faya*, *S. terebinthifolius*, *P. cattleianum*, *E. stipoides*, *S. cooperi* and grasses.
Notes: Much of the WCA is dominated by very large *Araucaria columnaris*. These trees originally were planted; while they are not naturalizing quickly, some keiki have been found. Removing the *Araucaria* would drastically alter light and moisture levels and could be quite biologically dangerous. For now, any young *Araucaria* will be controlled. Other portions of the WCA are dominated by a mix of native species. Weeding efforts will focus in these areas. The Palikea trail runs through the WCA; grass control, especially *E. stipoides,* will be a priority along the fence. The northern part of this WCA has native forest patches that are host to *A. mustelina*. These areas will be weeded cautiously to minimize potential impact to the tree snails. Some scattered *P. cattleianum* has been seen amongst the native patches and will be a priority when weeding in this WCA. Volunteers have weeded some *P. cattleianum* in this WCA and while some follow up with grass spraying is needed, much of the area has been grown over by *D. linearis*. *S. cooperi* also continues to periodically recruit in this area.

WCA: Palikea-08 (Mid-east Gulch/South of F line)

Veg Type: Mesic Mixed Forest (gulch, ridge)
MIP Goal: 25% or less alien cover (rare taxa in WCA). Monitoring data for this vegetation type is highly variable; while the 50% alien cover goal has been met for the MU as a whole, the mesic gulch forest type is highly variable in cover (80-100% alien).

Targets: All weeds, focusing on *M. faya, S. terebinthifolius, P. cattleianum, M. minutiflora*, and grasses.
Notes: This WCA is very similar to Palikea-04 in terms of vegetation types, topographic features, and resources. Control will focus on gradual removal of *S.terebinthifolius* from the gulch and *M. faya* from the ridges. Common natives may be used in the light gaps resulting from weeding. *A. mustelina* in the WCA are primarily found in a large *Freycinetia arborea* patch and in high numbers at the top of the WCA on host trees in the *D. linearis* patch. The *F. arborea* patch is nearly entirely surrounded by *S.terebinthifolius*. Controlling this weedy tree around the edges of the *F. arborea* to prevent it from expanding is a focus in this area. Open canopy created from control of *S. terebinthifolius* may be good candidate areas for common outplantings. The perimeters of this patch are easier to weed as they are near well-used trails, and not on steep cliffs like the center of the WCA. *A. concavospira* are also found in this WCA. The bottom of this WCA is along the fenceline and is often covered with *M. minutiflora*, and should be a priority for control to prevent it from spreading uphill into the remainder of the WCA, where the terrain is very steep, weed control difficult. Removing all the *S. terebinthifolius* from this WCA will be a big task and should be considered with other large projects in more native areas of the MU.

WCA: Palikea-09 (East Corner/F line/Clearcut)

Veg Type: Mesic-Wet Forest/ Mesic Mixed Forest
MIP Goal: 25% or less alien cover (rare taxa in WCA). This WCA spans two vegetation types. Monitoring shows that the mesic-wet vegetation type is already at 50% native cover, while the mesic gulch forest type is much more variable in cover (80-100% alien).
Targets: All weeds, focusing on *S. terebinthifolius, P. cattleianum, R. rosifolius,* and *P. suberosa*.
Notes: This WCA encompasses the long north-facing slope of the main ridge crossing the MU. The western end of the WCA borders on the uluhe flats, while the eastern end wraps around the central ridge in Palikea MU to include a small gulch. It is very diverse, with many native and weedy elements and *A. mustelina*. This WCA contains outplanted *Phyllostegia hirsuta* near the north fenceline. Control efforts will focus on conducting weed control around the native forest patches for both canopy and understory weeds. A large area of *P. cattleianum* was removed by clearcutting a large monotypic stand near the bottom of the WCA on the eastern fenceline. *A. koa* found on the ridge above the site has begun to recruit in the areas, but supplemental plantings of this species as well as other common natives are planned for this site. The fast-growing *Phytolacca octandra* is the predominant weed, replacing the bare ground after clearcutting, however, it is relatively easy to control. Along the fenceline, both *M. minutiflora* and *S. terebinthifolius* will be controlled to facilitate fenceline maintenance. Around *P. hirsuta*, weeding efforts will focus on maintenance of *M. minutiflora*, and removal of *R. rosifolius*, which has dominated the area after removal of *S. terebinthifolius*. Additionally, control of *P. suberosa* should be a focus in this WCA, as it appears to be spreading, especially along the fenceline near the *P. hirsuta* outplanting.

WCA: PalikeaNoMU-01 (Palikea Trail)

Veg Type: Mesic-Wet Forest (ridge)
MIP Goal: This WCA does not fall in the Palikea MU. The MIP does not specify weed control goals outside MUs, except with regards to incipient invasive species. The objective of this WCA is to maintain the access trail to the MU fence and to keep the highly invasive *E. stipoides* off the trail, thus reducing the potential to spread it.
Targets: *E. stipoides* and other grasses, *M. quinquenervia, Casuarina* spp., *M. faya*.
Notes: The Palikea trail runs through a variety of plant communities, ranging from separate monocultures of bamboo, *Casuarina* spp., and *M. quinquenervia*, to native dominated mesic-wet forest. *E. stipoides* is also found along much of the access trail and is well established in the region; it is the most invasive understory species in the area. Control of *E. stipoides* is a high priority. The trail will be sprayed regularly to reduce the potential of staff to accidentally spread it to intact areas of Palikea or other MUs. Weedy tree species found in the native-dominated portions of the WCA will be controlled as time permits; this is a low priority. Additionally, *M. minutiflora* has been spreading around the TNC *A. koa*

outplanting area, and focus on control of this invasive grass will be a priority when spraying the access trail.

WCA: PalikeaNoMU-02 (East SphCoo Bowl)
Vegetation Type: Mesic mixed forest (gulch)
MIP Goal: This WCA does not fall in the Palikea MU. The MIP does not specify weed control goals outside MUs, except with regards to incipient invasive species. The objective of this WCA is to control *S. cooperi* and reduce its ability to disperse into the MU.
Targets: *S. cooperi, Trema orientalis, M. faya* and other significant/unusual tree weeds.
Notes: Just outside the Palikea fence, in a gulch to the northeast, there is an infestation of *S. cooperi*. This species is widely but sparsely scattered, with immature recruits found across the Palikea exclosure. It is a target in all WCAs. *S. cooperi* is highly invasive, and can form dense stands in mesic/wet forest. Eliminating mature plants is a high priority and all known mature plants at this site have been controlled. NRS hope that by targeting large infestations outside of the MU, the number of recruits found inside the MU will be reduced. Other weedy source taxa such as *T. orientalis* will also be controlled in this WCA during weed sweeps.

Juveline *Sphaeropteris cooperi*

WCA: PalikeaNoMU-04 (Halona Ridge)
Veg Type: Mesic-Wet Forest (ridge)
MIP Goal: This WCA does not fall in the Palikea MU. The MIP does not specify weed control goals outside MUs, except with regards to incipient invasive species. The objective of this WCA is to maintain Halona ridge trail toward Nanakuli relatively free of *Crocosmia x crocosmiiflora, S. cooperi,* and weedy grasses.
Targets: *E. stipoides* and other grasses*, S. cooperi,* and *Crocosmia x crocosmiiflora* .
Notes: The Halona Ridge runs from the southwest corner outside the Palikea MU fence down towards Nanakuli, towards the Palikea IV MU. The upper portion of the ridge is native dominated mesic-wet

forest. This ridge area is also where the last *Vestiaria coccinea*, (Iiwi), was observed by OANRP on Oahu, in 2014. *E. stipoides* is also found along much of the ridge and is well established in the region; it is the most invasive understory species in the area. Control of *S. cooperi*, and *Crocosmia x crocosmiiflora* are a high priority and will be the focus of weeding efforts. Weedy tree species found in the native-dominated portions of the WCA will be controlled as time permits; this is a low priority as it falls outside of the Management Unit.

Rat Control

Threat level:	High
Current control method:	MU level Kamate trap grid
Seasonality:	Year-Round
Number of control grids:	180 Kamate traps

Primary Objective:

- To maintain rat/mouse populations to a level that facilitates stabilized or increasing rare plant and snail populations across the MU by the most effective means possible.

Management Objective:

- Continue to maintain Kamate traps to protect *Achatinella mustelina* populations throughout the MU, and reduce predation of fruit from rare plant taxa.
- Depending on the success of traps in other MUs, automatic resetting traps may be installed in place of Kamate traps in the future.

Monitoring Objectives:

- Monitor tracking tunnels quarterly to determine rat activity within the trapping grid.
- Monitor ground shell plots in and outside of snail enclosure for predation of *Achatinella mustelina* by rats.
- Monitor *Cyanea grimesiana* subsp. *obatae* for predation of fruits by rats.
- UH researcher continues to monitor arthropod composition and abundance in response to rat control.

Monitoring Issues:

- An acceptable level of rat activity, which promotes stable or increasing *A. mustelina* and *C. grimesiana* subsp. *obatae* populations, has not been clearly identified. In order to determine an acceptable level, more intensive monitoring of rare resources is required. Regardless of rat activity levels, resource response is the ultimate goal of rat control. Snail counts and seedling survival are two variables that will help determine if current rat control is sufficient.

- Threatened resources are widespread throughout the Palikea MU. The habitat quality is high, and the MU is of sufficient size for an effective trapping grid. Monitoring of rat activity via tracking tunnels, *A. mustelina* populations, and populations of *C. grimesiana* subsp. *obatae* will be vital in determining whether control is having the desired effect.

Ant Control

Species: *Cardiocondyla venustula*, *Solenopsis papuana*
Threat level: Low

Control level: Only for new incipient species
Seasonality: Varies by species, but nest expansion observed in late summer, early fall
Number of sites: ~5 (*Drosphila substenoptera, D. montgomeryi* sites, trails, campsite LZ and fenceline)
Acceptable Level of Ant Activity: Current level acceptable, sampling confirms ants are not abundant

Management Objective:

- If incipient species are found and deemed to be a high threat and/or easily eradicated locally (<0.5 acre infestation) begin control using a bait containing Hydramethylnon (Amdro, Maxforce or Seige).

Monitoring Objectives:

- Continue to sample ants at human entry points and a minimum of once a year. Use samples to track changes in existing ant densities and to alert OANRP to any new introductions.
- Sample ants at *Drosphila substenoptera* and *D. montgomeryi* sites annually, as well as along trails and fencelines, as ants are likely to attack immature larvae.

Ants have been documented to pose threats to a variety of resources, including native arthropods, plants (via farming of hemipteran pests), and birds. The distribution and diversity of ant species in upland areas on Oahu, including Palikea, has only begun to be studied and changes over time. Impacts to the rare species present in Palikea remain unknown, but it is likely they are having some type of effect on the ecosystem at large. OANRP have already conducted some surveys across Palikea to determine which ant species are present and where they are located. Surveys were conducted using a standardized sampling method (see Invasive Ant Monitoring Protocol http://manoa.hawaii.edu/hpicesu/DPW/2010_YER/027.pdf). *Solenopsis papuana* and *Cardiocondyla venustula* were found outside forested areas (on ridges) in low densities. These two species were at low numbers, and infrequently found at bait cards, therefore control is not merited at this time.

Slug Control

Species: *Limax maximus, L. flavus, Meghimatium striatum, Lehmannia valentiana, Deroceras leave*
Threat level: High
Control level: Localized
Seasonality: Present year round, more active in the wet season
Number of sites: 3 (*Cyanea grimesiana* subsp. *obatae and Phyllostegia hirsuta* populations)

Primary Objective:

- Reduce slug population to levels where germination and survivorship of rare plant taxa are optimal.

Management Objective:

- Continue to control slugs around the *Cyanea grimesiana* subsp. *obatae* populations. If surveys confirm no native snails are present, apply Sluggo at the *Phyllostegia hirsuta* populations to reduce herbivory and encourage seedling recruitment

Monitoring Objectives:

- Annual census monitoring of *Cyanea grimesiana* subsp. *obatae* and *Phyllostegia hirsuta* seedling recruitment following fruiting events
- Annual census monitoring of slug densities during wet season inside and outside of control areas

Effective molluscicides have been identified (Sluggo) and control programs are ongoing in Palikea. It has been established that in order for Sluggo to be effective, it needs to be applied across an area >100 m^2 and need to be reapplied at least every month. The rare plants protected via slug control are shown on the map below.

Map removed to protect rare resources

Predatory Snail Control

Species: *Euglandina rosea* (rosy wolf snail)
Threat level: High
Control level: Localized
Seasonality: Year-Round
Number of sites: One, potentially 13 (*A. mustelina* sites)
Acceptable Level of Activity: Unknown

Primary Objective:

- Reduce predatory snail populations to a level optimal for *A. mustelina* survival.

Management Objective:

- Continue to develop better methods to control predatory snails
- Keep sensitive snail populations safe from predatory snails by maintaining snail exclosure.

Monitoring Objectives:

- Annual or every other year census monitoring of *A. mustelina* population(s) to determine population trend.

- Annual searches for predatory snails to confirm their absence or presence in proximity to *A. mustelina.*

No baits have been developed for the control of predatory snails. Little is known regarding their distribution and prey preference. Control is limited to hand removal. Visual searches are time-consuming, difficult, and not feasible over large areas and in steep terrain. It is also unknown whether predatory snail populations are, in fact, reduced by hand removal. *Euglandina rosea* has been found in this MU, but in low numbers.

Section of snail exclosure fence

View from inside of snail exclosure fence before outplantings

Palikea snail exclosure panorama

Jackson's Chameleon Control

Threat: *Chameleon jacksonii* subsp. *xantholophus* (Jackson's Chameleon)
Threat level: Unknown, perhaps High
Control level: Localized
Seasonality: Year-Round
Number of sites: One, potentially 13 (*A. mustelina* sites)
Acceptable Level of *C. jacksonii* Activity: Zero within snail enclosure, unknown in remainder of MU

Primary Objective:

- Determine the threat level *C. jacksonii* pose in the MU.

Secondary Objectives:

- *C. jacksonii* presence will be mapped along the Palehua road.
- Determine if *C. jacksonii* are having an impact on *A. mustelina* in the MU, and dissecting captured *C. jacksonii* to determine gut content .

Management Objective:

- By end of 2015, conduct a distribution survey for *C. jacksonii* along Palehua Road and through the residential area.
- By end of 2015, survey the Palikea MU and determine whether *C. jacksonii* are present in the MU.
- If needed, develop a control technique and strategy for *C. jacksonii*.

Monitoring Objectives:

- Monitor extent and geographic distribution of resident population of *C. jacksonii* regularly.

Discovery of *A. mustelina* shells in the stomachs of *C. jacksonii* found in the Puu Kumakalii region show that beleaguered tree snails have yet another predator and that *C. jacksonii* pose a serious threat to rare taxa. Palikea is home to a large population of *A. mustelina*. NRS have reported observations of *C. jacksonii* along the Palehua road, the primary access point for Palikea. Additionally, one chameleon was captured in the MU near the campsite LZ. Additional surveys are vital to determining the extent of the chameleon population in the region. Once more information is known about the distribution of and threats posed by *C. jacksonii*, NRS will update the five year plan for Palikea.

Yellowjacket Control

Threat: *Vespula pensylvanica* (western yellowjacket)
Threat level: Unknown, perhaps High
Control level: MU level
Seasonality: Year-Round, abundance peaking in August–October
Number of sites: Bait network of about 30 heptyl butyrate traps
Acceptable Level of *V. pensylvanica* Activity: Unknown

Primary Objective:

- Determine the threat level *V. pensylvanica* poses in the MU.

Secondary Objectives:

- Map spatial distribution and seasonal abundance changes of *V. pensylvanica* in the MU.
- Determine if *V. pensylvanica* is having an impact on *Drosophila* spp. in the MU.

Management Objectives:

- By end of 2015, conduct a distribution and abundance survey for *V. pensylvanica* in areas of the MU where *Drosophila* are known to be or potentially present.
- If needed, develop a control technique and strategy for *V. pensylvanica*.

Monitoring Objectives:

- Monitor for unusually high summer/fall outbreaks and apply control if necessary.

The arrival of *Vespula pensylvanica,* a generalist predator on other invertebrates and scavenger, was followed shortly by major declines of many of the large endemic picture-wing *Drosophila* species. They are also known to have serious impacts on native *Hylaeus* bees, both through direct predation and by excluding bees from flowers. Two of the endangered *Drosophila* species found at Palikea, *D. substenoptera* and *D. hemipeza* (the latter is not managed by OANRP) may be particularly vulnerable to predation because they often stand conspicuously with their wings held to the side even when not actively displaying. In relatively dense forests such as Palikea, *V. pensylvanica* may occur in high abundance but still be inconspicuous by keeping primarily to the canopy. Wasps are strongly attracted to the non-toxic chemical lure heptyl butyrate, which can be used to quantitatively monitor populations over time. If they turn out to be highly abundant at Palikea, particularly in the late summer and fall when populations typically undergo booms, then control may be warranted. Work at Hawaii Volcanoes National Park has demonstrated successful control using poisoned meat baits.

Fire Control

Threat Level: Low
Available Tools: Fuelbreaks, Visual Markers, Helicopter Drops, and Wildland Fire Crew

Management Objective:

- To prevent fire from burning any portion of the MU at any time.

Preventative Actions
There is little infrastructure/construction which would be helpful to reduce fire threat. NRS will focus on maintaining good communication with the Wildland Fire Working Group to facilitate positive on-the-ground fire response in the event of another catastrophic Nanakuli brushfire. In 2014, a fire burned near Palikea MU in the Makakilo area. While the fire did not reach Palikea, similar fires in the area could impact management of the MU by limiting access. This could be an issue for slug and rat control in the future.

Nanakuli Fire

2005 Fire burning up leeward slopes in Nanakuli, towards the Waianae summit and Palikea

Grass control in the MU is discussed in the Weed Control section of the plan.

Fire Mitigation Activities at Palikea

Receiving watertank near Puu Palikea to support fire fighting efforts

Fuel break along the ridge

Action Type	Actions	OIP Year 11 Oct 2014-Sept2015				OIP Year 12 Oct 2015-Sept2016				OIP Year 13 Oct 2016-Sept2017				OIP Year 14 Oct 2017-Sept2018				OIP Year 15 Oct 2018-Sept2019			
		4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
General Survey	LZ-HON-107: Survey Puu Palikea LZ whenever used, not to exceed once per quarter. If not used, do not need to survey.																				
	LZ-HON-137: Survey Palikea Camp LZ whenever used, not to exceed once per quarter. If not used, do not need to survey.																				
	WT-Palikea-01: Survey Palikea trail, from gate around west (ridge) side of exclosure, ending at camp; annually.																				
	RS-Palikea-01: Survey road from bottom gate to Mauna Kapu, Palikea trailhead. No side roads. Every other year.																				
ICA	Palikea-Crocro-01: Monitor/control Crocro at Norfolk pine site annually. Sweep entire ICA each time. Dig out corms, remove from field. Pick and remove from field any potentially viable fruit.																				
	Palikea-Crocro-02: Monitor/control Crocro at DZ/akolea gulch site 1x year (2x year if needed). Once initial knockdown is complete, sweep entire ICA each time. Dig out corms, remove from field. Pick and remove from field any potentially viable fruit.																				
	Palikea-Crocro-03: Monitor/control Crocro on very steep slopes at steps site minimum 1x year (2x year if needed). Sweep entire steep portion of ICA each time (Outreach to get gentler slopes/trailside areas). Dig out corms, remove from field. Pick and remove from field an																				
	Palikea-Crocro-04:Monitor/control Crocro on fence N of lunch puu a minimum 1x year (2x year if needed). Sweep entire ICA each time. Dig out corms, remove from field. Pick and remove from field any potentially viable fruit.																				

	Palikea-Dicchi-01:Monitor/control Dicchi inside old TNC exclosure quarterly. This weed is roundup resistant. Pick and remove from field any potentially viable fruit or roots.																				
	Palikea-SetPal-01: Monitor/control Setpal at site east of camp quarterly/every 6 months. Handpull and remove from field all plants/fruit.																				
	Palikea-SetPal-02: Monitor/control SetPal at steps site quarterly/every 6 months. Handpull and remove from field plant and potentially viable fruit.																				
	Palikea-SetPal-03: Monitor/control SetPal at camp site quarterly. Handpull and remove from field plant and potentially viable fruit.																				
WCA 1: Campsite corner	Sweep entire WCA for understory and overstory weeds once per year																				
	Spray any grass found along ridgeline and fenceline, check quarterly, spray as needed																				
WCA 2: Uluhe flats/H line	Control in weedier portions of WCA. Sweep entire WCA one time focusing on mature *P. cattleianum*, *R. rosifolius*, and *P. suberosa*																				
	Control weedy grasses 2x year																				
WCA 3: Crestline	Spray *E. stipoides* and other grasses along fenceline 2s year																				
	Sweep accessible portions of WCA 1 time each year; reduce *M. faya* cover gradually																				
WCA 4:Midgulch	Sweep ridges, begin overstory control of *M. faya* and *S. terebinthifolius* once every two years																				
	Control understory weeds throughout WCA																				
	Spray weedy grasses found in WCA 2x year Control understory weeds throughout WCA																				
WCA 5: Cyagri Fence	Sweep WCA 2x year for understory and overstory weeds																				

	Gradually remove *C. japonica* above *C. grimesiana* outplanting
	Control weedy grasses along fenceline and within WCA 2x year
WCA 6:Tsugi Gulch	Thin *C. japonica* using drilling and herbicide method
	Control small portions of *P. cattleianum* 2x year and overstory weeds 2x year
	Control weedy grasses and understory species
WCA 7:Norfork/South Corner	Sweep entire WCA one time per year. Focus on understory species and gradual removal of overstory weeds.
	Spray grasses, *E. stipoides*, along trail two x year
WCA 8:Mideast Gulch	Spray any grass found in WCA 2x year
	Control understory and canopy weeds in gulch every other year
WCA 9: East Corner/F line/Clearcut	Control understory and canopy weeds across WCA once per year, focus on *S. terebinthifolius*, *P. cattleianum*, and *R. rosifolius*
	Control weedy grasses along fenceline and within WCA twice per year
Palikea NoMU-01: Palikea Trail	Spray *E. stipoides* and other grasses along the trail, from the trailhead to the MU fence; check quarterly, spray as needed
Palikea NoMU-02: Sphcoo Bowl	Sweep entire area for *S. cooperi*, *T. orientalis*, etc once, every two years
Palikea NoMU-04:	Sweep entire area for *S. cooperi*

	Conduct weed control on Halona ridgeline annually. Focus on Erikar, Sphcoo, grasses, canopy weeds.
Rat Control	Run tracking tunnels 1x quarter
	Trapout rat grid every six weeks
Slug Control	Apply Sluggo monthly at rare plant populations
	Monitor slugs with beer traps quarterly
Ungulate Control	Check MU fence for breaches and check transects Check *C. grimesiana obatae* fence for breaches
	Check *C. grimesiana obatae* fence for breaches
Predatory Snails/Snail Exclosure	Check snail enclosure for breaches and remove predatory snails under the hood quarterly
Ants	Survey for ants annually
Rare Insects	Quarterly survey at managed populations
Common Outplanting	Outplant and monitor common reintros

Appendix 1-2
Environmental Outreach 2014

VOLUNTEER TRIP PHOTOS:

Left: Boy Scouts implement a weed trial for controlling invasive *Crocosmia* x *crocosmiiflora* at Kaala as part of an Eagle Scout project.

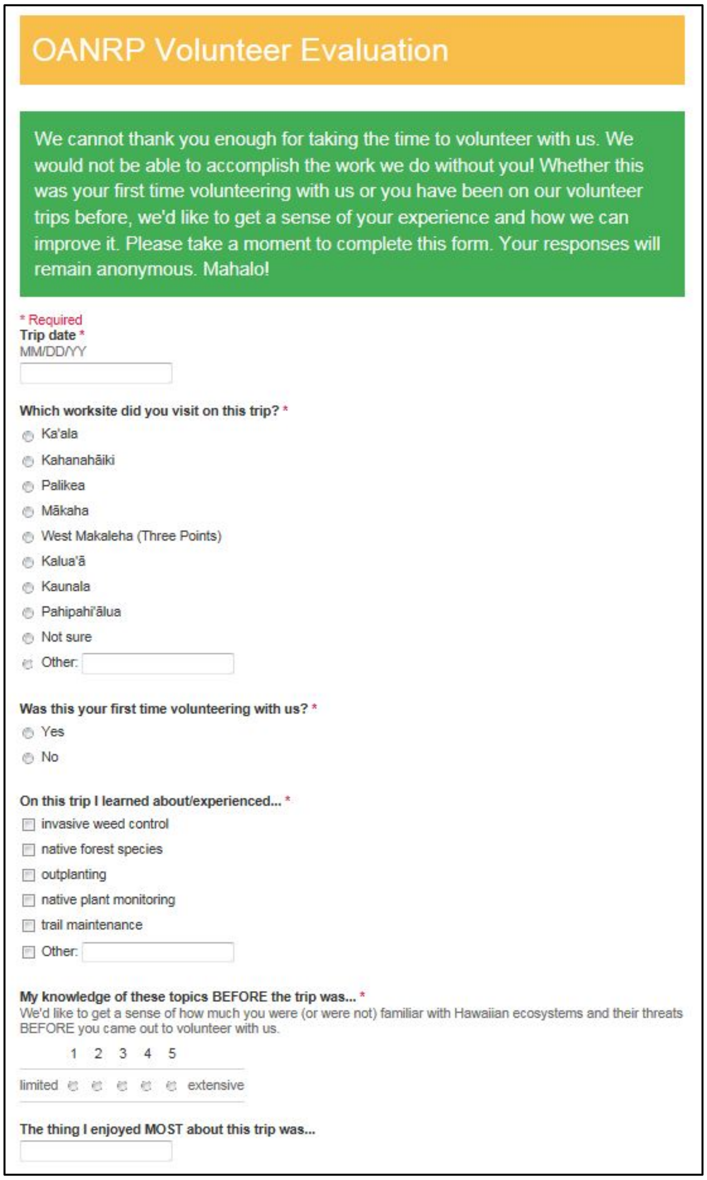
Below: Volunteers from a beginning Olelo Hawaii class at Leeward Community College hike out of Kahanahaiki after volunteering at the chipper site.

Above: Outreach staff and volunteer *Sphagnum palustre* control group.

Left: Volunteers help to control the invasive fern, *Cyclosorus dentatus*, in Kahanahaiki on National Public Lands Day.

VOLUNTEER FEEDBACK:

Below are samples of solicited feedback from volunteers using an online evaluation form (excerpt pictured below) to provide post-service trip comments and suggestions. Feedback is used to help outreach staff refine and improve service trip opportunities. While almost all of the feedback received was positive, one survey participant included a suggestion for improving the program, which is featured in the left column below.



OANRP Volunteer Evaluation

We cannot thank you enough for taking the time to volunteer with us. We would not be able to accomplish the work we do without you! Whether this was your first time volunteering with us or you have been on our volunteer trips before, we'd like to get a sense of your experience and how we can improve it. Please take a moment to complete this form. Your responses will remain anonymous. Mahalo!

* Required

Trip date *
MM/DD/YY

Which worksite did you visit on this trip? *
- Ka'ala
- Kahanahāiki
- Palikea
- Mākaha
- West Makaleha (Three Points)
- Kalua'ā
- Kaunala
- Pahipahi'ālua
- Not sure
- Other:

Was this your first time volunteering with us? *
- Yes
- No

On this trip I learned about/experienced... *
- invasive weed control
- native forest species
- outplanting
- native plant monitoring
- trail maintenance
- Other:

My knowledge of these topics BEFORE the trip was... *
We'd like to get a sense of how much you were (or were not) familiar with Hawaiian ecosystems and their threats BEFORE you came out to volunteer with us.

1 2 3 4 5
limited extensive

The thing I enjoyed MOST about this trip was...

"Depart baseyard earlier (8:00am) and limit waiting time to 15min for those who are late."

"Camp overnight and get more work done."

"[The staff] are fantastic! They are so knowledgeable and patient with all my questions. They balance the perfect amount of work with sight-seeing and set a very comfortable pace for the hike. I also appreciate how safety conscious everyone is."

"The staff was so knowledgeable, patient, and wonderful. Fellow seasoned volunteers were also knowledgeable, so helpful, and patient with us. The overall experience was amazing! We especially enjoyed the thought of helping the protect our ecosystem."

"I'm from another country, but I really appreciate accepting me to join this volunteer work. I really really enjoy this volunteer with my kumu and classmates. This experience was one of great experiences for me in Hawai'i. Mahalo nui loa!!"

"I want to mahalo [the staff] for sharing their wealth of knowledge with us. They are truly Akamai loa, hard-working individuals that represent your organization well. I have found this experience to be life changing, and I keep thinking about coming back to see-hear-touch Kahanahaiki again. The views were incredible, the misty and at times, heavy life-giving rain, refreshing. Mahalo you two for sharing your 'ike, and incredible passion for the restoration of our native forest! I cannot wait to go back and volunteer again!"

"So much to learn. I found this one of the best experiences ever."

"I am a long time volunteer and am still thrilled to visit, learn and do what I can to help restore the natural native eco-system. Thank you folks so very much for the opportunity to do so. Mālama honua me ke aloha pumehana."

INTERNSHIPS AND TEMPORARY STAFF:

Above: Natural Resources Field Technician Brittany Lawton teaches OANRP summer intern how to check and set a snap trap. **Below:** Hawaii Youth Conservation Corps team members learn about the management unit at West Makaleha (lower left) and study the geography of the Waianae mountains (lower right) from the ridge.

EDUCATIONAL MATERIALS:

Informational poster on what to do if nene are seen at Wheeler Army Airfield or Schofield Barracks.

Upper left: Sign denotes an area off limits to training at Schofield Barracks East Range and explains the large pile of sediment. **Right:** Sign identifies the bioretention area at West base and is intended to help prevent introduction of pesticides or rinsate into the area. **Lower left:** Administrative sign identifies the entrance to the OANRP office at East Range.

PUBLIC RELATIONS:

HawaiiReporter
PUBLISHED SINCE 2002
December 11th, 2013
Top Investigative Reporting and Online Journalism Awards
Best business and Government Reporting
DONATE
Log in | Register
HOME NEWS OPINION SPECIAL FEATURES VIDEOS TRENDING POLITICS BUSINESS EDUCATION COMICS

Tuesday, December 10th, 2013 | Posted by Guest Contributor | Print This Article

Army, state partner to protect Oahu's watersheds

SCHOFIELD BARRACKS, Hawaii — The Army and the state came together, here, to transport nearly 200,000 pounds of fencing into the Ko'olau Mountains, as part of an airlift operation to protect Oahu's watersheds, Dec. 5.

Soldiers from the 25th Infantry Division's Combat Aviation Brigade joined resources with the U.S. Army Garrison-Hawaii's natural resources program, known as the Oahu Army Natural Resources Program, and the State of Hawaii's Department of Land and Natural Resources, Natural Area Reserves staff to accomplish the mission.

The material will be used to build a 12-kilometer fence exclosure to protect 1,000 acres of native forest in the summ… and Kamehameha Schools Bishop Estate lands.

The steel fencing was hooked to a Chinook CH-47 helicopte… zones located in a remote area of the Poamoho Section of t…

"The Chinook's capabilities allowed us to haul 17 times more… saving time and money," said Kapua Kawelo, biologist, USA… able to exercise their sling-load skills."

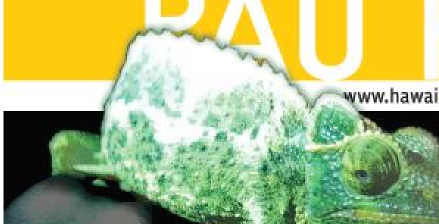
The fencing project is being led by the Department of Land a… Wildlife, with support from the Army and other members of t… majority of the funding for the $1 million project is provided b… additional $300,000 provided by the Army and $250,000 fro…

"This is a critical location for watershed recharge to Oahu's … communities. Protecting priority watersheds from damage ca… 'Rain Follows the Forest' program," said Marigold Zoll, proje… "Fencing is the most feasible way to prevent these animals f… the spread of non-native invasive species."

The project does not restrict access or recreational opportun…

HAWAI'I ARMY WEEKLY
PAU HANA
"When work is finished."
www.hawaiiarmyweekly.com
FRIDAY, March 7, 2014

ALIEN SPECIES



This Jackson Chameleon, captured in the native forest above Schofield Barracks, poses a threat to the endangered kahuli tree snails (Achatinella spp.) found in that same region.

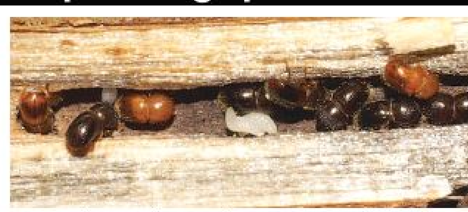
USAG-HI native plantings prevent invasive species

CELESTE VENTRESCA
Directorate of Public Works
U.S. Army Garrison-Hawaii

WHEELER ARMY AIRFIELD — The State of Hawaii is hosting the annual Hawai'i Invasive Species Awareness Week, March 3-9.

While it's only the second year for this event, word on invasive species is spreading — toward, hopefully, less invasive species in the process.

An invasive species is a plant, animal, pathogen or other organism that is non-native (not naturally found in) Hawai'i, and which may cause economic or environmental harm or adversely affect human health



Photos courtesy Oahu Army Natural Resources Program, Directorate of Public Works; U.S. Army Garrison-Hawaii

The invasive black twig borer (Xulosandruscompactus) forms tiny tunnels within trees and crops to lay its eggs, destroying them from within.

What's the big deal with invasive species?

Most of the plants in our current environments — in our schools, our streets or even our own yards — have been imported to Hawai'i from various locations throughout the world. Referred to as "non-native" or "exotic" species, these plants are often very beautiful — one of the reasons people brought them here, and they thrive in the lush climate Hawai'i offers.

Despite their beauty and success, they have not been a part of the natural ecosystem in Hawai'i and therefore could severely throw off the balance of the one we already have, becoming what scientists and natural resource managers call "invasive."

Joby Rohrer, senior Natural Resource manager with the O'ahu Army Natural Resources Program, who is contracted with the U.S. Army Garrison-Hawaii Natural Resources Program, talked about how non-native, invasive ornamental plants impact Hawai'i's natural areas.

"We continue to deal with invasive ornamentals," said Rohrer. "We are still finding coral tree (Erythrina poeppigiana) in new natural areas. … We have been spending a lot of time controlling them in (Schofield Barracks') West Range.

"Planting natives is preferred," added Rohrer. "It makes our job easier (with less weeds to control), so this policy is a great step towards protecting the natural areas we have left."

Coral tree is just one of many examples of non-native ornamental plants that have "escaped" their landscape setting and gone into natural areas.

Invasive species also come in the form of pests that sneak into the islands with other imports. The invasive black twig borer (Xylosandrus compactus) is one such pest, accidentally introduced to O'ahu in the 1960s on a shipment of plants. Now spread throughout the Hawaiian Islands, the black twig borer impacts many crops by creating destructive tunnels within plants to lay their eggs. Coffee farmers, in particular, have felt the economic impact of this pest and have been forced to get rid of many of their crops because of infestations.

The black twig borer is also decimating one of Hawai'i's rarest trees, the endangered mēhamehame (Flueggea neowawraea). The largest member of Hawai'i's forests, mēhamehame can reach heights over 100 feet and can stretch as wide as 10 feet in diameter.

Despite its stature, the mēheamehame is extremely vulnerable to the tunnels created by the black twig borer. USAG-HI's environmental team continues to research methods to control this tiny, lethal enemy that is leading the endangered mēhamehame into extinction.

Planting native on post

Jan. 7, USAG-HI formalized its commitment to environmentally beneficial landscape practices, and Hawai'i Invasive Species Awareness Week marks a perfect opportunity to celebrate that commitment.

The policy, which applies to all Army installations, facilities and work sites in the state, requires the use of native Hawaiian plants in landscaping. The policy also includes a list of recommended native plants for landscaping, which was developed by DPW Environmental staff.

See OANRP, B-3

Get Involved

Hawai'i Invasive Species Awareness week is March 3-9. USAG-HI's Natural Resources Program offers monthly volunteer trips to help control invasive species in the forest. Email outreach@oanrp.com to find out about how to become a volunteer.

Visit http://dlnr.hawaii.gov/hisc/hisaw/ for more details.

Learn more about planting native at www.plantpono.org, a resource produced by the Coordinating Group on Alien Pest Species, the Hawai'i Invasive Species Council and other experts on invasive species issues.

The Honolulu Board of Water Supply's planting guide for O'ahu recommends native plants for various zones on O'ahu based on climate and geography at www.boardofwatersupply.com/cssweb/display.cfm?sid=1360.

Upper left: Hawaii Reporter article on the Army and state partnership to fence native habitat in the Koolau mountains.

Lower right: Hawaii Army Weekly article for Invasive Species Awareness Week, highlighting how the Army has committed to planting native plants to prevent new invasive species from establishing on island.

Upper right: Hawaii Army Weekly article highlights why Ecosystem Restoration Program Manager Jane Beachy was awarded with the "Oahu MVP" this year by the Hawaii Invasive Species Council.

Lower left: Hawaii Army Weekly article shares the news about endangered nene showing up at Wheeler Army Airfield.

OANRP manager named 'Oahu MVP'

SARAH PACHECO
Staff Writer

HONOLULU — A staff member with U.S. Army Garrison-Hawaii's Oahu Army Natural Resources Program (OANRP) took home top honors from the Hawaii Invasive Species Council (HISC), Monday, during the kickoff of the second annual Hawaii Invasive Species Awareness Week at the state Capitol, here.

Jane Beachy, manager of the Ecosystem Restoration Program with OARNP, Directorate of Public Works, USAG-HI, earned the title "Oahu MVP 2014" for her work overseeing the Army's continued control and monitoring efforts to prevent the spread of devil weed on Oahu, expanding roadside weed surveys on military facilities, and displaying dedicated rapid response to new invasive species introduc-

Photo courtesy Oahu Army Natural Resources Program; Directorate of Public Works; U.S. Army Garrison-Hawaii

WAIANAE — Jane Beachy, manager, ERP, OANRP, monitors the endangered Sanicula mariversa plant species along the Ohikilolo Ridge above Makua Valley Military Reservation, here.

Rohrer noted. "Her planning and execution of projects are extremely impressive; she does not miss a detail.

"I have watched Jane grow in her position for more than 10 years," Rohrer added, "and I am looking forward to seeing what she can do in the future."

State bird touches down at Wheeler

KIM WELCH
Oahu Army Natural Resources Program
Directorate of Public Works-Environmental
U.S. Army Garrison-Hawaii

WHEELER ARMY AIRFIELD — Several nene geese (Branta sandvicensis) landed at a construction site east of the runway, here, Aug. 14.

"I was contacted by DPW Engineering branch regarding an observation of geese at a construction site east of the Wheeler airfield," said Kapua Kawelo, biologist, Oahu Army Natural Resources Program, Directorate of Public Works-Environmental Division, U.S. Army Garrison-Hawaii.

Kawelo was surprised at the notification, noting the geese appeared to be Hawaii's endangered state bird.

"The DPW observer reported that the birds were banded," said Kawelo. "I dropped everything, grabbed some binoculars and drove over to Wheeler by 8:45 a.m. They were, in fact, nene — four in total — happily munching on newly planted and well-watered grass."

Given their endangered status and close proximity to the WAAF runway, careful considerations had to be made about the safety of the nene and how the presence of these large birds might affect airfield operations — just 300 meters from where the nene grazed is a hot refueling station on the runway.

The geese were fitted with leg bands, and one had a radio-tracking device. The bands contain individual identification numbers that can usually be read at a distance, without disturbing the birds.

Tyler Miyamoto, project engineer, U.S. Army Corps of Engineers, assisted Kawelo with the nene observations.

A few phone calls later, Honolulu biologists with the U.S. Fish and Wildlife Service (USFWS), one of the lead agencies for implementing the Endangered Species Act, quickly mobilized at WAAF to assess the situation.

One of the USFWS biologists was Annie Marshall, who had placed the bands on two of the nene earlier this year. The leg band information gathered upon last week's sighting was quickly shared with many of the state's leading biologists, including staff at the Department of Land and Natural Resources Division of Forestry and Wildlife, and Pacific Rim Conservation.

The combined knowledge revealed some fascinating facts about this feathered foursome.

Of the 2,500 nene statewide, 1,400-1,500 are on Kauai, 416 on Maui, 77 on Molokai and 543 on Hawaii Island. The four that showed up at WAAF are the only known nene geese on Oahu. Coming from Hawaii Island, two nene touched down on Oahu for the first time in years this past January at the James Campbell National Wildlife Refuge, located in Kahuku on the North Shore. The couple nested in February and hatched three eggs in March. Two of the goslings survived and were banded by Marshall May 15 and shortly afterwards were observed flying around the refuge.

Until recently, this nene family seemed content to stay on the refuge. However, this time of year is flocking season, when nene typically fly greater distances in search of other food and other nene. Two weeks prior to their arrival at WAAF, sightings of this same nene family were reported by a Mililani golf course.

Nene are critically endangered and threatened by the presence of introduced predators and loss of habitat.

(Editor's note: Welch is an environmental outreach contractor with OANRP.)

Photos courtesy Oahu Army Natural Resourses Program, Directorate of Public Works-Environmental, U.S. Army Garrison-Hawaii

A family of endangered nene geese lands at WAAF, Aug. 14, to sample newly planted grass in a construction area adjacent to the runway and an active refueling station.

Biologists from the USFWS and USAG-HI DPW-Environmental Division gather, Aug. 14, to document several nene visiting a construction site on the airfield. Pictured (from left) are Lasha-Lynn Salbosa, USFWS; Kapua Kawelo, natural resources, DPW Environmental Division, USAG-HI; Annie Marshall and Michelle Bogardus, both with USFWS; and Larry Hirai, chief, DPW Environmental Division, USAG-HI.

Nene sightings

If you think you've spotted Hawaii's state bird on post, take the following actions:

- Call Oahu Army Natural Resources Program at 655-919 and the USFWS office at 792-9400.
- Take a photo, if possible.
- Note the time of sighting.
- Give the location of sighting (address, landmarks).
- Provide the number of nene.
- Describe their behavior.
- Keep pets indoors, as required by Army Hawaii Family Housing.
- Keep our nene wild; do not approach them or feed them!

Left/below: Public Works Digest article highlights the work OANRP is doing to improve rodent control throughout management units.

OANRP Investigates the Utility of Automatic Rat Traps

by Katie Franklin

The O'ahu Army Natural Resources Program (OANRP) has managed more than 60 endangered species since 1995 across the island of O'ahu to include plants, invertebrates and one forest bird species. Because invasive rats (Rattus spp.) are known predators of many Hawaiian flora and fauna, a rodent control program plays a critical role in the stabilization and recovery of many of these endangered species.

The haha (Cyanea superba subsp. superba) is one species that has shown particular vulnerability to rat predation. In the late 1990s, the species was facing extinction with only six C. superba plants in the Wai'anae Mountains. The OANRP installed rat bait stations and traps around the last remaining wild plants in order to protect their invaluable fruit. Thankfully, viable seeds were collected before the last plants died. Because of the effort, there are now hundreds of C. superba plants in the forests of the Wai'anae Mountains.

Recently, the OANRP acquired a new tool that may prove to be an important component for long-term rat control efforts: automatic rat traps. These automatic traps are designed to kill rats and stoats (a New Zealand pest) and are powered by compressed carbon dioxide (CO2). Goodnature® Ltd., a New Zealand-based company, invented and designed the traps specifically for conservation use. Unlike single-kill snap traps, which can often be found unsprung with bait missing or sprung with no animal, the automatic traps remain set and baited. The traps can reset up to 24 times before the CO2 canister needs to be replaced and are a humane alternative to other rat control methods.

Acronyms and Abbreviations	
CO_2	Carbon Dioxide
KNHP	Kalaupapa National Historical Park
OANRP	O'ahu Army Natural Resources Program

The haha, or Cyanea superba subsp. superba, is an endangered species managed by the O'ahu Army Natural Resources Program on Army Training lands. Non-native rats feed on the haha fruit (pictured here), threatening the survival of this fragile Hawaiian forest plant.

The OANRP began putting this new rat control technology to the test in October of 2012, when the staff installed a small grid of 45 automatic traps around an outplanting site of C. superba in Pahole Natural Area Reserve in the northern Wai'anae Mountains. The objective of the project was to systematically collect data regarding trap performance, rat activity levels and ecological response to the traps. This data was compared to two neighboring areas: Kahanahaiki, where 464 traditional Victor snap traps were set in a grid across 26 hectares; and Kapuna, a control area with no rat control measures in place. Data was collected until the project concluded in August 2013.

Analysis of the data indicated that the automatic traps were successful at reducing local rat abundances at Pahole. The automatic traps eliminated 1.5 times more rats per hectare and were maintained with roughly 35 percent of labor required for the Kahanahaiki snap trap grid.

The automatic traps appeared to give "more bang for the buck" than snap traps.

Finding bait that lasts as long as possible is crucial to maximizing the effectiveness of both traditional snap traps and automatic traps. The bait is contained in a compartment at the top of the trap, behind the trigger, and is virtually inaccessible to the rats.

Even with the high cost per trap ($123 each), the OANRP is optimistic that the automatic traps could reduce long-term costs for maintenance of rat control grids and foresees their greatest utility in remote areas that are typically accessed by helicopter. Rats are a difficult pest to control as they are abundant, very prolific and highly adaptable to their environment. Using a combination of methods, adaptive management strategies and defining management goals (i.e., localized control around vulnerable species or ecosystem-wide protection) will lead to the best strategy for each rat control site.

Ultimately, decisions regarding future rat control strategies must be made by ➤

n Infrastructure

ms and Abbreviations	
s	Army Commands
M	Office of the Assistant Chief of Staff, Installation Management

tions participate in these programs age Army timber and agriculture ing out-leases. These programs are d on one-year cycles requiring a y to predict proceeds for the fiscal d manage expenses during the execution. Annual funding for Commands (ACOMs) and support ns through the U.S. Army Corps ineers is provided by the Office of sistant Chief of Staff, Installation ement (OACSIM). The U.S. Environmental Command provides al assistance to the ACOMs ancial tracking support for these ms to OACSIM.

ing the last five years the Army y and Agricultural/Grazing vation Reimbursable Programs eraged approximately $20 million in revenue that is used to fund resource management on Army tions.

ddition to supporting the local and l logging industry, 40 percent of the ome that a participating installation from the sale of forest products timber, firewood, and pine straw nated for schools and roads in the counties where the installation is located, with an average of $1.6 million dollars paid over the past five years for these purposes.

More information on how the Army's Conservation Reimbursable Programs can benefit your installation can be found at http://aec.army.mil/Services/Conserve/ConservationReimbursablePrograms.aspx.

POC is Matt Mattox, 210 466-1767, matthew.w.mattox2.civ@mail.mil

Matt Mattox works in the Conservation Reimbursable and Fee Collection Programs at the U.S. Army Environmental Command.

(continued from previous page)

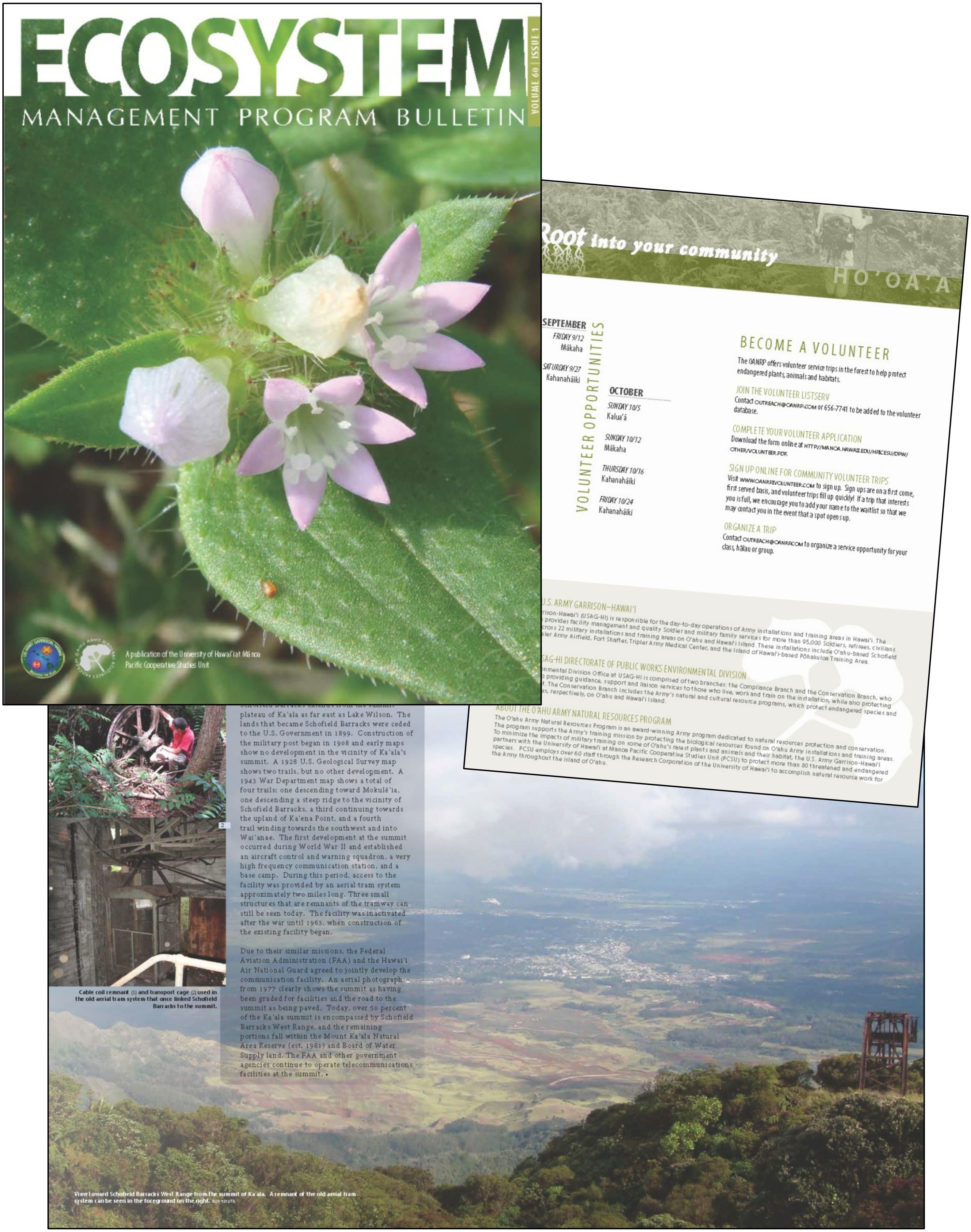
weighing options and assessing the costs and benefits of using each type of trap. While the data in Hawai'i is not yet ready for such a cost-benefit analysis, the C. superba in Pahole will continue to benefit from reduced rat predation, thanks to this new rat control technology.

This project was partially funded by Kalaupapa National Historical Park (KNHP) in order to share traps and information. The conclusion of the project culminated in a visit to KNHP in September 2013 to share the results and provide recommendations for use at their field sites.

POC is Kimberly M. Welch, (808) 656-7741, kmwelch@hawaii.edu.

Katie Franklin, is a small vertebrate pest stabilization specialist with the O'ahu Army Natural Resources Program in the Directorate of Public Works at the U.S. Army Garrison, Hawaii. Kimberly Welch is an environmental outreach specialist with the O'ahu Army Natural Resources Program in the Directorate of Public Works at the U.S. Army Garrison, Hawaii.

Cover and excerpts from the newly redesigned **Ecosystem Management Program Bulletin**.



ECOSYSTEM
MANAGEMENT PROGRAM BULLETIN
VOLUME 60 | ISSUE 1

A publication of the University of Hawai'i at Mānoa
Pacific Cooperative Studies Unit

Root into your community
HO'OA'A

VOLUNTEER OPPORTUNITIES

SEPTEMBER
FRIDAY 9/12
Mākaha
SATURDAY 9/27
Kahanahāiki

OCTOBER
SUNDAY 10/5
Kalua'ā
SUNDAY 10/12
Mākaha
THURSDAY 10/16
Kahanahāiki
FRIDAY 10/24
Kahanahāiki

BECOME A VOLUNTEER

The OANRP offers volunteer service trips in the forest to help protect endangered plants, animals and habitats.

JOIN THE VOLUNTEER LISTSERV
Contact OUTREACH@OANRP.COM or 656-7741 to be added to the volunteer database.

COMPLETE YOUR VOLUNTEER APPLICATION
Download the form online at HTTP://MANOA.HAWAII.EDU/HPICESU/DPW/OTHER/VOLUNTEER.PDF.

SIGN UP ONLINE FOR COMMUNITY VOLUNTEER TRIPS
Visit WWW.OANRPVOLUNTEER.COM to sign up. Sign ups are on a first come, first served basis, and volunteer trips fill up quickly! If a trip that interests you is full, we encourage you to add your name to the waitlist so that we may contact you in the event that a spot opens up.

ORGANIZE A TRIP
Contact OUTREACH@OANRP.COM to organize a service opportunity for your class, hālau or group.

U.S. ARMY GARRISON–HAWAI'I
...rison-Hawai'i (USAG-HI) is responsible for the day-to-day operations of Army installations and training areas in Hawai'i. The ... provides facility management and quality Soldier and military family services for more than 95,000 Soldiers, retirees, civilians ...cross 22 military installations and training areas on O'ahu and Hawai'i Island. These installations include O'ahu-based Schofield ...eler Army Airfield, Fort Shafter, Tripler Army Medical Center, and the Island of Hawai'i-based Pōhakuloa Training Area.

...SAG-HI DIRECTORATE OF PUBLIC WORKS ENVIRONMENTAL DIVISION
...onmental Division Office at USAG-HI is comprised of two branches: the Compliance Branch and the Conservation Branch, who ...o providing guidance, support and liaison services to those who live, work and train on the installation, while also protecting ...t. The Conservation Branch includes the Army's natural and cultural resource programs, which protect endangered species and ...es, respectively, on O'ahu and Hawai'i Island.

ABOUT THE O'AHU ARMY NATURAL RESOURCES PROGRAM
The O'ahu Army Natural Resources Program is an award-winning Army program dedicated to natural resources protection and conservation. The program supports the Army's training mission by protecting the biological resources found on O'ahu Army installations and training areas. To minimize the impacts of military training on some of O'ahu's rarest plants and animals and their habitat, the U.S. Army Garrison-Hawai'i partners with the University of Hawai'i at Manoa Pacific Cooperative Studies Unit (PCSU) to protect more than 80 threatened and endangered species. PCSU employs over 60 staff through the Research Corporation of the University of Hawai'i to accomplish natural resource work for the Army throughout the island of O'ahu.

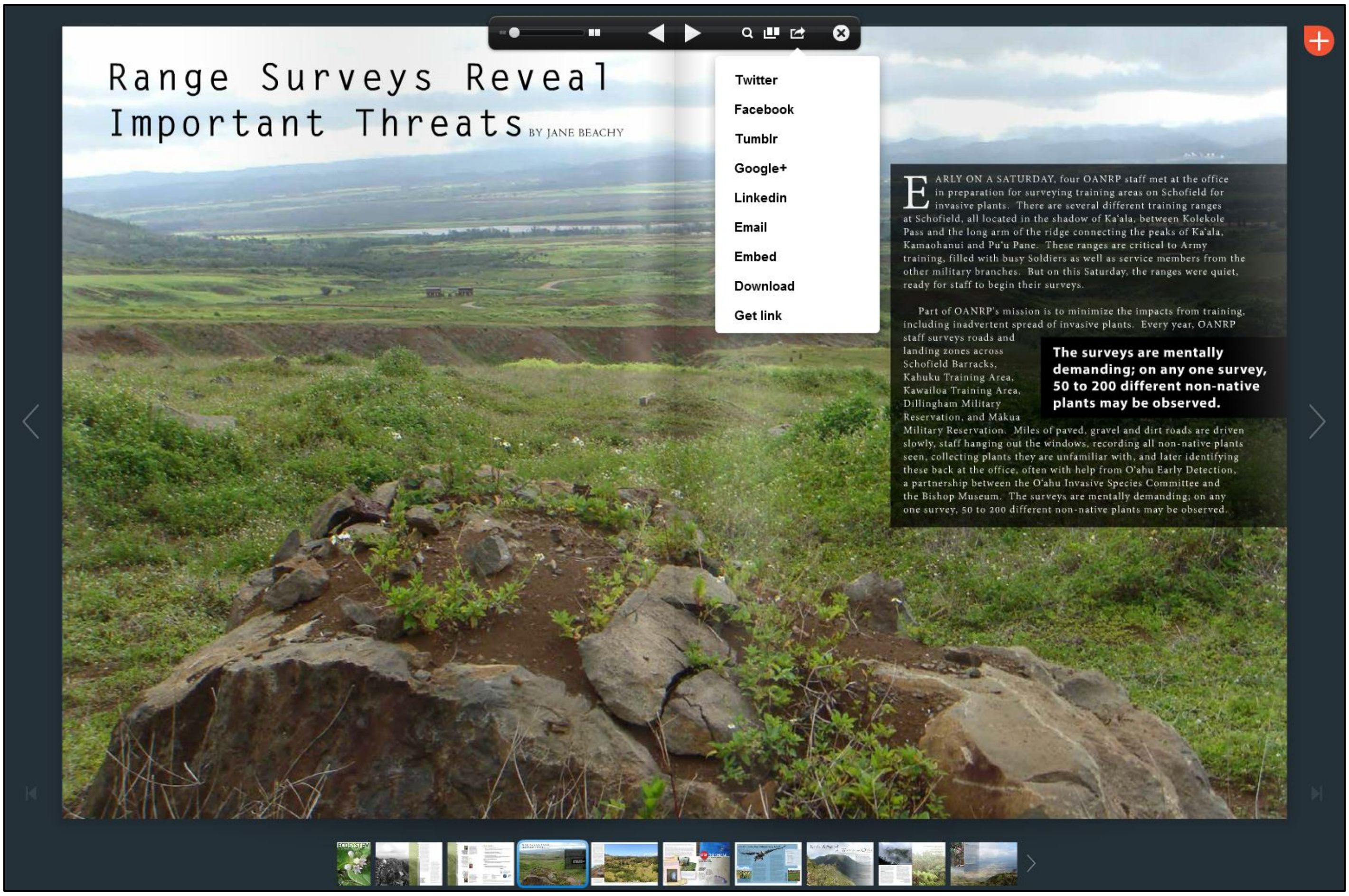
...plateau of Ka'ala as far east as Lake Wilson. The lands that became Schofield Barracks were ceded to the U.S. Government in 1899. Construction of the military post began in 1908 and early maps show no development in the vicinity of Ka'ala's summit. A 1928 U.S. Geological Survey map shows two trails, but no other development. A 1943 War Department map shows a total of four trails: one descending toward Mokulē'ia, one descending a steep ridge to the vicinity of Schofield Barracks, a third continuing towards the upland of Ka'ena Point, and a fourth trail winding towards the southwest and into Wai'anae. The first development at the summit occurred during World War II and established an aircraft control and warning squadron, a very high frequency communication station, and a base camp. During this period, access to the facility was provided by an aerial tram system approximately two miles long. Three small structures that are remnants of the tramway can still be seen today. The facility was inactivated after the war until 1963, when construction of the existing facility began.

Due to their similar missions, the Federal Aviation Administration (FAA) and the Hawai'i Air National Guard agreed to jointly develop the communication facility. An aerial photograph from 1977 clearly shows the summit as having been graded for facilities and the road to the summit as being paved. Today, over 50 percent of the Ka'ala summit is encompassed by Schofield Barracks West Range, and the remaining portions fall within the Mount Ka'ala Natural Area Reserve (est. 1981) and Board of Water Supply land. The FAA and other government agencies continue to operate telecommunications facilities at the summit. •

Cable coil remnant (1) and transport cage (2) used in the old aerial tram system that once linked Schofield Barracks to the summit.

View toward Schofield Barracks West Range from the summit of Ka'ala. A remnant of the old aerial tram system can be seen in the foreground on the right. ROY KIKUTA

In addition to posting the bulletin online at http://manoa.hawaii.edu/ hpicesu/dpw_emb.htm, the bulletin is now available online through ISSUU at www.issuu.com/oanrp. **Below:** A sample of the ISSUU interface featuring the latest bulletin.



O'AHU INVASIVE SPECIES COMMITTEE

Control and Eradication of the Invasive Plant Species *Chromolaena Odorata*

October 1, 2013—September 30, 2014

Mature devil weed (*Chromolaena odorata*) in the Kahuku Training Area

Summary of Project Objectives

The O‘ahu Invasive Species Committee (OISC) was founded by a concerned group of citizens and land managers volunteering their weekends to control fountain grass and miconia on O‘ahu. Since then, OISC has grown into a partnership of federal, state and municipal agencies with a full-time field crew that works across all land ownerships.

OISC now systematically controls the island’s most damaging forest invaders, employs 17 people and educates the public about forest health and invasive species. OISC’s partners include the Hawai‘i Department of Land and Natural Resources/Division of Forestry and Wildlife, Honolulu Board of Water Supply, Hawai‘i Department of Transportation, Hawai‘i Department of Agriculture, Honolulu Botanical Gardens, and other state and federal agencies. The O‘ahu Army Natural Resources Program (OANRP) is a founding partner of OISC and one of OISC’s most supportive partners throughout its ten-year history. OISC is a project of the Pacific Cooperative Studies Unit of the University of Hawai‘i at Mānoa.

Mature devil weed plant

During the reporting period, OISC dedicated an average of 173 field hours a month to the detection and control of *Chromolaena odorata* at Kahuku Training Area (KTA). Close to 2,200 plants were treated during OISC’s surveys of subunits 3, 4, 7 and 8.

The 2014 management strategy was to prioritize surveying all hotspots to count plants and outline the area with flagging prior to aerial or power-sprayer control operations conducted by OANRP staff. The second priority was to survey once through all assigned subunits (3, 4, 7, 8), treating all plants encountered except hotspots. A hotspot is defined by five or more mature plants. The third priority was to survey and treat the adjacent private lands near the subunit 8 area. The last priority was to survey and map trails within the 800-meter buffer to delimit the extent of the infestation at KTA. These priorities were reevaluated after six months because OANRP was able to hire on a temporary field crew to address delimiting the population by surveying trails and roadsides within the 800m buffer and beyond.

OISC conducted monthly management camping trips to reduce the time spent commuting to the work site in order to increase logistics efficiency. OISC works with OANRP to acquire access using KTA’s range control protocols. OANRP staff observed that *C. odorata* tends to set seed between March and April so management actions are scheduled to minimize the chance that control work will inadvertently spread this species.

OISC also conducts survey and control efforts outside the property boundaries of the Kahuku training area. The OISC outreach specialist obtains permission from private landowners on the northwestern side of KTA to survey and control populations on their properties. These efforts complement work efforts on KTA to prevent the spread of *C. odorata* to other locations on the island. Non-OANRP funds are supporting this work.

PROJECT ACCOMPLISHMENTS: October 01, 2013 — September 30, 2014

Chromolaena odorata, also known as devil weed, is a state-listed noxious weed, toxic to other plants, livestock and humans, possesses the ability to root vegetatively, produces up to 800,000 wind-dispersed seeds a year and is a fire promoting species that forms dense, monotypic stands of vegetation. The OANRP discovered *Chromolaena odorata* at the Kahuku Training Area (KTA) on the north shore of Oahu in January 2011. The Biological Opinion for military activities on O‘ahu requires the Army to respond immediately to incipient weeds brought in via training operations. What is currently known about *C. odorata* supports the assumptions that the center of the population is the Kahuku Training Area and that *C. odorata* was introduced to KTA because of military activities:

> Between 2006 and 2009, botanical surveys of all publicly accessible roads on O‘ahu were conducted by OISC’s O‘ahu Early Detection program. *C. odorata* was not found during these surveys. This means that it is unlikely *C. odorata* was introduced somewhere else and dispersed onto KTA. *C. odorata* is a major pest on the island of Guam, and units from Hawai‘i sometimes train in Guam. The seeds are wind dispersed and readily attach to clothing. One plant can produce approximately 800,000 seeds a year. Given these factors, it is highly likely the pathway of introduction was military activities.

OISC conducts survey and treatment for devil weed in the Kahuku Training Area in partnership with the Hawai‘i Department of Agriculture and the O‘ahu Army Natural Resources Program. The OISC field crew conducted delimiting surveys to determine population distribution and density in the Kahuku region. The management trips averaged 173 fieldwork hours per month. During the reporting period, OISC staff dedicated 2,031 personnel hours, of which 1,818 were field personnel hours. OISC surveyed 1,248 acres and treated 294 mature and 1,902 immature plants for a total of 2,196 plants. It should be noted that these control numbers are not a reflection on the total amount of plants detected or that actually exist within the subunits OISC manages, just the total that were treated by OISC staff.

From L to R: The field crew strategizing the day’s survey; basal-bark treatment of a devil weed plant; preparation for a cut-stump herbicide treatment application.

CHALLENGES

There were a few challenges noted during the year of treatment. The primary challenge to a successful eradication in the KTA region is the logistics of spraying the infestation area. Logistical challenges include the actual acreage needed to spray, lack of access to a water supply, steep, uneven terrain, and multiple equipment failures. KTA is extremely hot and dry in the summer months, which limits productivity and may be a potential safety hazard. OISC will reduce its control work during the hottest months of the year. While conducting ground surveys, the invasive vegetation, like small vines in the Passifloraceae family, create impenetrable ground cover and significantly impede survey progress. In addition, there are several large populations of devil weed growing within inaccessible areas, making them nearly impossible to treat plants. Two of these hotspot locations are known as Kaunala cliffs and "the View." Aerial control methods must be incorporated on a regular basis if eradication is to be achieved.

Steep terrain encountered during a routine survey in KTA

Arid, full sun areas are common within the subunits OISC manages, which increase the risk of heat related illnesses during the hot summer months

The ideal management strategy for devil weed in KTA would be:

1. OISC staff survey subunits 3, 4, 7 and 8 two to three times a year;
2. Treat plants encountered, except large hotspots;
3. Map & flag all hotspot boundaries that need power-sprayer, UTV or aerial control management actions;
4. Share data with OANRP staff who follow up on a monthly basis to treat all hotspots;
5. Delimit population within KTA and adjacent private lands;
6. Enact a large community outreach effort to educate nearby residents and users of KTA of the potential impacts this specie may have on Oahu and the state as well as what management activities are occurring. This would help facilitate support for more through surveys on adjacent lands.

Table 1: OISC *Chromolaena odorata* Work Effort Summary
October 1, 2013 - September 30, 2014

Location	Acres Surveyed	Mature Plants Treated	Immature Plants Treated	Total Plants Treated	Effort (Hours)
KTA	1248	294	1902	2196	1647
Private Property	1.73	27	72	99	84
TOTAL	**1249.73**	**321**	**1974**	**2295**	**1731**

Figure 1: OISC *Chromolaena odorata* Work Effort in Kahuku Training Area October 1, 2013 - September 30, 2014

Map removed to protect rare resources

DATA MANAGEMENT

OISC tracks its survey and control efforts in Microsoft Access and ArcGIS databases. It uses this data to plan field operations and report on progress. The OISC field crew completes field forms daily and is trained in the use of ArcPad and ArcGIS programs and the OISC Access database. The OISC Operations Planner and Data Analyst compiles and analyzes data collected in the field to assess survey buffer areas, work effort and if target work goals are being met.

PUBLIC EDUCATION & OUTREACH

OISC's outreach specialist hosted an informational booth at Agriculture Awareness Day and the Hawaii Invasive Species Awareness week events at the State Capital, at the Bishop Museum's Science Alive event and the Landscape Industry Council of Hawaii conference highlighting the potential impact of *C. odorata* and other invasive species. She also wrote an article regarding the status update for devil weed in Hawaii for the international newsletter, *Chromolaena odorata Newsletter*.

OTHER

In January 2013, botanists confirmed a satellite population of devil weed in Kahana Valley. Since then, OISC obtained funding from the Watershed Partnership Program Grants to conduct delimiting surveys in this region. As of September 30, the majority of the 200m initial survey buffer had been surveyed and 1,681 plants controlled. OISC will continue to delimit and control this population in the upcoming year.

Table 2: OISC *Chromolaena odorata* Work Effort Summary in Kahana Valley October 1, 2013 - September 30, 2014

Location	Acres Surveyed	Mature Plants Treated	Immature Plants Treated	Total Plants Treated	Effort (Hours)
Kahana Valley	35.7	37	1644	1681	210

COMPLIANCE

OISC is a project of the Pacific Cooperative Studies Unit through the Research Corporation of the University of Hawaii, an equal opportunity employer. OISC utilizes RCUH and PCSU standard operating procedures and employee guidelines. OISC employees are trained in wilderness first aid, off-trail hiking safety and pesticide safety.

Appendix 1-3-2

VEGETATION MONITORING AT PALIKEA MANAGEMENT UNIT, 2014

INTRODUCTION

Vegetation monitoring was conducted at Palikea Management Unit (MU) in 2014 in association with MIP/OIP requirements for long term monitoring of vegetation composition and change over time (OANRP 2008a). The primary objective of MU monitoring is to assess if the percent cover of non-native plant species is less than 50% across the MU, or is decreasing towards that threshold requirement. The secondary objective is to assess if the percent cover of native plant species is greater than 50% across the MU, or is increasing towards that threshold recommendation. Palikea MU vegetation monitoring occurs on a three-year interval, and took place twice previously.

METHODS

Fifty-one 5 x 10 meter (m) plots were monitored along five transects in 2014 (Figure 1). Transects were spaced 100 m apart, and plots were located every 20 m along transects. These same plots were also monitored in 2008 (OANRP 2008b) and 2011 (OANRP 2011). Additional plots were monitored in 2008 and 2011, but were not monitored in 2014 due to a lack of sampling independence. Understory [occurring from 0 – 2 m above ground level (AGL), including low branches from canopy species] and canopy (occurring greater than 2 m AGL, including epiphytes) vegetation was recorded by percent cover for all non-native and native species present, summary percent cover by vegetation type (shrub, fern, grass/sedge) in the understory, overall summary percent cover of non-native and native vegetation in the understory and canopy, as well as bare ground. Understory recruitment (defined as having a maximum height of less than 2 m AGL) data for tree species was recorded in 2014, but not documented previously. Monitoring results were compared with data from 2008 and 2011. Canopy percent cover results for 2008 were based on different measurement parameters, and were not comparable with data from 2011 and 2014. *Youngia japonica* and *Lepisorus thunbergianus* were not recorded consistently in 2008, and data for these species from that year were not included in the analysis. Based on MIP recommendations, $\alpha = 0.05$ was used for significance determinations. Additional methodology information is detailed in Monitoring Protocol 1.2.1 (OANRP 2008a).

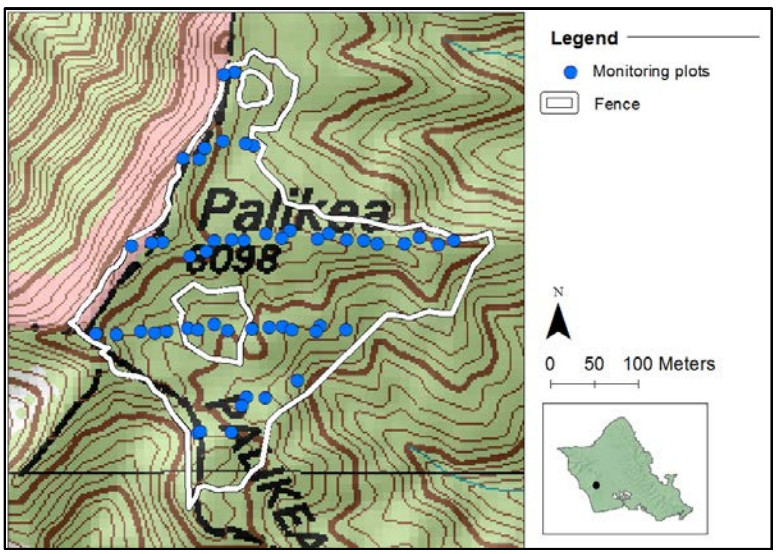


Figure 1. Palikea MU vegetation monitoring plot locations, 2014.

RESULTS

Understory and canopy cover

Management objectives of having < 50% non-native understory and canopy and > 50% native understory and canopy cover were only met with respect to the non-native understory (Table 1). There were a few small but significant changes in percent cover of vegetation and bare ground. The median bare ground cover decreased from 25% in 2008 and 2011 to 15% in 2014 (Friedman test: S = 6.07, p = 0.048[1]) (Figure 2). However, caution should be applied in interpreting the results of the change in bare ground, as the method for this measurement is not as clearly defined as that of the vegetation measurements, and as such is less repeatable. The median native canopy cover increased from 15% in 2011 to 25% in 2014 (Wilcoxon signed-rank test: W = 361.0, p = 0.027) (Figure 3). While the median non-native canopy cover remained at 55% from 2011 to 2014, their relative distributions shifted towards a marginally significant increase in cover (Wilcoxon signed-rank test: W = 457.5, p = 0.051) (Figure 4).

Table 1. Percent cover of native and non-native vegetation in the canopy and understory at Palikea from 2008 to 2014. Median values are represented (n=51). P-values obtained from Friedman test (for understory data) and Wilcoxon signed-rank test (for canopy data). Statistically significant values are in boldface. Categories specifically addressed in management objectives are shaded. Canopy percent cover results for 2008 were based on different measurement parameters, and were not comparable with data from 2011 and 2014.

	2008	2011	2014	p	Management objective currently met?
Understory					
Native shrubs	7.5	7.5	15	0.408	
Native ferns	25	35	25	0.111	
Native grasses	0	0	0	0.957	
Total native understory	35	45	35	0.170	No
Non-native shrubs	15	25	15	0.486	
Non-native ferns	0.5	0.5	0.5	0.373	
Non-native grasses	0.5	0.5	0.5	0.255	
Total non-native understory	35	35	35	0.222	Yes
Bare ground	25	25	15	**0.048**	
Canopy					
Native canopy	NA	15	25	**0.027**	No
Non-native canopy	NA	55	55	0.051	No
Total native and non-native canopy	NA	85	95	0.271	

[1]**Notes for readers less familiar with statistics:** P-values indicate to what extent the results support a hypothesis (the lower the number, the stronger the support for the hypothesis). In this study, the hypotheses would be that there are changes occurring in percent cover, frequency, and species richness. In this study, p-values less than 0.05 were significant. P-values only slightly greater than 0.05 were denoted as marginally significant, meaning that while not technically significant, it is worthy of note, e.g., perhaps a change is occurring, but at a gradual rate that may only become apparent in future monitoring, should that pattern continue. In figures, significant differences between years are indicated by differing letter notations.

Locations of low to high percent cover of native and non-native understory and canopy in 2014 were patchily distributed across the MU (Figure 5), as were locations where cover changes occurred (Figure 6).

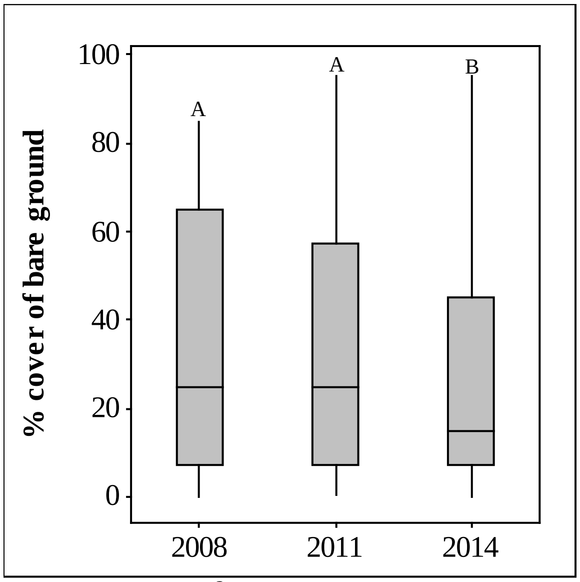


Figure 2: Boxplot[2] of percent cover of bare ground from 2008 to 2014.

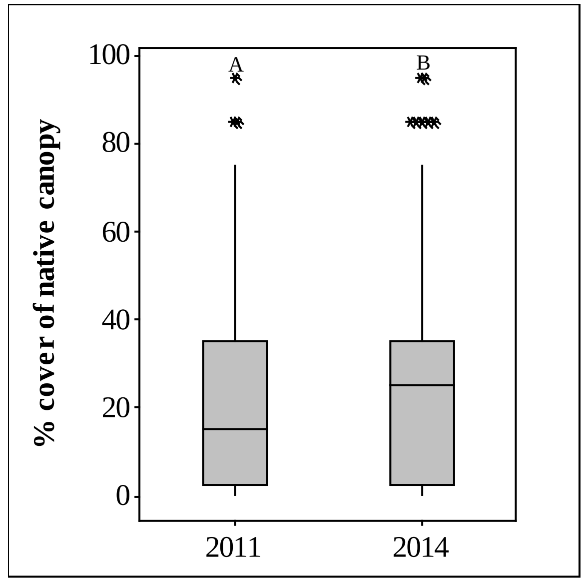


Figure 3: Boxplot of native canopy percent cover in the years 2011 and 2014.

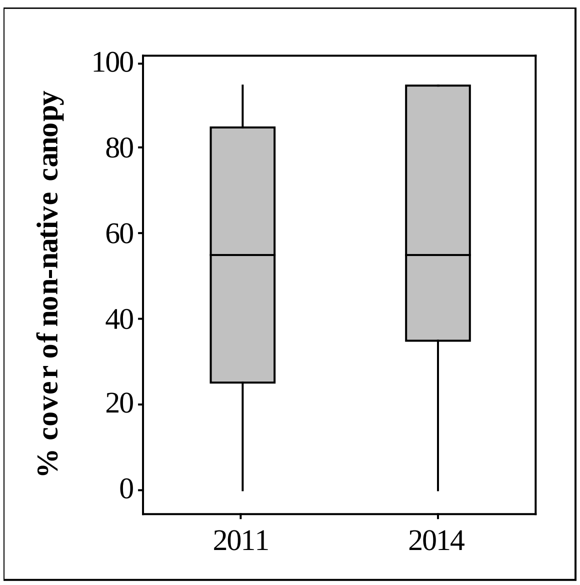


Figure 4: Boxplot of non-native canopy percent cover in the years 2011 and 2014.

[2]**Additional notes for readers less familiar with statistics**: Boxplots show the range of data values for a given variable. The shaded boxes depict 75% of the data values, and the horizontal line inside the shaded box represents the median value. Asterisks represent unusually high or low values, while the lines extending above and below the shaded box depict the range in values for all remaining data.

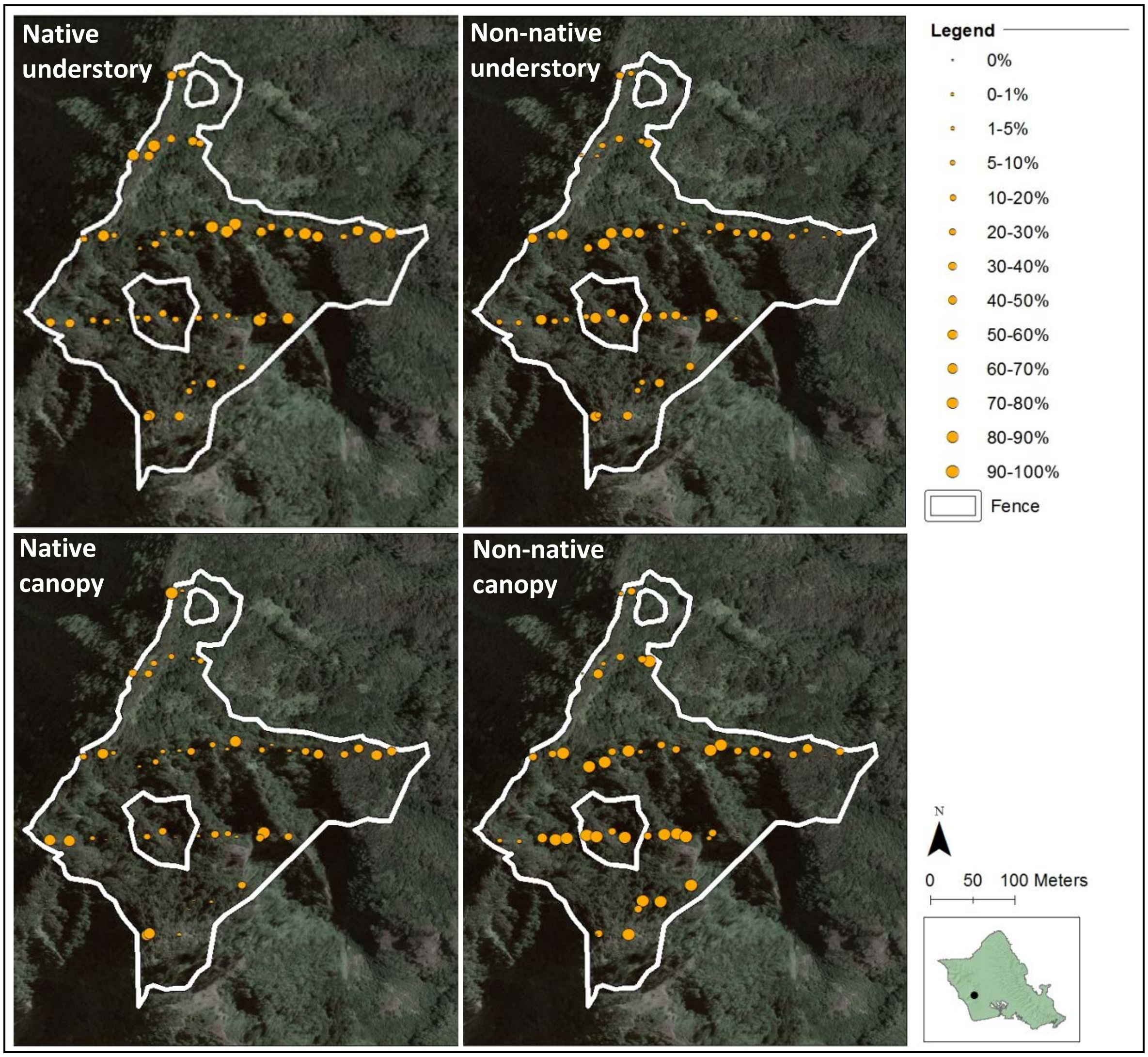


Figure 5. Locations of low to high percent cover of native and non-native understory and canopy vegetation among monitored plots at Palikea in 2014. Larger circles denote higher percent cover, while smaller circles represent lower percent cover.

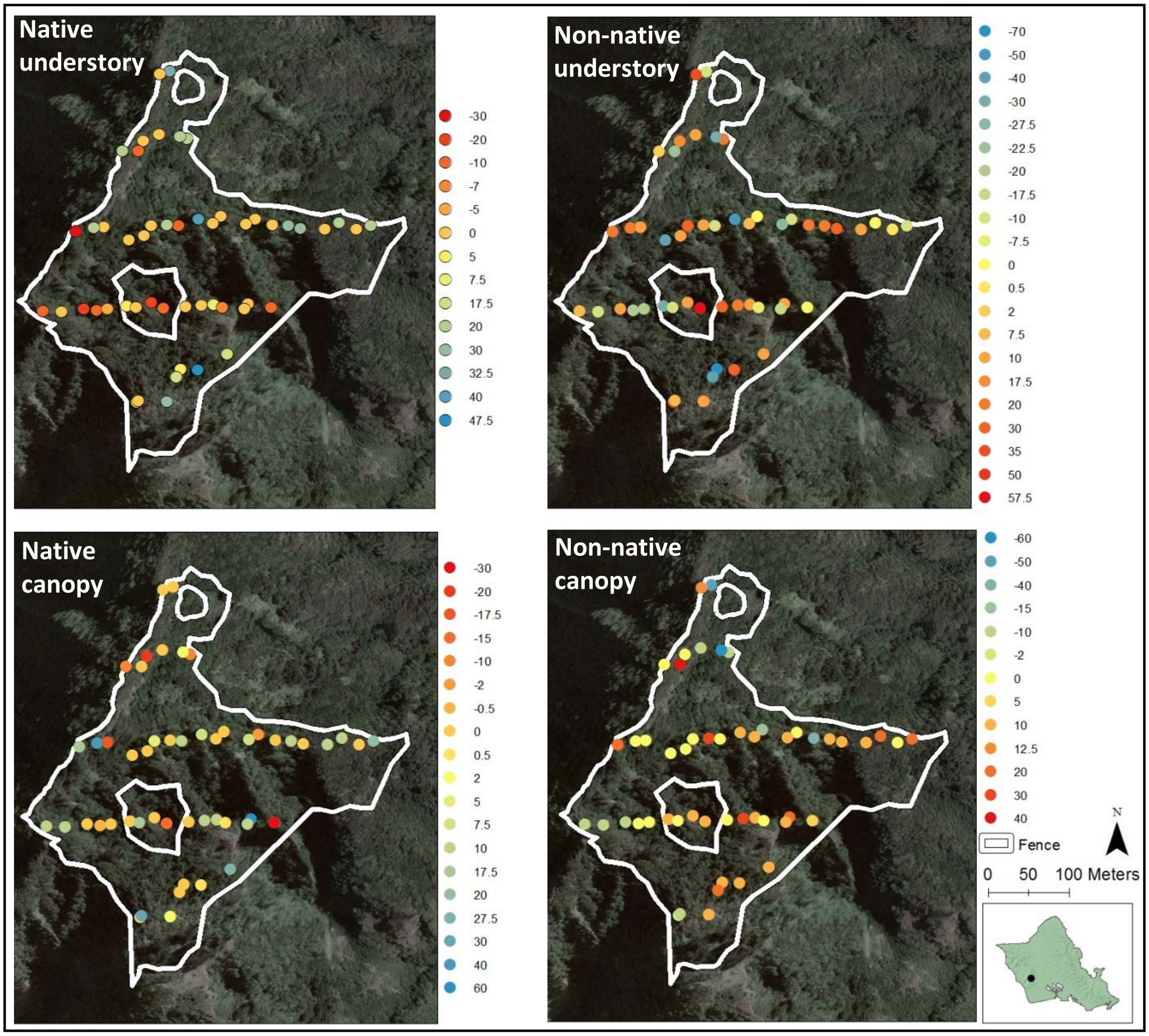


Figure 6. Locations of change in native and non-native percent cover for the understory (from 2008 to 2014) and canopy (from 2011 to 2014) vegetation in monitored plots at Palikea. Color gradients are inverted for native and non-native vegetation, such that blue indicates beneficial change, red depicts worsening conditions. Cover change of 0 indicates there was no change in percent cover.

Species richness

During the 2014 monitoring, 130 species were recorded in the understory (74% native species), and 45 species were identified in the canopy (78% native species). All species present in the canopy (defined as vegetation occurring from > 2 m AGL) were also represented in the understory (defined as occurring from 0 – 2 m AGL, including low branches of canopy species). Locations of high and low species richness for the native and non-native understory and canopy were patchily distributed across the MU (Figure 7). Native species richness among plots differed in the understory between the years monitored (Friedman's test: $S = 10.09$; $p = 0.006$), with a small increase in median values from 12 to 14 species per plot between the years 2008 and 2014 (Wilcoxon signed-rank test: $W = 797$; $p = 0.002$) (Table 2). No detectable change occurred in species richness among plots in the non-native understory, non-native canopy, or native canopy. Seven species found in 2014 were not observed previously, while 26 species (20 of which are native taxa) recorded in 2008 and/or 2011 were not observed in 2014 (Table 3).

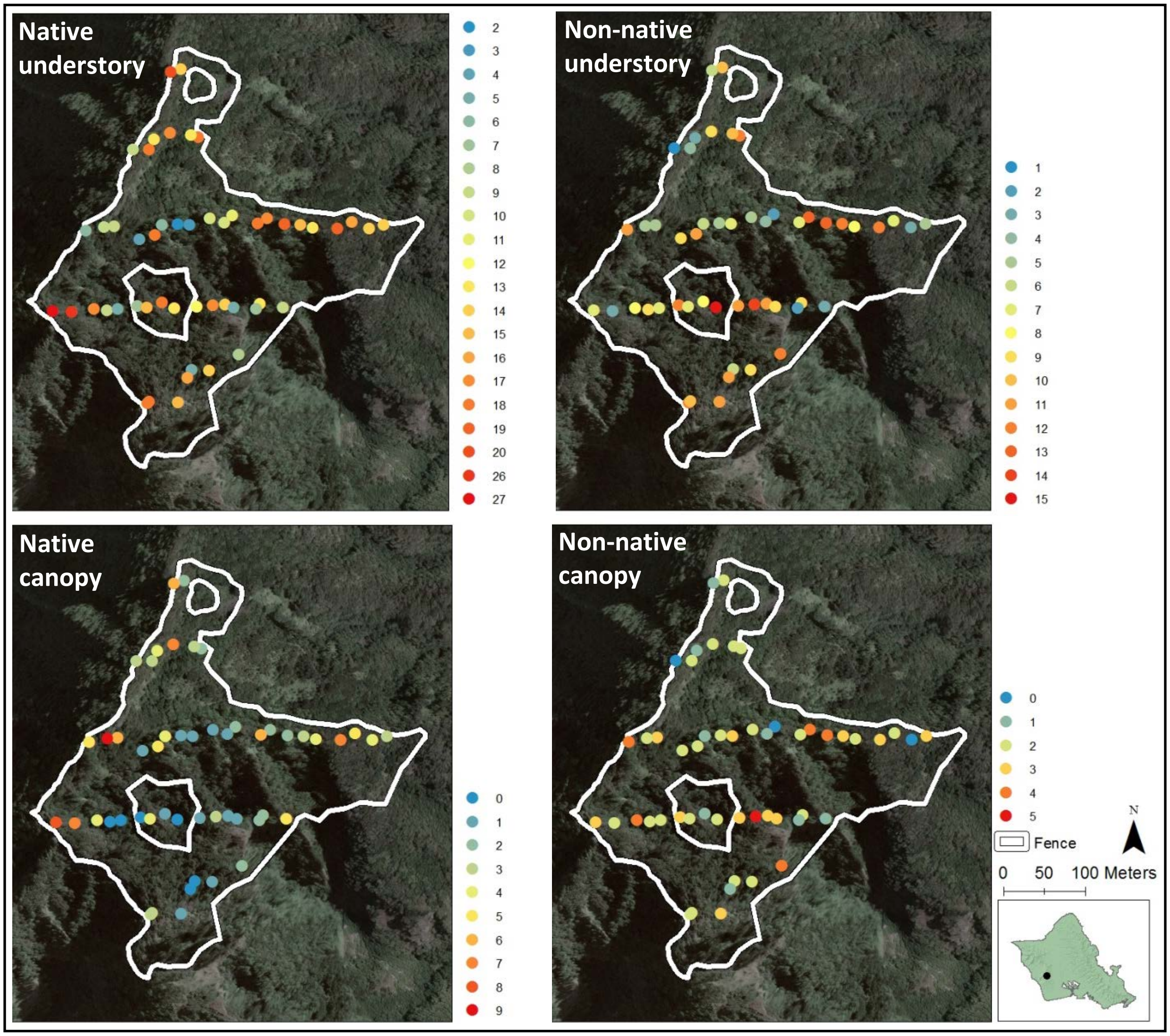


Figure 7. Locations of low to high species richness among plots in the native and non-native understory and canopy in Palikea MU, 2014. Color gradients of blue to red indicate low to high values, respectively, of the number of species occurring in plots.

Table 2. Palikea MU understory and canopy species richness. Median values of species richness per plot during vegetation monitoring is shown by year, with the total number of species recorded among all plots in parenthesis (n=51). P-values obtained from Friedman's test for species richness. Statistically significant value is in boldface.

	2008	2011	2014	p
Non-native understory	7 (36)	7 (35)	8 (34)	0.083
Native understory	12 (101)	13 (99)	14 (96)	**0.006**
Non-native canopy	2 (9)	2 (8)	2 (10)	0.521
Native canopy	2 (36)	3 (39)	3(35)	0.298

Table 3. Newly recorded, and no longer present, species from 2014 Palikea MU monitoring.

New species recorded in plots in 2014	Species not recorded in 2014 but recorded in same plots previously
Non-Native	
Angiopteris evecta	*Drymaria cordata* var. *pacifica*
Emilia sonchifolia	*Eleocharis radicans*
	Schefflera actinophylla
	Sphaeropteris cooperi
	Nephrolepis brownii
	Phyllanthus tenellus
Native	
Cyperus polystachyos	*Asplenium unilaterale*
Korthalsella cylindrica	*Canavalia galeata*
Peperomia spp.	*Cibotium glaucum*
Solanum americanum	*Dryopteris unidentata*
Vaccinium calycinum	*Dryopteris wallichiana*
	Dubautia laxa
	Elaeocarpus bifidus
	Melicope christophersenii
	Microlepia speluncae
	Myoporum sandwicense
	Myrsine lanaiensis
	Nothocestrum latifolium
	Peperomia sandwicensis
	Polyscias oahuensis
	Psilotum nudum
	Scaevola mollis
	Syzygium sandwicense
	Urera glabra
	Urera kaalae
	Vaccinium reticulatum

The presence or absence of species may be due in part to human error, including misidentification (e.g., *Nephrolepis exaltata* subsp. *hawaiiensis*, may have been misidentified as *N. brownii*, and *Melicope oahuensis* misidentified as *M. christophersenii*); observer bias regarding plot boundaries, amount of time spent searching, or searching for specific species (e.g. *Lepisorus thunbergianus* in the canopy); or accidental non-recording. The presence of short-lived, less common species is expected to vary over time. All of the species that were not present in 2014 were uncommon in previous years, with frequencies less than 0.08. Despite the significant increase in native understory richness among plots, the overall native understory diversity for the MU has declined slightly. A decrease in MU-scale diversity paired with an increase in plot-scale diversity could occur if the frequencies of less common species are declining, while frequencies of more common species are increasing.

Species frequency

Non-native species that most frequently occurred in plots in the understory included *Clidemia hirta, Psidium cattleianum,* and *Schinus terebinthifolius,* while those most commonly occurring in the canopy were *S. terebinthifolius, Morella faya,* and *P. cattleianum* (Table 4). The most frequent native species included *Metrosideros polymorpha, Kadua affinis,* and *Dicranopteris linearis* in the understory, and *M. polymorpha* in the canopy. Small increases in frequency occurred for several species. These included two species in the non-native understory (McNemar's test: *Deparia petersenii*, p = 0.0269 for years 2008 versus 2014; and *Ehrharta stipoides*, p = 0.0026 for years 2008 vs. 2014, and p = 0.0159 for years 2011 vs. 2014), one non-native canopy species (*Passiflora suberosa*, p = 0.0056 for years 2008 vs. 2014), and two native understory fern species (*Elaphoglossum paleaceum*, p = 0.0412 for years 2008 vs. 2014; and *Nephrolepis exaltata* subsp. *hawaiiensis*, p = 0.0133 for years 2008 vs. 2011, and p = 0.0455 for years 2008 vs. 2014) (Figure 8). A decline in frequency occurred for only one species (non-native understory, *S. terebinthifolius*, p = 0.0159 for years 2008 vs. 2014).

Table 4. Species frequency among plots (proportion of plots in which a given species occurs) during 2014 Palikea MU monitoring (n= 51), in order of most to least frequent. Native species are in bold print.

Species	Frequency
Understory	
Clidemia hirta	0.88
Psidium cattleianum	0.69
Schinus terebinthifolius	0.63
Metrosideros polymorpha	0.61
Passiflora suberosa	0.59
Kadua affinis	0.57
Rubus rosifolius	0.57
Dicranopteris linearis	0.55
Youngia japonica	0.53
Dryopteris glabra	0.49
Blechnum appendiculatum	0.47
Cyclosorus parasiticus	0.47
Asplenium macraei	0.43
Deparia petersenii	0.41
Dianella sandwicensis	0.41
Cibotium chamissoi	0.39
Cocculus orbiculatus	0.37
Ehrharta stipoides	0.37
Elaphoglossum paleaceum	0.37
Lepisorus thungbergianus	0.37
Alyxia stellata	0.35
Melinis minutiflora	0.35
Paspalum conjugatum	0.35
Microlepia strigosa	0.33
Nephrolepis exaltata* subsp. *hawaiiensis	0.31
Peperomia membranacea	0.29
Asplenium contiguum	0.27
Coprosma longifolia	0.27
Kadua cordata	0.27
Ageratina riparia	0.25
Wikstroemia oahuensis* var. *oahuensis	0.25
Diplazium sandwichianum	0.24
Vaccinium dentatum	0.24
Cheirodendron trigynum	0.22
Morella faya	0.22
Asplenium acuminatum	0.20
Carex wahuensis	0.20
Cyrtandra waianaeensis	0.20

Table 4, continued.

Species	Frequency
Understory, continued	
Lantana camara	0.20
Ageratina adenophora	0.18
Athyrium microphyllum	0.16
Broussaisia arguta	0.16
Dryopteris sandwicensis	0.16
Nephrolepis cordifolia	0.16
Peperomia tetraphylla	0.16
Perrottetia sandwicensis	0.16
Coprosma foliosa	0.14
Elaphoglossum aemulum	0.14
Elaphoglossum crassifolium	0.14
Freycinetia arborea	0.14
Sadleria cyatheoides	0.14
Cryptomeria japonica	0.12
Cyclosorus dentatus	0.12
Diplopterygium pinnatum	0.12
Dodonaea viscosa	0.12
Selaginella arbuscula	0.12
Acacia koa	0.10
Antidesma platyphyllum	0.10
Asplenium caudatum	0.10
Charpentiera obovata	0.10
Conyza bonariensis	0.10
Doodia kunthiana	0.10
Pipturis albidus	0.10
Pittosporum confertiflorum	0.10
Psychotria hathewayi	0.10
Ageratum conyzoides	0.08
Bidens torta	0.08
Leptecophylla tameiameiae	0.08
Phlebodium aureum	0.08
Polypodium pellucidum* var. *pellucidum	0.08
Sphenomeris chinensis	0.08
Carex meyenii	0.06
Clermontia kakeana	0.06
Crassocephalum crepidoides	0.06
Dryopteris fusco-atra	0.06
Elaphoglossum alatum	0.06
Epidendrum x *obrienianum*	0.06
Erechtites valerianifolia	0.06
Euphorbia multiformis	0.06
Ilex anomala	0.06
Labordia kaalae	0.06
Melicope clusiifolia	0.06
Melicope oahuensis	0.06
Myrsine lessertiana	0.06
Myrsine sandwicensis	0.06
Phytolacca octandra	0.06
Psilotum complanatum	0.06
Psychotria mariniana	0.06

Table 4, continued.

Species	Frequency
Understory, continued	
Pteridium aquilinum	0.06
Rumex albescens	0.06
Scaevola gaudichaudiana	0.06
Asplenium kaulfussii	0.04
Asplenium lobulatum	0.04
Cyanea grimesiana* subsp. *obatae	0.04
Kadua acuminata	0.04
Korthalsella cylindrica	0.04
Pisonia brunoniana	0.04
Pteris excelsa	0.04
Vaccinium calycinum	0.04
Vandenboschia davallioides	0.04
Adenophorus pinnatifidus	0.02
Adenophorus tamariscinus	0.02
Adenophorus tenellus	0.02
Adiantum radianum	0.02
Angiopteris evecta	0.02
Asplenium excisum	0.02
Buddleja asiatica	0.02
Crocosmia x *crocosmiifolia*	0.02
Cyperus polystachyos	0.02
Dubautia plantaginea	0.02
Emilia sonchifolia	0.02
Gahnia beecheyi	0.02
Grevillea robusta	0.02
Huperzia phyllantha	0.02
Hymenophyllum recurvum	0.02
Lobelia yuccoides	0.02
Nothocestrum longifolium	0.02
Oxalis corniculata	0.02
***Peperomia* sp.**	0.02
Physalis peruviana	0.02
Planchonella sandwicensis	0.02
Psidium guajava	0.02
Pteris irregularis	0.02
Smilax melastomifolia	0.02
Solanum americanum	0.02
Solanum sandwicense	0.02
Tectaria gaudichaudii	0.02
Vandenboschia cyrtotheca	0.02
Viola chamissoniana* subsp. *tracheliifolia	0.02
Zanthoxylum dipetalum* var. *dipetalum	0.02
Canopy	
Metrosideros polymorpha	0.73
Schinus terebinthifolius	0.63
Morella faya	0.45
Psidium cattleianum	0.43
Passiflora suberosa	0.37
Lepisorus thungbergianus	0.27
Cryptomeria japonica	0.22

Table 4, continued.

Species	Frequency
Canopy, continued	
Cheirodendron trigynum	0.18
Kadua affinis	0.16
Alyxia stellata	0.14
Cibotium chamissoi	0.14
Pittosporum confertiflorum	0.12
Broussaisia arguta	0.10
Coprosma longifolia	0.10
Acacia koa	0.08
Adenophorus tamariscinus	0.08
Dicranopteris linearis	0.08
Dodonaea viscosa	0.08
Perrottetia sandwicensis	0.08
Psychotria mariniana	0.08
Coprosma foliosa	0.06
Freycinetia arborea	0.06
Ilex anomala	0.06
Antidesma platyphyllum	0.04
Melicope clusiifolia	0.04
Pipturis albidus	0.04
Adenophorus pinnatifidus	0.02
Cocculus orbiculatus	0.02
Diplopterygium pinnatum	0.02
Dubautia plantaginea	0.02
Elaphoglossum crassifolium	0.02
Epidendrum x *obrienianum*	0.02
Grevillea robusta	0.02
Lantana camara	0.02
Leptecophylla tameiameiae	0.02
Lobelia yuccoides	0.02
Melicope oahuensis	0.02
Nothocestrum longifolium	0.02
Peperomia tetraphylla	0.02
Phlebodium aureum	0.02
Planchonella sandwicensis	0.02
Polypodium pellucidum* var. *pellucidum	0.02
Psidium guajava	0.02
Psychotria hathewayi	0.02
Smilax melastomifolia	0.02

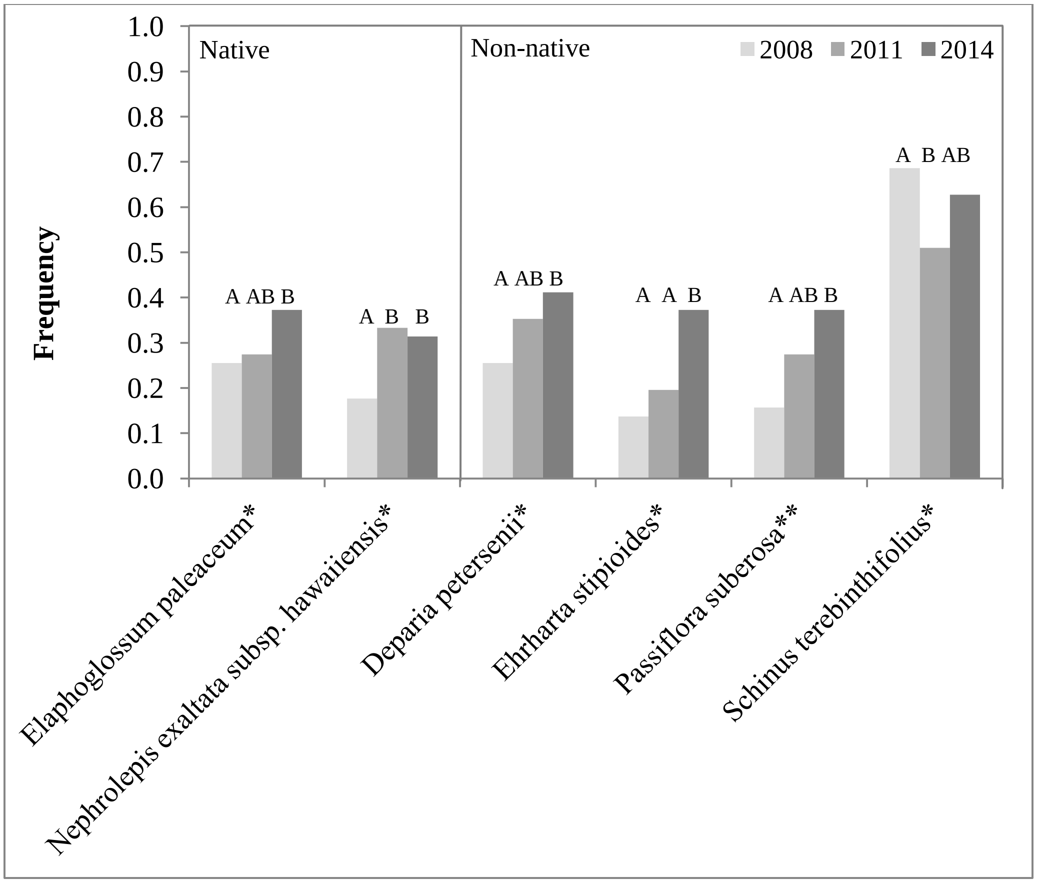


Figure 8. Species frequencies at Palikea MU between 2008 and 2014, among taxa with significant changes over time. Frequency values represent the proportion of plots in which species are present (n=51). *Understory. **Canopy

Species cover

No significant changes occurred in the percent cover of species in the understory between years 2008, 2011 and 2014, or in the canopy between years 2011 and 2014. The change in total native canopy cover from 15% in 2011 to 25% in 2014 does not appear to be driven by any one species, but rather may be a result of cumulative changes in the percent cover of multiple native canopy species.

Canopy replacement

Most canopy tree species were found recruiting (defined as having a maximum height of less than 2 m above ground level) in the understory (Table 5). *Kadua affinis* and *M. polymorpha* were the most commonly recruiting native tree species, while non-native recruiting tree species were primarily *P. cattleianum* and *S. terebinthifolius*. Native species with no recruitment in the understory were also infrequent in the canopy. Recruitment was infrequent relative to their occurrence in the canopy for non-native species *M. faya* and *Cryptomeria japonica*.

Weed control

Weed control efforts at Palikea between the 2011 and 2014 monitoring intervals included approximately 1,305.41 person hours, which was three times more than spent weeding between the 2008 and 2011 monitoring intervals (440.40 person hours). The total amount of effort varied among the nine

Table 5. Summary of canopy tree species recruitment in the understory during 2014 Palikea MU monitoring, in order of most to least frequent. Frequency represents the proportion of tree species with a maximum height < 2 meters (seedlings to small trees) among plots (n=51).

Species	Frequency
Native	
Kadua affinis	0.41
Metrosideros polymorpha	0.27
Coprosma longifolia	0.16
Dodonaea viscosa	0.12
Perrottetia sandwicensis	0.08
Pipturis albidus	0.08
Psychotria hathewayi	0.08
Antidesma platyphyllum	0.06
Broussaisia arguta	0.06
Cheirodendron trigynum	0.06
Labordia kaalae	0.06
Melicope clusiifolia	0.06
Melicope oahuensis	0.06
Acacia koa	0.04
Charpentiera obovata	0.04
Pisonia brunoniana	0.04
Cibotium chamissoi	0.02
Coprosma foliosa	0.02
Pittosporum confertiflorum	0.02
Psychotria mariniana	0.02
Ilex anomala	0.00
Nothocestrum longifolium	0.00
Planchonella sandwicensis	0.00
Zanthoxylum dipetalum var. *dipetalum*	0.00
Non-native	
Psidium cattleianum	0.61
Schinus terebinthifolius	0.25
Grevillea robusta	0.02
Morella faya	0.02
Psidium guajava	0.02
Cryptomeria japonica	0.00

weed control areas (WCA) that encompass Palikea MU, ranging from 2.8 to 91.75 hours per WCA between 2008 and 2011, and from 3.5 to 422.5 hours per WCA between 2011 and 2014. There was a significant correlation between person hours spent weeding and change in native understory cover between years 2011 and 2014 by WCA ($p = 0.006$, $r^2 = 0.143$). The change in native and non-native cover in the understory and canopy did not correlate with the amount of time spent weeding per WCA for any other time range comparisons.

In concert with the increase in hours spent weeding, more plots fell within weeded areas between the 2011 and 2014 monitoring intervals (65% of the plots were weeded), as compared with the 2008 to 2011 interval (55% weeded) (Figure 9). The proportion of plots weeded was similar to the percent total area weeded within Palikea MU (48% of the MU was weeded between the 2008 and 2011 monitoring intervals, and 61% was weeded between the 2011 and 2014 monitoring intervals). Change in native and non-native cover did not differ among plots weeded vs. not weeded between 2008 and 2011, or between 2008 and 2014. There was no correlation between the number of times weeded and cover change for native and non-native understory and canopy for years 2008-2011 and 2011-2014. Grass control occurred in 12% of the plots from 2008 to 2011, and in 33% of the plots from 2011 to 2014. The increased extent of grass control in the 2011 to 2014 monitoring interval was not sufficient to reduce grass cover. Though field crews anecdotally noticed an increase in understory weeds in certain areas where non-native canopy was removed, reductions in non-native canopy did not correlate with increases in non-native understory vegetation among the monitored plots. Similarly, there was no correlation between changes in non-native canopy and native understory or canopy vegetation.

Target weed species (OANRP 2009) were identified during monitoring. Two incipient non-native species, *Angiopteris evecta* and *Crocosmia* x *crocosmiifolia*, were identified, each in a single plot. These species were already known to occur in the MU. A third target weed grass species, *E. stipoides*, is now widespread sporadically across the MU, occurring in over a third of the plots, following a significant increase in frequency from in 0.20 in 2011 to 0.37 in 2014 (Figure 10). The increase in frequency of *E. stipoides* included expansion into plots that had grass control between 2011 and 2014. Grass control at Palikea primarily occurred along fencelines and trails. Grass control between 2011 and 2014 occurred in 9 out of the 19 plots containing *E. stipoides* in 2014, but did not reduce its coverage among those plots. The expansion of this species may be exacerbated by the presence of a network of trails throughout the MU established in 2010 in association with rodent control, along which the easily spread seeds may be inadvertently dispersed by field crews.

Caution should be applied in interpreting the results of vegetation monitoring in association with weed control due to error associated with GIS data for both vegetation plots and weeded areas. Accuracy for vegetation plot locations were often poor, at times requiring hand plotting. Weeded areas were often hand plotted, with estimations of size and location that may be inexact to varying degrees.

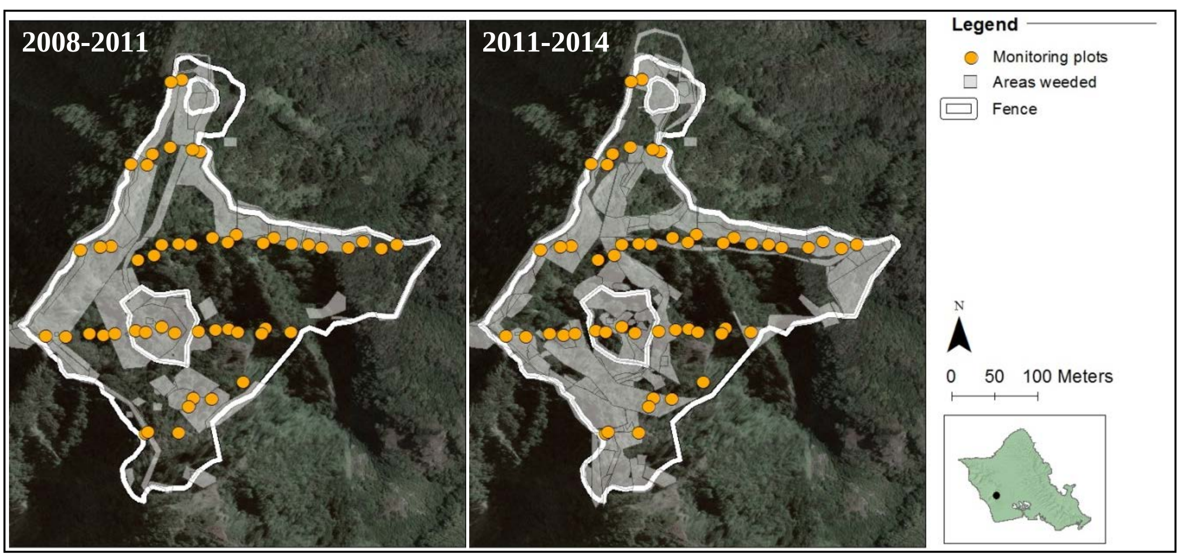


Figure 9. Locations of vegetation monitoring plots at Palikea in relation to areas weeded during the 2008 to 2011, and the 2011 to 2014, monitoring intervals.

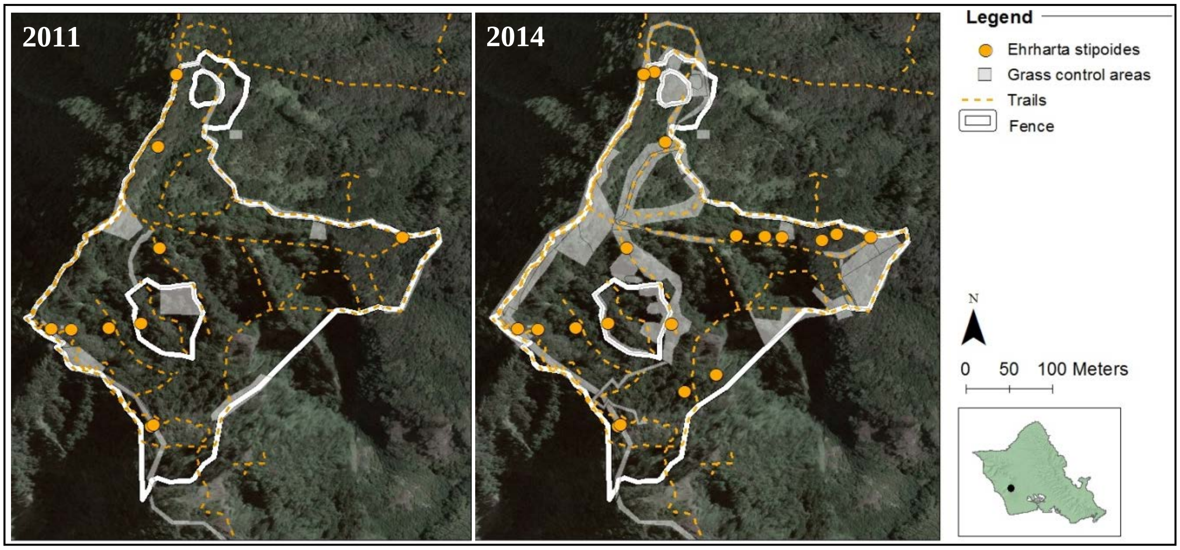


Figure 10. Locations of target weed grass species *Ehrharta stipoides* occurrence in monitored plots in 2011 and 2014, in relation to trails and areas controlled for grass during the three years prior at Palikea.

SUMMARY AND DISCUSSION

Management objectives were not met for percent cover of native understory, native canopy, and non-native canopy vegetation. Objectives were only met for non-native understory percent cover. While no changes were striking, there were a number of small but significant differences in the 2014 data as compared with three and six years ago, including:

- less bare ground (compared with 3 and 6 years ago)
- greater native canopy cover (compared with 3 years ago)
- greater native understory species richness (compared with 6 years ago)
- an increase in frequency for native species:
    - *Elaphoglossum paleaceum* (compared with 6 years ago)
    - *Nephrolepis exaltata subsp. hawaiiensis* (compared with 6 years ago)
- an increase in frequency for non-native species:
    - *Deparia petersenii* (compared with 6 years ago)
    - *Ehrharta stipoides* (compared with 3 and 6 years ago)
    - *Passiflora suberosa* (canopy only, compared with 6 years ago)
- native understory cover change correlation with amount of time spent weeding per WCA (between 2011 and 2014).

The vegetation changes observed at Palikea follow a similar pattern to that of prior studies comparing fenced and unfenced areas, wherein both native and non-native species respond positively to ungulate removal during the initial years following fencing (Weller et al. 2011, Cole and Litton 2014). The correlation between the amount of time spent weeding and the change in native understory cover by WCA gives evidence for the potential of weed management, when done in greater amounts, to effect change towards meeting management objectives. However, greater efforts are needed to increase cover of native understory and canopy vegetation and to reduce the cover of non-native canopy vegetation and target weed species *E. stipoides*. The increased frequency for *E. stipoides* of particular concern, as it is highly invasive and easily spread within and between management units on clothing and field gear.

RECOMMENDED MANAGEMENT ACTIONS

In order to meet management objectives for Palikea MU, a number of general and specific actions are recommended. More aggressive weed control across the MU is necessary. Partial canopy removal/thinning for *Morella faya* and *Cryptomeria japonica* is recommended, as these are among the more frequently occurring and more easily managed canopy weeds, and have infrequent recruitment. Incision Point Application (IPA) herbicide delivery technique is recommended for *Grevillea robusta* and *Psidium guajava* across the entire MU, as these weeds occur relatively infrequently in the canopy, and may be a more achievable target for elimination. Due to the prevalence of *Schinus terebinthifolius*, strategies for control of this species in the canopy need to be carefully considered. The removal of non-native canopy may promote an increase in both native and non-native understory cover; however, the response of non-native taxa may outpace that of native taxa. Caution should be applied to avoid opening too much canopy, as considerable time will be required to address the subsequent non-native response in the understory. *Passiflora suberosa* should be targeted during WCA efforts, especially in the canopy. Target species *Angiopteris evecta* and *Sphaeropteris cooperi* (though not found in any plots during monitoring, this species was anecdotally observed in the MU in 2014) should be treated where found as WCA actions. An increased priority for control and the development of new control strategies for *Ehrharta stipoides* is needed. Restoration projects should be planned and implemented to assist in the recovery of native species.

The discovery of incipient species in vegetation monitoring plots at Palikea prompted the need for management action plans for addressing the potential problems associated with weeding in permanent vegetation plots. All incipient weeds found within management units must be eliminated, with these areas regularly inspected until extirpation is complete. Specific targeting of weed actions in MU vegetation monitoring plots diminishes the ability of the monitoring data to fairly represent vegetation distributions on the MU scale. As a means of addressing concerns for both weed control needs and MU monitoring validity, it is recommended that in the event that target species are found during MU vegetation monitoring, discussions take place on a case by case basis to determine what actions should be taken and how those actions will benefit weed management without affecting the integrity of vegetation monitoring. For example, if a zero-tolerance species is found during monitoring, it may be removed from the plot, but additional control must be done on a larger scale in the surrounding area. For target species that are of less concern, control within monitoring plots should not be done without justification for prioritization, and should only be done in combination with larger scale control in the surrounding area.

REFERENCES

Cole, R. J. and C. M. Litton. 2014. Vegetation response to removal of non-native feral pigs from Hawaiian tropical montane wet forest. Biological Invasions 16:125–140.

Oahu Army Natural Resource Program. 2008a. Appendix 2.0 MIP/OIP Belt Plot Sampling Monitoring Protocol *in* Status Report for the Makua Implementation Plan.

Oahu Army Natural Resource Program. 2008b. Chapter 1 Ecosystem Management *in* Status Report for the Makua Implementation Plan.

Oahu Army Natural Resource Program. 2009. Chapter 1.4.8 Palikea Ecosystem Restoration Management Plan *in* Status Report for the Makua and Oahu Implementation Plans.

Oahu Army Natural Resource Program. 2011. Appendix 1-3 Vegetation Monitoring Trend Analysis for the Palikea MU *in* Status Report for the Makua and Oahu Implementation Plans.

Weller, S. G., Cabin, R. J., Lorence, D. H., Perlman, S., Wood, K., Flynn, T. and Sakai, A. K. (2011). Alien Plant Invasions, Introduced Ungulates, and Alternative States in a Mesic Forest in Hawaii. Restoration Ecology, 19: 671–680.

Appendix 1-3-3. Snail Enclosure Re-vegetation Summaries

1.1 <u>Palikea Snail Enclosure</u>

This year restoration activities inside the Palikea snail enclosure included aggressive grass control, minimal understory weed control, strategic *Schinus terebinthifolius* overstory removal, and outplanting of native snail host trees. As there were ample outplants this year, plantings were conducted throughout the enclosure, focusing on connecting existing native patches, filling in open areas, and establishing an understory of native canopy species ahead of non-native canopy removal.

Weed Control Summary:
Paspalum conjugatum control accounted for the greatest weeding effort inside the enclosure this year. This removal was done by hand clearing the grass while searching for *Euglandina rosea* in the understory. Other understory weeds, including *Rubus rosifolius*, *Passiflora suberosa*, *Phytolacca octandra*, and *Clidemia hirta*, were controlled during these searches as well. Anecdotally, it appears that native cover is filling in previously open areas, and both the abundance of understory weeds and time spent weeding have substantially declined since the construction of the enclosure.

Blechnum appendiculatum (fern) growing near the *Laminella sanguinea* area has thickened and expanded in some areas. Control of this species must be conducted carefully and thoughtfully as *L. sanguinea* forage through leaf litter on the ground. This weed, however, remains a high priority target as it forms a dense mat in the understory and is only established locally inside the enclosure. A zero tolerance for *Ehrharta stipoides* will remain in the enclosure. Patches of this grass continually recruit inside.

Non-native canopy removal was focused on thinning a stand of *S. terebinthifolius* trees below the largest density of *L. sanguinea*. Cover directly over the *L. sanguinea* area was maintained, but the majority of cover over areas without snails was removed. Outplants were planted on the same day as this removal, and within six months, many of the outplants in this area had more than doubled in height. Native understory has also filled in the light gap created by the *S. terebinthifolius* removal. At this point, no more aggressive overstory weed control is planned. This will be re-considered when the hundreds of outplants in the enclosure begin to reach canopy levels.

The 1 m buffer outside of the enclosure is maintained as bare ground to prevent weeds from growing into or above the first barriers. This area is sprayed regularly with a glyphosate product and a pre-emergent herbicide when needed.

Re-vegetation Summary:
This year, a total of 212 plants were planted (Table 1). Outplantings were conducted in November 2013, and in January and March 2014. At this point, open spaces appear sufficiently planted, and no more plantings are planned for next year. The exception to this may be *Freycenetia arborea*, a woody climber that is an important snail host, and *Cheirondendron trigynum*, a significant canopy component in Palikea, both of which have been slow to grow.

Vegetation monitoring will be conducted in 2017 (five years since construction), to assess the need for additional outplantings in order to reach canopy cover goals of establishing over 80% native cover by the 10th year of existence. Monitoring protocols will be developed before 2017 to address vegetation monitoring objectives and identify triggers for management response.

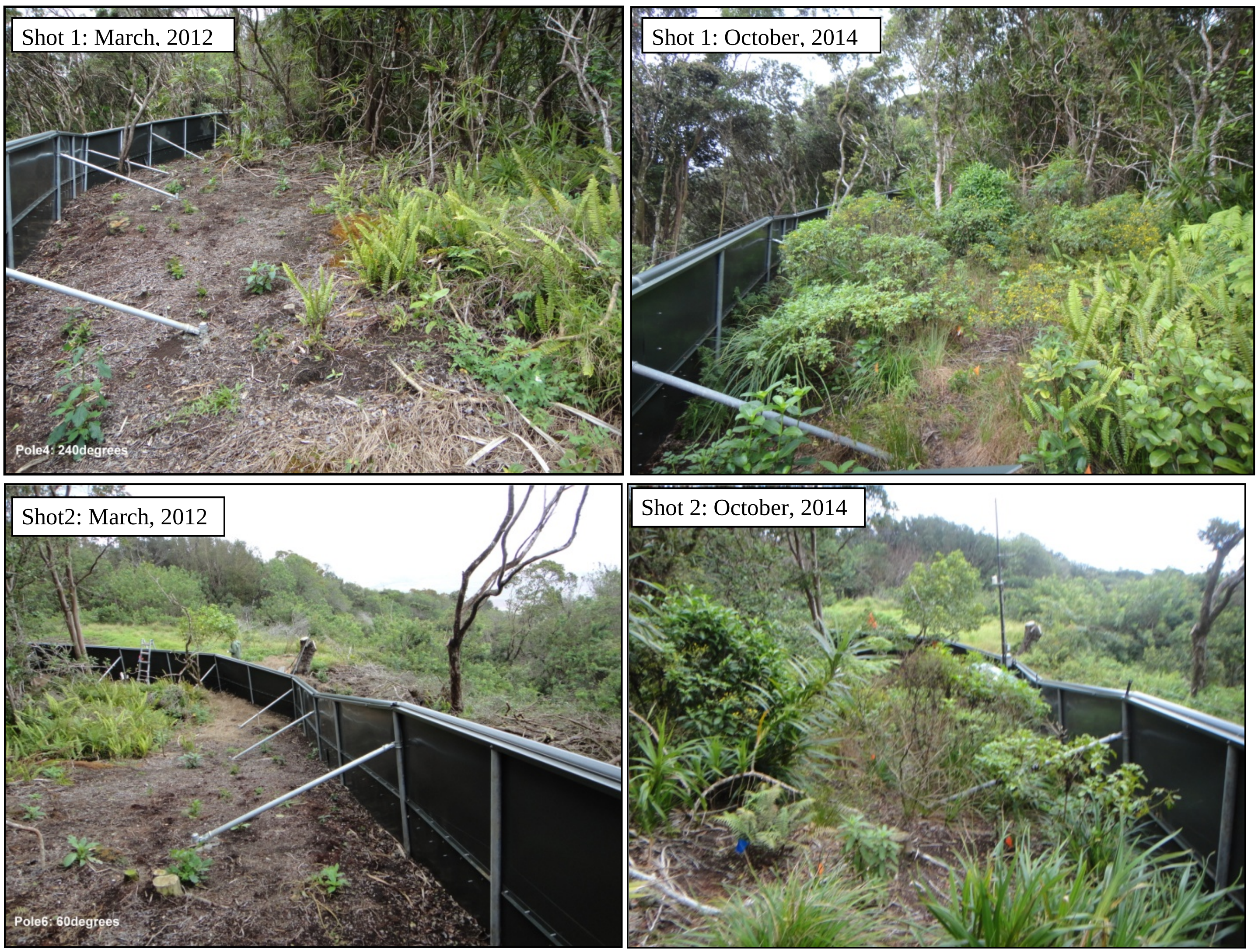
All species of outplants were most recently monitored in September 2014. Overall survival for all outplants (including Year 1) is 81% and is summarized in the table below.

Table 1. Outplanting Summary:

Species	# Planted Year 1	Goal for Year 2	# Planted Year 2	Total remaining September 2014	Survival	Comments
Antidesma platyphyllum	20	50	52	67	93%	Many individuals of this species looking poor throughout Palikea MU. Hopeful that outplant survivorship remains high and that these plants establish inside the enclosure.
Coprosma longifolia	6	50	40	44	96%	Outplants of this species established and grew quickly; good restoration species.
Cheirodendron trigynum	0	0	0	N/A	N/A	Conducted fruit collection across MU this year. Propagation will begin this year. Unclear when plants will be ready to plant.
Freycenetia arborea	0	N/A	N/A	N/A	N/A	Seedlings in growth chamber and less than a dozen in small communal pots in the greenhouse. May not be ready for outplanting for another year.
Kadua affinis	26	50	66	82	89%	These plants are easy to collect from, store, and propagate fairly well; good restoration species.
Metrosideros polymorpha	6	15	10	13	81%	Easy to collect cuttings for this species, but has inconsistent propagation results. Need to refine appropriate collection material.
Myrsine lessertiana	0	N/A	N/A	N/A	N/A	While generally known as an important snail host species, only a handful of known trees from inside the Palikea fence, and none seen flowering/fruiting. Should look outside MU if want to work with this species in the future.
Perrottetia sandwicensis	47	25	27	41	55%	The first planting of this species fared poorly as may have been planted too young. Consequent plantings had sporadic death.
Pipturis albidis	50	0	0	31	62%	Survival not as good as expected; however most of these plants were planted on open slopes in areas formerly dominated by *Psidium cattleianum*. Seed sow may be best way to establish this plant in an area.
Urera glabra	28	25	17	41	91%	High survivorship of this species.

In addition to out-plants, recruitment of native species was also observed within the enclosure; some passive, and some assisted by seed sows. Natural recruitment has been observed most abundantly for *Kadua affinis* inside the enclosure where seedling beds have formed under mature plants. The lack of rats inside the enclosure is credited as the main reason for this success. A species of *Dryopteris glabra* fern also recruited along the southern enclosure wall. *Carex wahuensis* recruited in open areas where broadcast sows were conducted. *Coprosma longifolia* germinated at almost all of 12 ‘plots’ where 20 fruit were broadcast over a 1ft square area. Nearly a year later, over half of the plots maintain at least one individual. *Pisonia umbellifera* are also germinating from seed sows throughout the enclosure, and will serve as a host tree for *Achatinella concavospira* moved into the enclosure from Pualii this year.

Photopoints below show some of the native vegetation recovery over the last two years. *Freycenetia arborea* (IeIe) patches are thicker, *Metrosideros polymorpha* (Ohia) trees have filled in, and *Microlepia strigosa* (Palapalai) at the bottom northeast corner of the enclosure now completely covers what was once bare ground.



Above photos: Two different angles of an area previously dominated by bare ground now filling in with outplants, seed sows, and native fern recruits and expansion.

Above shot: March photo shows thin F.arborea *that was previously growing in P. cattleianum stand.* F. arborea *has filled out, with many new IeIe 'heads'. Outplants and recruits are connecting with this existing vegetation.*

Above shot: Bare corner of enclosure (formerly thimbleberry weed) filled in with expanded M. strigosa *fern, transplanted* Cibotium chamissoi, *and outplants (*C. longifolia *visible).*

1.2 <u>Hapapa Snail Enclosure</u>

This year restoration activities inside the Hapapa snail enclosure included understory weed control as needed, and outplanting of native snail host trees. Most of this work is conducted by the snail management team.

Weed Control Summary*:*

The most dedicated weed effort this year focused on controlling fast-growing, sun-loving understory weeds that colonized during winter rains. One weed in particular, *Drymaria cordata* var. *pacifica* was persistent regardless of multiple control efforts. This low growing weed forms dense mats in disturbed areas and produces sticky fruits that disperse easily. Initial controls by handpulling were unsuccessful and mats would re-form quickly after rains. Now, dense areas are controlled using a glyphosate product at a 2% mix-rate, carefully applied to minimize non-target impact to surrounding vegetation. This technique was successful in knocking back levels, and will be used this coming year if recruit levels are high after rains. Aside from the flushes of herbaceous weeds, most other understory weed control is conducted as needed by snail program staff during regular snail work inside the enclosure. *Passiflora suberosa* recruits are commonly targeted, along with the recruits of weedy tree species such as *Toona ciliata*, *Spathodea campanulata*, *Schinus terebinthifolius* and *Grevillea robusta*.

Opportunistic weed control is sufficiently maintaining low levels of understory weed cover. New problematic weed infestations are not anticipated, and treatment of the suite of weeds that recruit in open areas is expected to reduce as native canopy cover levels continue to increase.

Re-vegetation Summary:

The number of individuals planted is much lower than goals set for this year. As planting began early in the year, staff most familiar with the area noted early on in the year that open areas, and corridors between snail habitats were well planted, and that outplant survivorship was high all around. At that point, no more cuttings were taken, or seeds sowed to meet previously set goals. However, plants in the greenhouse slated for the Hapapa enclosure were still planted at a later date.

Vegetation monitoring will be conducted in 2017/2018 to assess the need for additional outplantings in order to reach canopy cover goals of establishing over 80% native cover across the core of the enclosure after 10 years of existence. Monitoring protocols will be developed before 2017 to address vegetation monitoring objectives and identify triggers for management response.

Plants were planted in November and February and all were grown at the OANRP West Base Nursery facility. A total of 99 plants were planted throughout the enclosure. Survival data for all species of plants was most recently collected in October 2014. Overall survivorship for all outplants (excluding *A. koa* that were not monitored) is 80% and is summarized by species in the table below.

The most rewarding result of these outplantings is observing the consistent use by snails of all age classes on these plants.

Table 1. Outplanting Summary:

Species	# Planted Year 1	Goal for Year 2	# Planted Year 2	Total remaining October 2014	Survival	Comments
Acacia koa	11	0	0	unk	unk	Plants from Year 1 were mostly planted outside the enclosure to replace *S. terebintifolius* removed from the Hapapa bench. Did not monitor these plants.
Antidesma platyphyllum	9	50	34	41	91%	*A. platyphyllum* is slow to propagate and did not meet propagation goals early on. While a valuable snail host tree, plantings of other hosts and overall canopy trees seemed sufficient to not have to continue to propagate to meet original goals.
Cyanea membranacea	4	0	0	1	25%	Year 1 plantings with this 4 individuals of this species were opportunistic as plants were available in the greenhouse.
Freycenetia arborea	11	25	0	1	9%	Plants slated for Year 2 were not ready, and 25 plants will instead be planted winter 2014.
Labordia kaalae	15	50	12	22	81%	Lower numbers of seedlings were produced than expected from seed sows in seed lab. These plants were slow to grow, and a handful remains in the greenhouse. These will be used in other restoration projects in the area.
Myrsine lessertiana	97	15	17	103	90%	Outplants of *M. lessertiana* fared very well. Snails have been observed on outplants of this species.
Perrottetia sandwicensis	46	25	27	57	78%	After first planting, was a low priority to continue to collect to reach goals.
Pisona umbellifera	0	25	0	0	N/A	This species occurs as huge, emerging canopy trees across the Hapapa Bench, which were known to support *many* snail individuals. Planting these trees inside the enclosure is a priority. Trials made with cuttings were successful and the resulting plants will be planted winter 2014.
Planchonella sandwicensis	6	25	1	6	83%	Not enough fruit from this species was collected to meet Year 2 goals, however no more plantings of this species are planned.
Urera glabra	62	0	8	62	89%	Snails have been observed on outplants of this species.
Urera kaalae	40	0	0	18	44%	Original outplanting conducted with plants available in the greenhouse.

Above Photos: Left: OANRP Rare Snail Conservation Specialist looks for snails on outplanted U. glabra*. Right: Two snails utilize outplanted* U. glabra*.*

In addition to outplanting, a minimal amount of transplanting was also conducted inside the enclosure. Divisions of *Microlepia strigosa* and *Dianella sandwicensis* were collected from outside of the enclosure, and planted the same. *D. sandwicensis* was planted around the base of some of one of the larger *Pisonia umbellifera* to discourage walking with tabis on exposed roots, and with the hopes of increasing moisture for this keystone species inside the enclosure. *M. strigosa* were transplanted under *P. albidus* canopy to increase patches of groundcover in bare areas.

Above photos: Left: D. sandwicensis transplanted at the base of *P. umbellifera. Right: D. sandwicensis and M. strigosa divisions prepared before planting. Aall soil material is removed and plants are searched to prevent* E. rosea *introduction.*

In order to discourage native snails from utilizing the enclosure wall inside the enclosure, there has been a greater focus this year on creating a buffer between understory vegetation within one meter of the wall. Native recruits in this buffer may be transplanted elsewhere inside the enclosure during the rainy season when possible, and weeds will be controlled to maintain bare ground adjacent to the enclosure wall. Native canopy trees are also regularly trimmed within this buffer to prevent issues with the FVA wire.

This coming year, there are still plans to plant the *F. arborea* that have been under seedlab or greenhouse propagation for the last three years. This species occurs in limited localities inside the enclosure, mostly growing in two large *P. umbellifera* stands. It is important to establish more 'patches' of this important snail host species in new localities throughout the enclosure. The first round of plantings with *F. arborea* mostly failed, but there are expectations that larger plants will fare better. The plants slated for planting in November, 2014, are mostly in 6" pots, and those in 4" pots are much larger and healthier than the first round planted in Year 1. Additionally, a focus to get more *P. umbellifera* outplants from larger cuttings will be made this year in order to continue to establish new stands of this critical species inside the Hapapa enclosure.

The photopoints below highlight the increased levels of native cover throughout the enclosure, and the positive response of existing native plants.

Above shot: Seed sows of B. torta *were used to create cover and as a nurse crop for outplants planted underneath.*

Above shot: The P. sandwicensis *in center is host to many snails. Surrounding plants now forming a more connected band of habitat around this host tree.*

Above shot: Existing vegetation filling in, supplemented with outplants (marked by orange flags)

Above shot: A stand of P. umbellifera isolated after initial clearing of alien canopy filled in with native vegetation at its base.

1.3 Kahanahaiki Snail enclosure

This year structural improvements and new threat barriers were completed at the Kahanahaiki Snail Enclosure in order to support existing and translocated snails. Re-vegetation efforts coincided with these upgrades. The canopy is comprised of native and non-native trees that occur in patches on either side of the enclosure, with an open strip about 3 meters wide that runs through the middle. Understory is somewhat minimal under the densest canopy, and nearly non-existent under the dense *Psidium cattleianum* stand inside the enclosure. The goals for re-vegetation inside the enclosure were to: fill canopy gaps with snail host trees, establish snail host trees under non-native canopy, and diversify snail host trees. As the Kahanahaiki enclosure is much smaller than either Hapapa or Palikea enclosures, it was realistic to conduct all the plantings in one year, without a multiple year planting plan.

Weed Control Summary:
As mentioned, understory vegetation is somewhat sparse, and understory weed control is maintained by handpulling weeds while conducting other work inside the enclosure. Due to the small size of the enclosure, it is essential to preserve the existing non-native canopy so as to maintain a shady, cool environment for the snails. As the outplants fill in canopy gaps and establish below non-native canopy, strategic removal of non-native canopy will be conducted. In the case of the *P. cattleianum* stand, plants will have to be thinned in the near future in order to foster the growth of outplants.

Re-vegetation Summary:
A total of 100 plants were planted on three different trips. The following species were out-planted: *Antidesma platyphyllum, Kadua affinis, Metrosideros polymorpha,* and *Myrsine lessertiana.* Some *Nestegis sandwicensis* fruit was collected, but unsuccessfully propagated. Transplants of this species have been brought into the

enclosure over the years, with mostly unsuccessful results. Further propagation work with this species in the greenhouse will likely be conducted, and outplantings of this critical *Achatinella mustelina* host species will be planted inside the enclosure as available. Survivorship data was not recently collected, but anecdotal observations note that plants are establishing. Survivorship from a planting in June may be low due to some trampling that occurred during a night survey shortly after planting, and also affected by the hot, dry weather during that month. The photo below shows established outplants denoted by an orange flag. Many plants have doubled in size since planting.

Photo: Kahanahaiki Snail Enclosure Outplants

Hawaiian Hoary Bat

Seasonal Acoustic Monitoring Study on Oahu Army Installations 2010-2014

Data prepared by C. Pinzari, for CSU, March 2014

Survey Goals

Establish bat presence or absence on U.S. Army managed lands. If bats present, survey throughout the year (at least 3 times) to document potential seasonal use of habitats by bats. Record bat events at station locations and determine temporal patterns of bat use.

Survey Methods

Acoustic surveys for bats were conducted on a seasonal basis at each installation for a total of 301 nights from 2010 to 2014. Three to four SM2Bat+ ultrasonic "bat detectors" (Wildlife Acoustics) were placed at least 800 meters apart in six regional installations of interest; Kahuku Training Area, Kawailoa Training Area, Schofield Barracks East and West Ranges (SBE, SBW), Dillingham Air Field, and Makua Military Reservation. Surveys were conducted on bi-monthly basis if possible, and recorded at least 3 and up to 19 nights consecutively during each deployment. The three installations in the Koolau Group (Kahuku, Kawailoa, and East Range) received at least 6 surveys, while the three installations in the Waianae Group (West Range, Dillingham, and Makua) only received 3 surveys each.

Bat detectors were set to record bat echolocation calls or "pulses" from dusk until dawn, and a bat "event" was triggered, recorded as a sound file, and logged for each pass a flying bat made by the microphone of a detector during the night. The number of bat events and number of echolocation pulses within an event can be used to confirm bat presence and describe bat activity levels. Bat events can also contain information on foraging activity, by the presence of characteristic echolocation pulses that form a "feeding buzz". Files collected during the recordings were scanned and filtered for bat presence using the program Kaleidoscope (version 1.1.22, Wildlife Acoustics) and visually inspected by sound and sight to confirm and count bat echolocation pulses. Foraging activity was also noted in call events containing feeding buzzes. Bat detectability (p), signifying presence or absence of the species for each survey was calculated using the program Presence (version 6.2, J.E. Hines, USGS)

Survey Map

Figure 1. Map of the six installation areas which received bat acoustic surveys and locations of bat detector stations. Yellow dots represent bat stations which with no bat detections. Red dots indicate positively confirmed bat detections, with the size of dot corresponding to the total number of events (1-11) recorded during all surveys at that point station. The purple dot represents the only station to record over 11 events (723), and show significant foraging activity.

Results and Discussion

Survey results show low measures of bat detectability at most locations, yet bats were present at all areas surveyed at least during half of the bat detector stations (Figure 1). Bats were present during a minimum of 3% and a maximum of 28% of the nights during a survey period. Bats were present 61 nights out of 301 total nights surveyed, around 20% of the nights based on these overall seasonal measures. This study recorded 790 bat call events, and 10,958 echolocation pulses. However, there were individual differences in bat activity and detectability at each installation, and the variation in these measures can be seen in the following subsections.

Koolau and Waianae Regions

Survey areas around the Waianae Mountains group (Makua, Dillingham, and SBW) returned higher detectability values than the Koolau Mountains group (East Range, Kawailoa, and Kahuku); however the Waianae group surveys had a smaller sample size, and were only conducted in the second half of the year when bats are usually more active and location means do not accurately reflect the true seasonal nature of the area (Figure 2). The Koolau group which received a larger number of surveys covering the entire seasonal period is a more accurate reflection of bat activity.

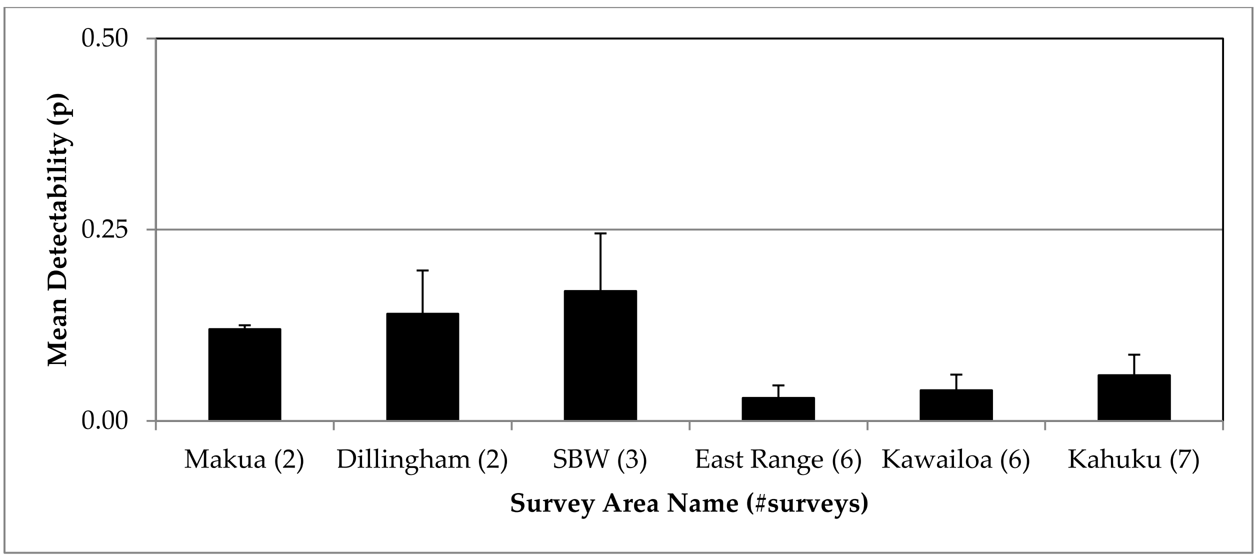


Figure 2. Mean bat detectability (p) with standard error for each survey area. Number of surveys conducted at each location appears in parenthesis.

Seasonal Activity and Foraging Behavior

Bat activity was seasonal in nature, with bat presence being detected and greater numbers of call events and pulses usually being recorded during the fall months (August through November) while little to no activity is typical during the winter months (December through March). However, some installations showed notable activity during the pupping season (June at Kawailoa) and over the winter period (December at SBW and Makua). The majority of bat events recorded at all stations were indicative of a single pass by the microphone with search-like echolocation pulses.

Foraging behavior was documented in several recordings from Kahuku in May, Dillingham in November, and overwhelmingly from SBW during the December 2013 survey period.

Bat Presence Comparisons

Compared to other locations on Oahu – Bat detectability values are similar to nearby locations sampled by USGS around Kawailoa, Kahuku, and SB East Range (C. Pinzari, personal communication).

Compared to outer Hawaiian Islands – Bat detectability values on Oahu in general are much lower than those from surveys on Hawaii, Maui, and Kauai Islands, where bats are usually detected above 20% of the time throughout the seasonal cycle when comparing values from week-long bi-monthly surveys (C. Pinzari, personal communication). Without accurate methods to directly count individuals from recorded events, and without available population estimates, the low bat detectability (low bat presence) on Oahu may be due to lower density of bats or may be due to lower availability of desired habitat for roosting and foraging, or a combination of both. Bats may be more dispersed, and need to travel greater distances to find suitable roosts, to track prey resources, and find mates.

'Kahuku' Training Area

Bats were present at the Kahuku Training Area surveys during May, August, October, and September (Figure 3). Foraging activity was documented in May, and the highest activity occurred during September and August (Table 1). When present, bats were recorded throughout the night, with greater activity during 20:00 and 1:00 (Figure 4).

Survey	Month - Year	Start Date	End Date	Recording Stations	Nights Sampled	Active Nights	Events	Pulses	Detectability (p)	Foraging
1	September-10	9/23/2010	9/29/2010	4	7	3	4	77	0.17	No
2	December-10	12/29/2010	1/5/2011	4	8	0	0	0	0.00	No
3	March-11	2/28/2011	3/2/2011	3	3	0	0	0	0.00	No
4	April-11	4/11/2011	4/18/2011	4	8	0	0	0	0.00	No
5	May-11	5/19/2011	5/27/2011	4	9	2	2	38	0.03	Yes
6	August-11	8/8/2011	8/15/2011	4	8	4	9	124	0.13	No
7	October-11	10/26/2011	11/1/2011	4	7	2	2	24	0.07	No
				Totals	50	11	17	263		

Table 1. Results from Kahuku Training Area bat surveys. For each survey; start date, end date, numbers of recording stations, nights sampled, nights with bat activity, number of events and echolocation pulses recorded. Presence reported as detectability (p), the probability of detecting a bat given the sampling effort. The presence of foraging activity is also listed for each survey.

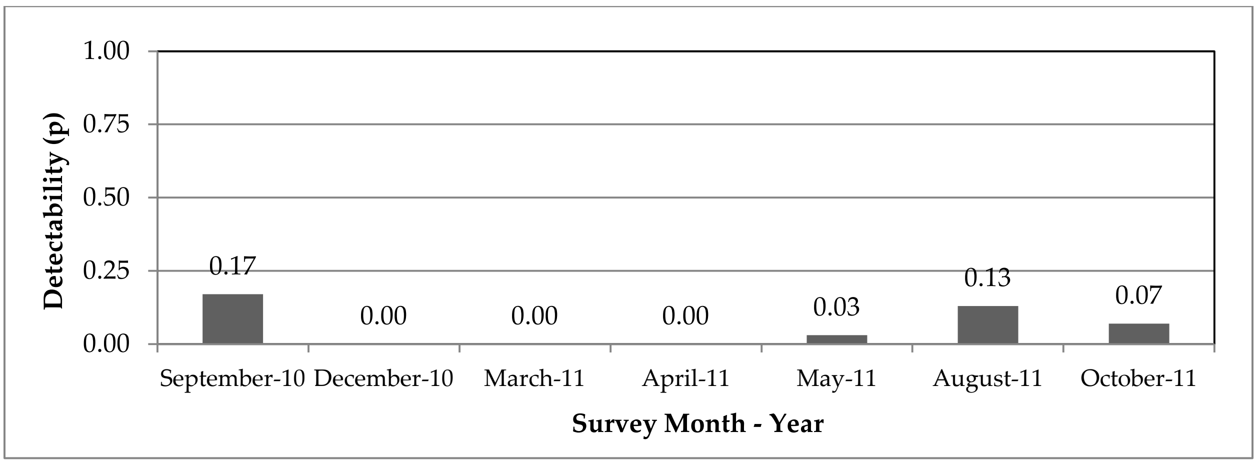


Figure 3. Bat detectability values for seven surveys conducted at Kahuku Training Area from September 2010 to October 2011. Numbers above bars represent the detection frequency (1.0 is equivalent to 100%) of pooled units for each survey. For example, 0.17 would represent bats being present 17% of the time during the recording period for all units recording during the survey. A zero represents a survey which recorded no bat detections, meaning bats were absent during the recording period.

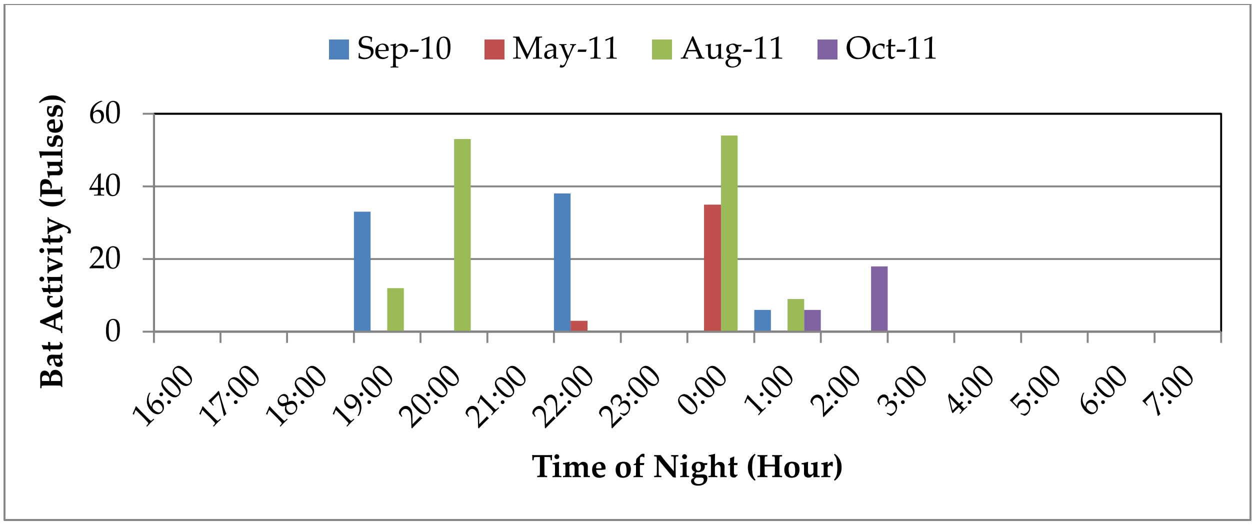


Figure 4. Temporal distribution of bat activity at Kahuku Training Area. Number of bat echolocation pulses recorded during each one hour period of the night (16:00 to 07:00) for all surveys in which bats were present.

Schofield Barracks 'East Range'

Bats were present at the East Range surveys during March, August, and November (Figure 5). No foraging activity was documented, and the highest activity occurred during August (Table 2). When present, bats were recorded throughout the night, with greater activity during 19:00 and 2:00 (Figure 6).

Survey	Month-Year	Start Date	End Date	Recording Stations	Nights Sampled	Active Nights	Events	Pulses	Detectability (p)	Foraging
1	November-10	11/1/2010	11/9/2010	4	8	2	2	30	0.06	No
2	January-11	1/6/2011	1/13/2011	4	7	0	0	0	0.00	No
3	March-11	3/22/2011	3/28/2011	4	7	1	1	3	0.03	No
4	May-11	5/5/2011	5/13/2011	4	9	0	0	0	0.00	No
5	August-11	8/17/2011	8/25/2011	3	9	3	10	96	0.11	No
6	November-11	11/7/2011	11/14/2011	4	8	0	0	0	0.00	No
				Total	48	6	13	129		

Table 2. Results from the Schofield Barracks East Range bat surveys. For each survey; start date, end date, numbers of recording stations, nights sampled, nights with bat activity, number of events and echolocation pulses recorded. Presence reported as detectability (p), the probability of detecting a bat given the sampling effort. The presence of foraging activity is also listed for each survey.

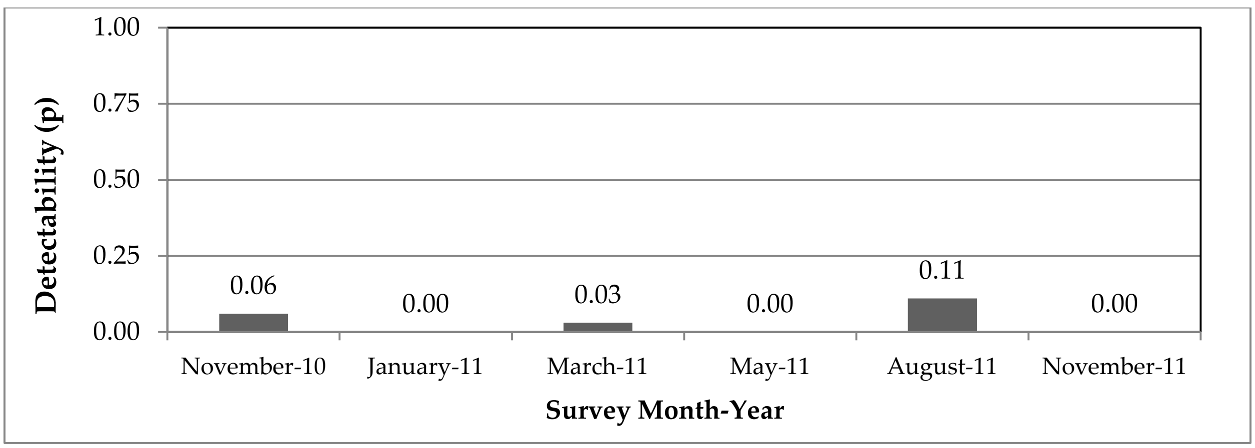


Figure 5. Bat detectability values for six surveys conducted at Schofield Barracks East Range from November 2010 to November 2011. Numbers above bars represent the detection frequency (1.0 is equivalent to 100%) of pooled units for each survey. For example, 0.06 would represent bats being present 6% of the time during the recording period for all units recording during the survey. A zero represents a survey which recorded no bat detections, meaning bats were absent during the recording period.

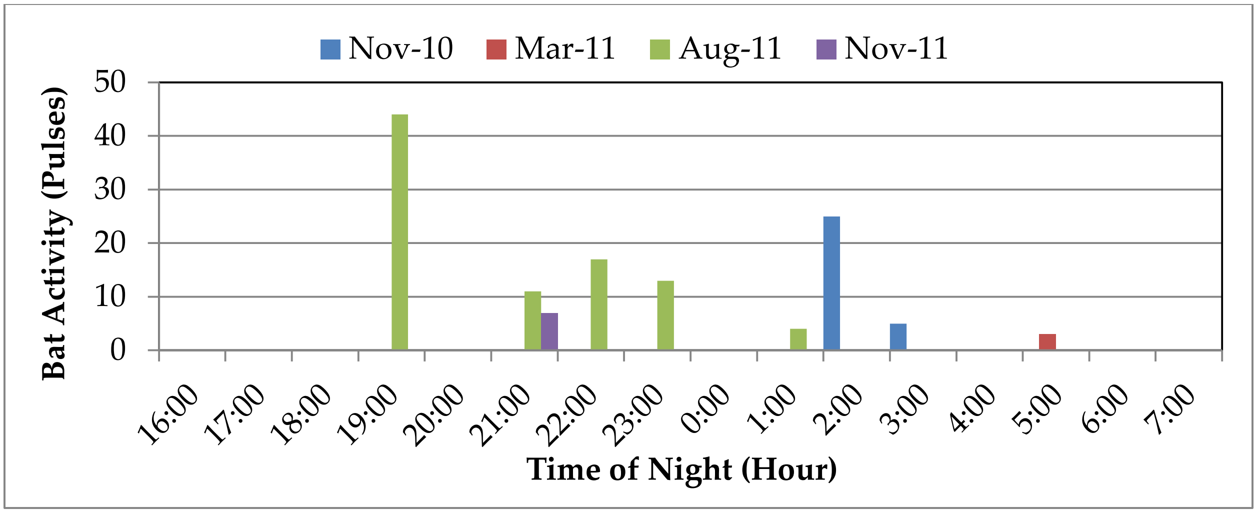


Figure 6. Temporal distribution of bat activity at Schofield Barracks East Range. Number of bat echolocation pulses recorded during each one hour period of the night (16:00 to 07:00) for all surveys in which bats were present.

'Kawailoa' Training Area

Bats were present at the Kawailoa surveys during June, September, and October (Figure 7). No foraging activity was documented, and the highest activity occurred during June (Table 3). When present, bats were recorded throughout the night, with greater activity during 18:00 and 2:00 (Figure 8).

Survey	Month - Year	Year	Start Date	End Date	Recording Stations	Nights Sampled	Active Nights	Events	Pulses	Detectability (p)	Foraging
1	September-11	2011	9/14/2011	9/22/2011	3	9	1	1	21	0.04	No
2	December-11	2011	12/5/2011	12/11/2011	3	7	0	0	0	0.00	No
3	February-12	2012	2/13/2012	2/20/2012	4	7	0	0	0	0.00	No
4	June-12	2012	6/26/2012	7/2/2012	3	7	3	3	42	0.14	No
5	October-12	2012	10/16/2012	10/29/2012	4	14	2	3	44	0.05	No
6	January-13	2013	1/8/2013	1/21/2013	1	14	0	0	0	0.00	No
					Totals	58	6	7	107		

Table 3. Results from the Kawailoa Training Area bat surveys. For each survey; start date, end date, numbers of recording stations, nights sampled, nights with bat activity, number of events and echolocation pulses recorded. Presence reported as detectability (p), the probability of detecting a bat given the sampling effort. The presence of foraging activity is also listed for each survey.

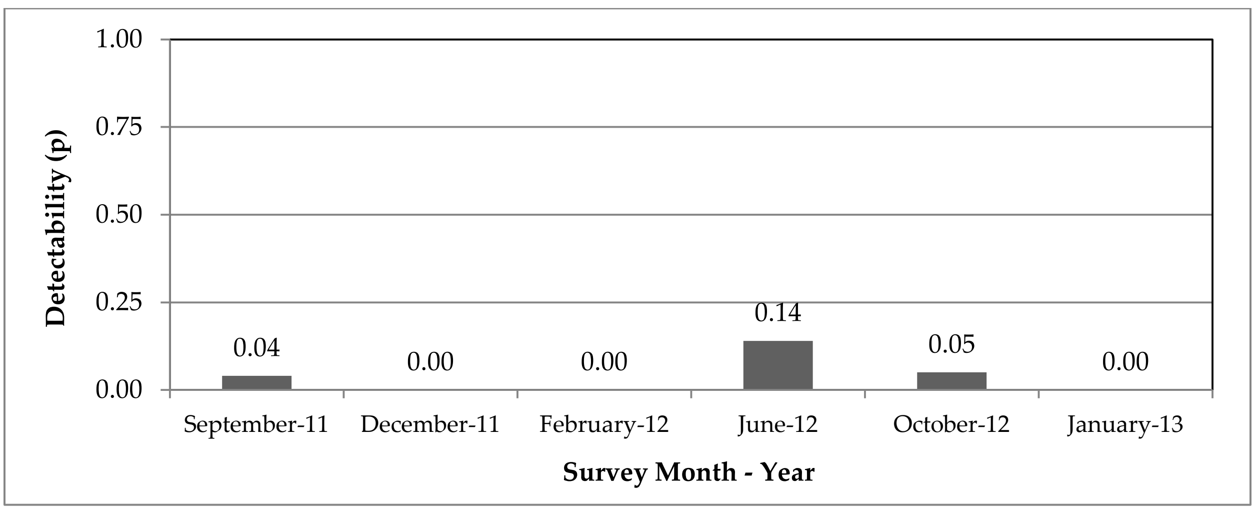


Figure 7. Bat detectability values for six surveys conducted at Kawailoa Training Area from September 2011 to January 2013. Numbers above bars represent the detection frequency (1.0 is equivalent to 100%) of pooled units for each survey. For example, 0.04 would represent bats being present 4% of the time during the recording period for all units recording during the survey. A zero represents a survey which recorded no bat detections, meaning bats were absent during the recording period.

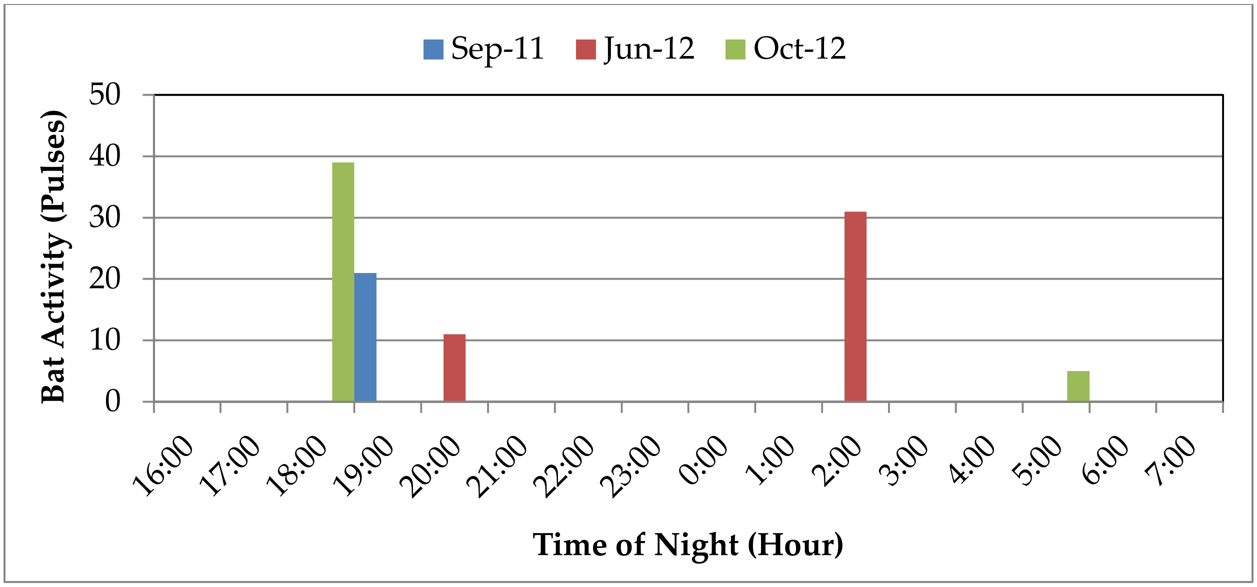


Figure 8. Temporal distribution of bat activity at Kawailoa Training Area. Number of bat echolocation pulses recorded during each one hour period of the night (16:00 to 07:00) for all surveys in which bats were present.

'Mauka' Military Reservation

Bats were present at the Makua surveys during October and December (Figure 9). No foraging activity was documented, and the highest activity occurred during October (Table 4). When present, bats were recorded throughout the night, with greater activity during 22:00 and 2:00-3:00 (Figure 10).

Survey	Month -Year	Year	Start Date	End Date	Recording Stations	Nights Sampled	Active Nights	Events	Pulses	Detectability (p)	Foraging
1	December-12	2012	12/17/2012	1/1/2013	1	16	2	3	48	0.12	No
2	April-13	2013	4/3/2013	4/22/2013	2	19	x	x	x	x	No data
3	October-13	2013	9/30/2013	10/18/2013	3	18	6	8	92	0.13	No
					Total	53	8	11	140		

Table 4. Results from the Makua Military Reservation bat surveys. For each survey; start date, end date, numbers of recording stations, nights sampled, nights with bat activity, number of events and echolocation pulses recorded. Presence reported as detectability (p), the probability of detecting a bat given the sampling effort. The presence of foraging activity is also listed for each survey.

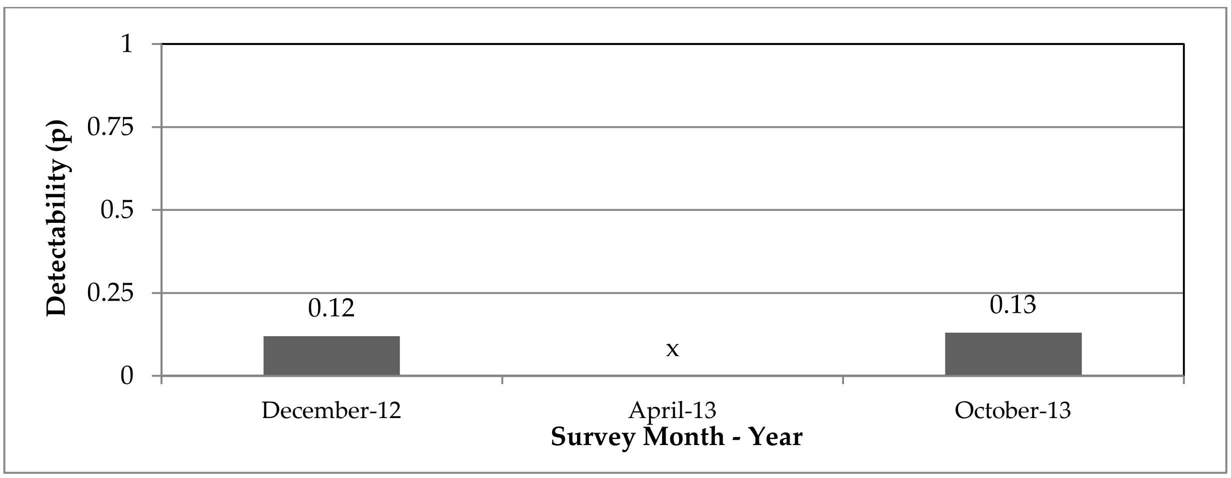


Figure 9. Bat detectability values for two surveys conducted at Makua Military Reservation from December 2012 and October 2013. Survey during April 2013 (x) retrieved no data due to equipment malfunction. Numbers above bars represent the detection frequency (1.0 is equivalent to 100%) of pooled units for each survey. For example, 0.12 would represent bats being present 12% of the time during the recording period for all units recording during the survey. A zero represents a survey which recorded no bat detections, meaning bats were absent during the recording period.

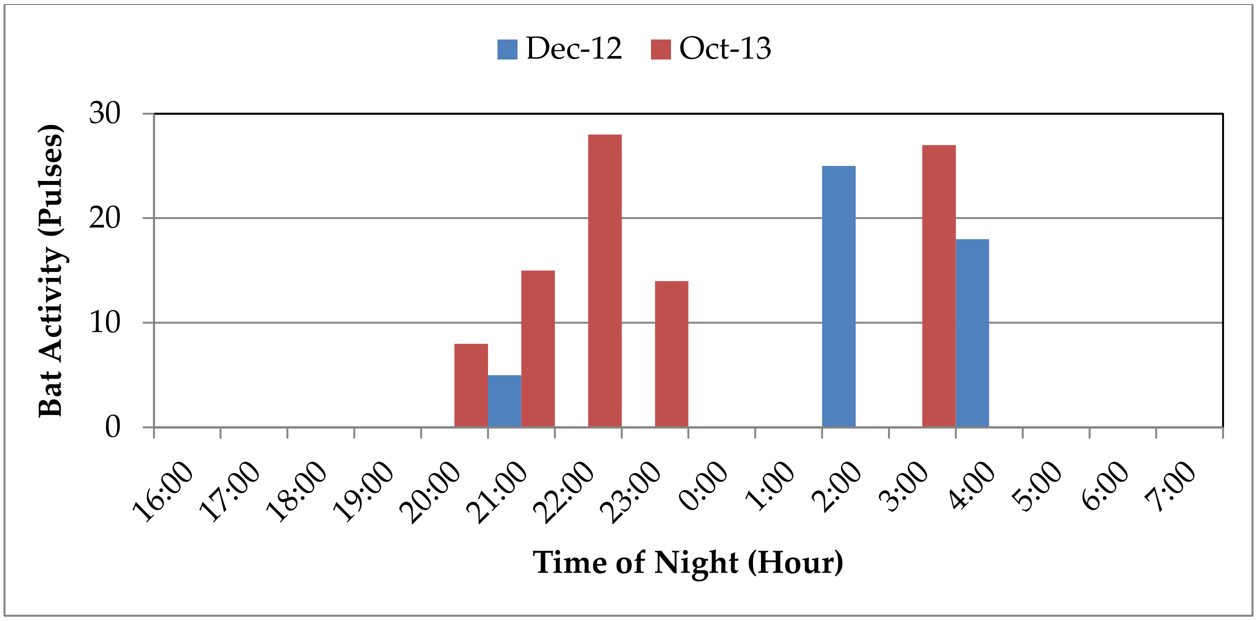


Figure 10. Temporal distribution of bat activity at Makua Military Reservation. Number of bat echolocation pulses recorded during each one hour period of the night (16:00 to 07:00) for all surveys in which bats were present.

'Dillingham' Air Field

Bats were present at the Dillingham surveys during September and November (Figure 11). Foraging activity was documented during November, and the highest activity occurred during September (Table 5). When present, bats were recorded throughout the night, with greater activity during 22:00 and 0:00-1:00 (Figure 12).

Survey	Month- Year	Year	Start Date	End Date	Recording Stations	Nights Sampled	Active Nights	Events	Pulses	Detectability (p)	Foraging
1	November-12	2012	10/30/2012	11/14/2012	3	16	4	4	45	0.08	Yes
2	March-13	2013	3/1/2013	3/19/2013	2	18	x	x	x	x	No
3	September-13	2013	9/9/2013	9/22/2013	3	14	8	10	83	0.20	No
					Total	48	12	14	128		

Table 5. Results from the Dillingham Air Field bat surveys. For each survey; start date, end date, numbers of recording stations, nights sampled, nights with bat activity, number of events and echolocation pulses recorded. Presence reported as detectability (p), the probability of detecting a bat given the sampling effort. The presence of foraging activity is also listed for each survey.

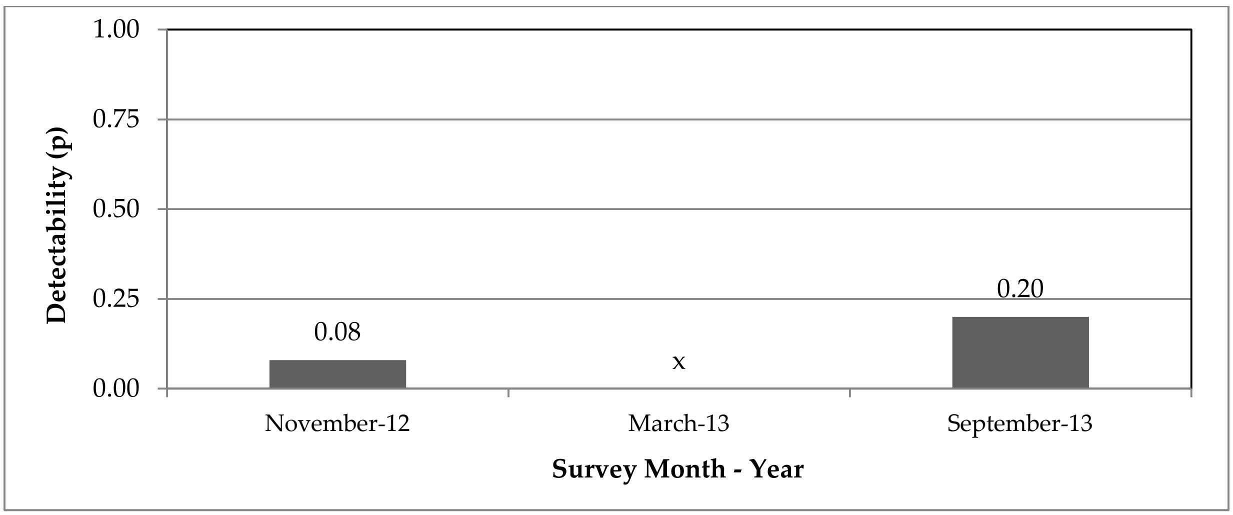


Figure 11. Bat detectability values for two surveys conducted at Dillingham Air Field from November 2012 and September 2013. Survey during March 2013 (x) retrieved no data due to equipment malfunction. Numbers above bars represent the detection frequency (1.0 is equivalent to 100%) of pooled units for each survey. For example, 0.20 would represent bats being present 20% of the time during the recording period for all units recording during the survey. A zero represents a survey which recorded no bat detections, meaning bats were absent during the recording period.

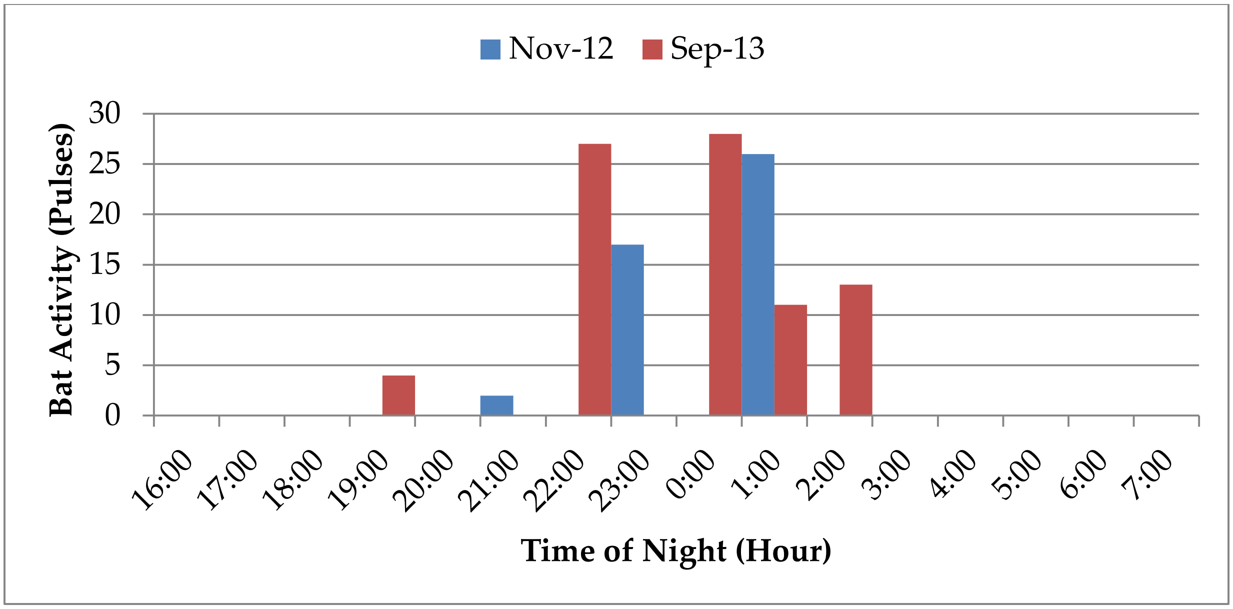


Figure 12. Temporal distribution of bat activity at Dillingham Air Field. Number of bat echolocation pulses recorded during each one hour period of the night (16:00 to 07:00) for all surveys in which bats were present.

Schofield Barracks West Range (SBW)

Bats were present during each of the West Range surveys during July, November, and December (Figure 13). Foraging activity coincided with the highest activity, which was documented during December (Table 6). Bats were recorded throughout the night, with greater activity during 1:00-2:00 and 5:00 (Figure 14).

Survey	Month - Year	Year	Start Date	End Date	Recording Stations	Nights Sampled	Active Nights	Events	Pulses	Detectability (p)	Foraging
1	November-12	2012	11/21/2012	12/5/2012	4	14	6	7	87	0.20	No
2	July-13	2013	7/6/2013	7/21/2013	3	15	1	1	25	0.02	No
3	December-13	2013	12/22/2013	1/2/2014	3	15	11	720	10,079	0.28	Yes
					Totals	44	18	728	10191		

Table 6. Results from the SBW bat surveys. For each survey; start date, end date, numbers of recording stations, nights sampled, nights with bat activity, number of events and echolocation pulses recorded. Presence reported as detectability (p), the probability of detecting a bat given the sampling effort. The presence of foraging activity is also listed for each survey.

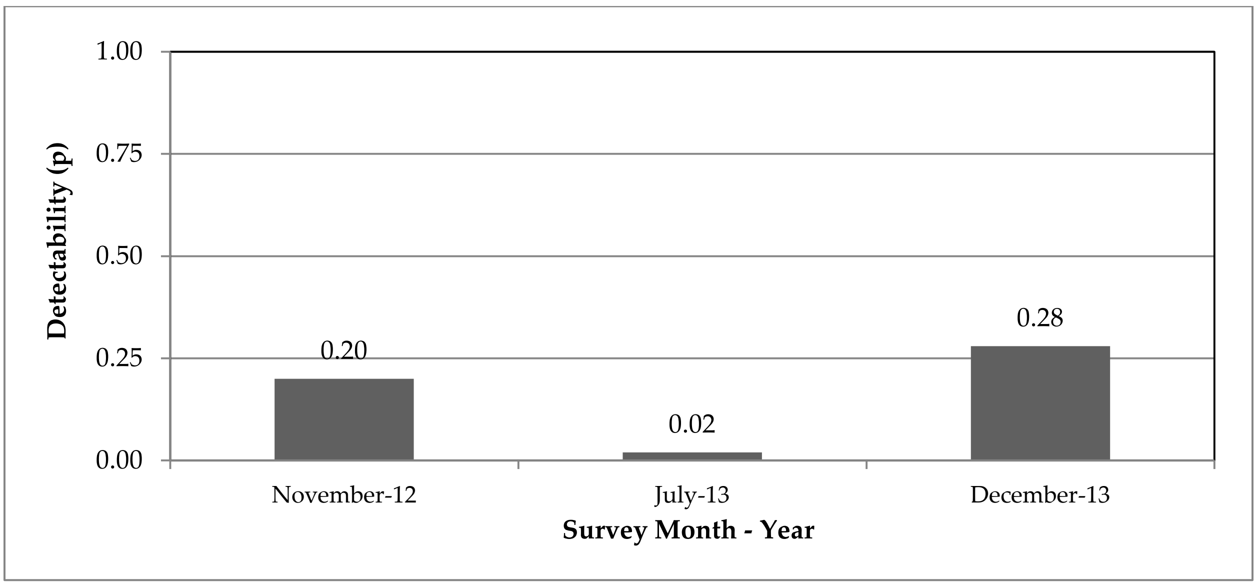


Figure 13. Bat detectability values for three surveys conducted at SBW from November 2012, July 2023, and December 2013. Numbers above bars represent the detection frequency (1.0 is equivalent to 100%) of pooled units for each survey. For example, 0.28 would represent bats being present 28% of the time during the recording period for all units recording during the survey. A zero represents a survey which recorded no bat detections, meaning bats were absent during the recording period.

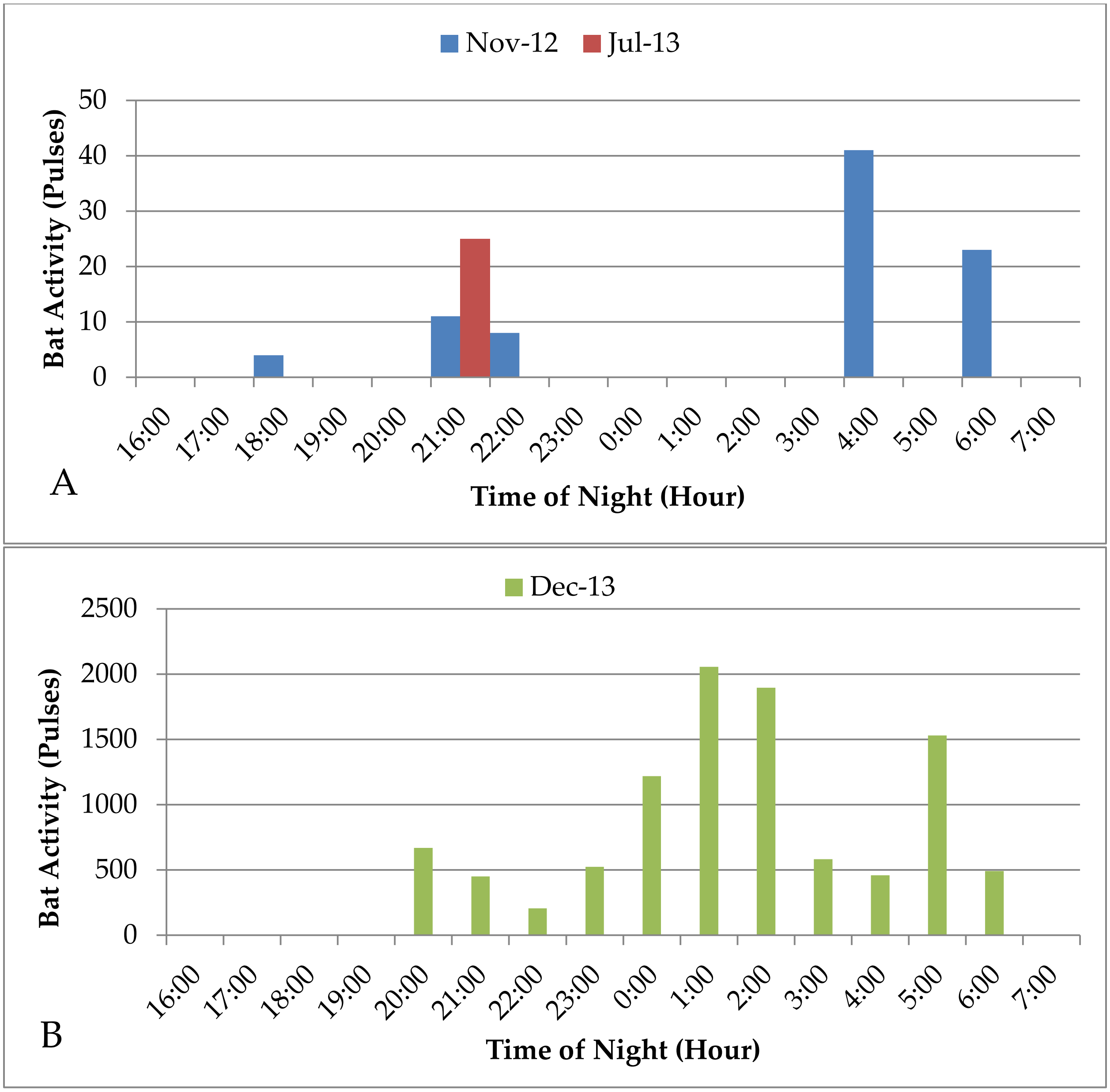


Figure 14. Temporal distribution of bat activity at Schofield Barracks West Range. Number of bat echolocation pulses recorded during each one hour period of the night (16:00 to 07:00) for all surveys in which bats were present. Panel A displays the activity from the November 2012 and July 2013 surveys. Panel B displays the activity from the December 2013 survey, which recorded the heaviest activity levels with 89 foraging events throughout the night, with maximum activity reaching 2,000 echolocation pulses recorded during the hour.

Recommendations

Now that bat presence has been established, extend survey periods to longer than one week. The number of stations has been sufficient for each area considered, and future surveys should maintain monitoring at these sites. Waianae group locations need more surveys to balance out survey effort, collect data over one entire season, especially due to notable foraging activity and use during the winter months.

Design of recording station set up should change to increase potential detection opportunity for bats, decrease the collection of noisy recordings, and ensure that data collected may be comparable to outside studies on Oahu and the outer islands. The microphone should not be installed on the side of SM2bat device; the microphone should be mounted on top of a 10 foot pole with a cord to connect it to the unit, thus is becomes elevated into the airspace used by flying bats. This pole should then be placed in an area with open air space around it, preferably on the edge of vegetation or a structure, so that it blends into the surroundings. It's possible that microphone placement could have limited the number of bat call detections recorded, and in turn resulted in low detectability estimates for this study.

Appendix ES-1 Spelling of Hawaiian Names

Place name	Hawaiian spelling
Aiea	‘Aiea
Aihualama	‘Aihualama
Aimuu	Aimuu
Alaiheihe	Alaiheihe
Alau	Alau
Ekahanui	‘Ēkahanui
Halawa	Hālawa
Haleauau	Hale‘au‘au
Halona	Hālona
Hawaii	Hawai‘i
Hawaii loa	Hawai‘iloa
Helemano/Halemano	Helemano/Halemano
Honolulu	Honolulu
Honouliuli	Honouliuli
Huliwai	Huliwai
Kaaikukai	Ka‘aikūka‘i
Kaala	Ka‘ala
Kaawa	Ka‘awa
Kaena	Ka‘ena
Kahaluu	Kahalu‘u
Kahana	Kahana
Kahanahaiki	Kahanahāiki
Kaimuhole	Kaimuhole
Kaipapau	Kaipāpa‘u
Kaiwikoele	Kaiwikō‘ele
Kalauao	Kalauao
Kaleleliki	Kaleleiki
Kalena	Kalena
Kaluaa	Kalua‘ā
Kaluakauila	Kaluakauila
Kaluanui	Kaluanui
Kamaileunu	Kamaile‘unu
Kamaili	Kamā‘ili
Kamananui	Kamananui
Kapakahi	Kapakahi
Kapuna	Kapuna
Kauai	Kaua‘i
Kauhiuhi	Kauhiuhi
Kaukonahua	Kaukonahua
Kaumoku Nui	Kaumoku Nui
Kaunala	Kaunala
Kawaihapai	Kawaihāpai
Kawaiiki	Kawaiiki
Kawailoa	Kawailoa
Kawainui	Kawainui
Kawaipapa	Kawaipapa
Kawaiu	Kawaiū

Keaau	Kea‘au
Kealia	Keālia
Keawapilau	Keawapilau
Keawaula	Keawa‘ula
Kihakapu	Kihakapu
Kipapa	Kīpapa
Koiahi	Ko‘iahi
Koloa	Koloa
Konahuanui	Kōnāhuanui
Koolau	Ko‘olau
Kuaokala	Kuaokalā
Laie	Lā‘ie
Lanai	Lāna‘i
Lualualei	Lualualei
Lulumahu	Lulumahu
Maakua	Ma‘akua
Makaha	Mākaha
Makaleha	Makaleha
Makaua	Makaua
Makua	Mākua
Malaekahana	Mālaekahana
Manana	Mānana
Manini	Manini
Manoa	Mānoa
Manuka	Manukā
Manuwai	Manuwai
Maui	Maui
Maunauna	Maunauna
Maunawili	Maunawili
Mikilua	Mikilua
Moanalua	Moanalua
Mohiakea	Mohiākea
Mokuleia	Mokulei‘a
Molokai	Moloka‘i
Nanakuli	Nānākuli
Niu	Niu
Nuuanu	Nu‘uanu
Oahu	O‘ahu
Ohiaai	‘Ōhi‘a‘ai
Ohikilolo	‘Ōhikilolo
Oio	‘Ō‘io
Opaeula	‘Ōpae‘ula
Paalaa Uka	Pa‘ala‘a Uka
Pahipahialua	Pahipahi‘ālua
Pahoa	Pāhoa
Pahole	Pahole
Palawai	Pālāwai
Palehua	Pālehua
Palikea	Palikea
Papali	Papali
Peahinaia	Pe‘ahināi‘a
Pohakea	Pōhākea
Puaakanoa	Puaakanoa*
Pualii	Puali‘i

Puhawai	Pūhāwai
Pukele	Pūkele
Pulee	Pule‘ē
Punapohaku	Punapōhaku
Puu Hapapa	Pu‘u Hāpapa
Puu Kailio	Pu‘u Ka‘īlio
Puu Kanehoa	Pu‘u Kānehoa
Puu Kaua	Pu‘u Kaua
Puu Kawiwi	Pu‘u Kawiwi
Puu Kumakalii	Pu‘u Kūmakali‘i
Puu Pane	Pu‘u Pane
Puuhapapa	Pu‘u Hāpapa
Puukaaumakua	Pu‘u Ka‘aumakua
Puukailio	Pu‘u Ka‘īlio
Puukainapuaa	Pu‘u Ka‘inapua‘a
Puukanehoa	Pu‘u Kānehoa
Puukaua	Pu‘u Kaua
Puukawiwi	Pu‘u Kawiwi
Puukeahiakahoe	Pu‘u Keahiakahoe
Puukumakalii	Pu‘u Kūmakali‘i
Puulu	Pū‘ulu
Puuokona	Pu‘u o Kona
Puupane	Pu‘u Pane
Waahila	Wa‘ahila
Wahiawa	Wahiawā
Waialae Nui	Wai‘alae Nui
Waialua	Waialua
Waianae Kai	Wai‘anae Kai
Waiawa	Waiawa
Waieli	Wai‘eli
Waihee	Waihe‘e
Waikane	Waikāne
Wailupe	Wailupe
Waimalu	Waimalu
Waimano	Waimano
Waimea	Waimea
Waimea	Waimea
Wiliwilinui	Wiliwilinui

*Diacriticals unknown

Appendix ES-2

Tutorial: Operating the OANRP Database (Distribute Version)

Overview

The Oahu Army Natural Resources Program Database (OANRP Database) is a multi-level database, coordinating diverse data from rare plant observations, reintroductions, rare snail monitoring, plant nursery propagation, and weed/ungulate management. The database files are developed with Microsoft Access. It is recommended that Access software versions 2007, 2010, or 2013 be used.

The database allows the Army staff to know which plant individual has been collected, matured, or died thus providing a better understanding of the genetic diversity that remains for any given rare species that the Army must manage. Using this database, the Army maintains consistent tracking and reporting for its managed rare species.

The APD is based upon the criteria established by the Hawaii Rare Plant Restoration Group (HRPRG). As part of the Makua and Oahu Implementation Plans, the Army Propagation database has been a 15 year effort in developing and coordinating the collection, propagation, management, and tracking of rare species.

The following appendix will briefly cover the database requirements and database procedures. Only important search criteria will be discussed. Most data fields are self-explanatory. This tutorial will be a guide to the database reports presented in previous OANRP status updates.

Several database reports may take a several minutes to compile within the database, thus pdf versions of the three major database reports (Population Unit Status, Threat Control Summary, and Genetic Storage Summary) have been created and may be found in the database reports subdirectory. Therefore, running the database may not be necessary unless more information is needed beyond the pdf version of the reports provided. Data provided is as of September 30, 2014.

Modification to the data and/or structure of the database is prohibited. The database version provided is read-only. It is intended for Implementation Team and collaborating agencies only. Distribution of the database structure and/or data is prohibited without the consent by the Oahu Army Natural Resources Program.

Questions may be directed to:

Roy Kam
Natural Resources Database Programmer Specialist
Oahu Army Natural Resources Program
Email: rkam@hawaii.edu

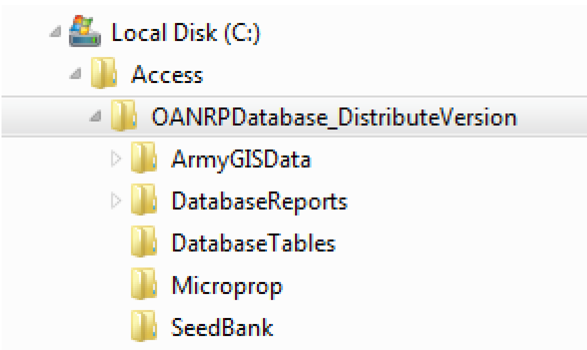
Linda Koch
Natural Resources GIS Specialist
Oahu Army Natural Resources Program
Email: lkoch@hawaii.edu

I. Database Settings

Setting Database Directories and Security Warning

Database directories

The database must be placed under the following directories. Copy the following directories and data files from the data disc to the C: drive. Database path and GIS files must be within the following directories. All subdirectories should be under **C:**



Descriptions of the files within each subdirectory are as follows under C:\Access\OANRPDatabase_DistributeVersion:

OANRPDatabase_DV.mdb

Front-End database file what most database users see, the database file manages the data forms, queries and reports. Data used in the OANRP Database is kept in the back-end data file (OANRPDataTables_DV.mdb) located in the database tables subdirectory. Forms are locked and may only be used for viewing purposes.

C:\Access\OANRPDatabase_DistributeVersion\ArmyGISData\

GIS shapefiles depicting the rare plant sites, managed areas, and fence lines.

C:\Access\OANRPDatabase_DistributeVersion\DatabaseTables\OANRPDataTables_DV.mdb

Back-End database file containing data for the Front-End database file.

C:\Access\OANRPDatabase_DistributeVersion \Microprop\Microprop.mdb

Lyon Arboretum Micropropagation Database. Contact Nellie Sugii for more information.

C:\Access\OANRPDatabase_DistributeVersion \SeedBank\SeedBankDatabase.mdb

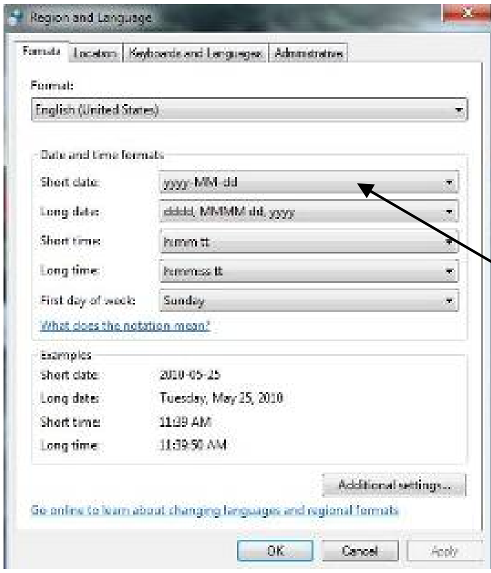
Army SeedLab Database. Contact Lauren Weisenberger for more information.

C:\Access\ OANRPDatabase_DistributeVersion \TaxaDatabaseReports

Population Unit Status, Threat Control Summary, and Genetic Storage Summary PDF reports for each IP taxa.

Setting Default Date Format

The default date format for most computers is normally set to mm/dd/yy. The format can be confusing and not sort properly for Access database records. Although, not required, the date format for computers using this Access database should be changed to yyyy-mm-dd.



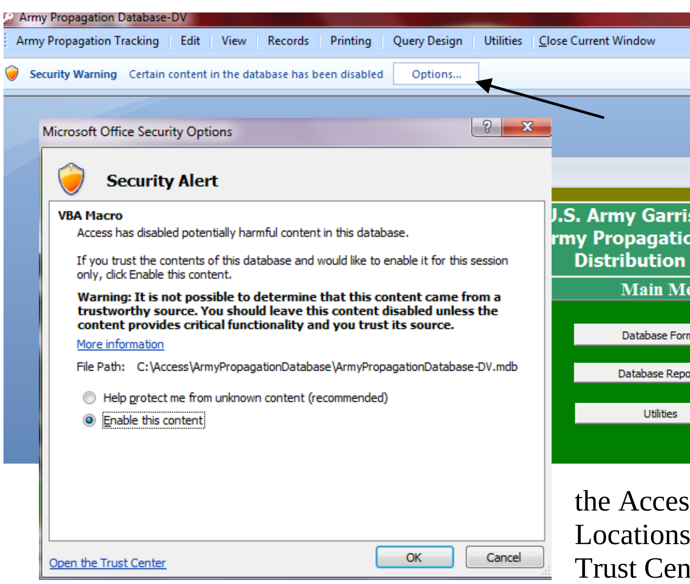
- Open Regional and Language Options by clicking the **Start** button, clicking **Control Panel**, clicking **Clock, Language, and Region**, and then clicking **Regional and Language.** Under the Formats, change the **Short Date** to **yyyy-MM-dd.**

Change to yyyy-MM-dd

Security Warning

Security features in Microsoft Access 2007, 2010, and 2013 automatically disables any executable content. The Access database with customized, buttons, commands, etc. will have a warning and not work unless the following is set within your computer.

To help you manage how executable content behaves on your computer, Office Access 2007/2010/2013 database content must be enabled when the Security Warning appears.



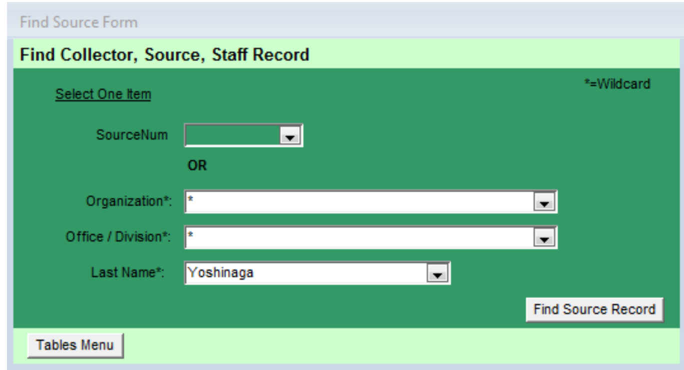
After opening the OANRPDatabase_DV.mdb file in Microsoft Access, click on Options when it appears at the top of your screen.

A window stating Security Alert will appear. Click on the button to select Enable this content, and click OK. Enabling the content will allow the database functions to operate.

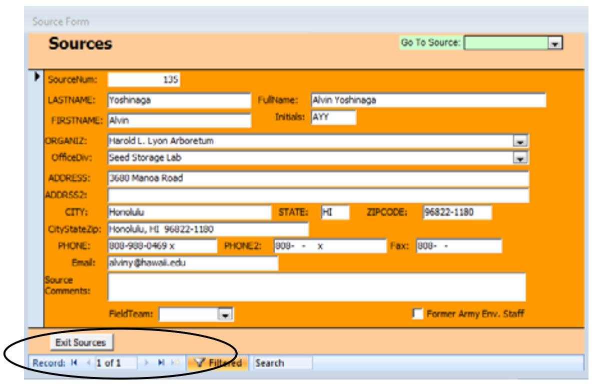
Enabling content will have to be done every time the database file is opened. You may avoid having this Security Warning appear if the Access subdirectory is added to the Trust Center Locations. Contact Roy Kam if you need to establish a Trust Center Location.

Data Search Methods

Most data form and report sections start with a Find Form. These Find Forms have drop downs that allow you to find an existing record. In the adjacent example, locating the Sources record for Alvin Yoshinaga.

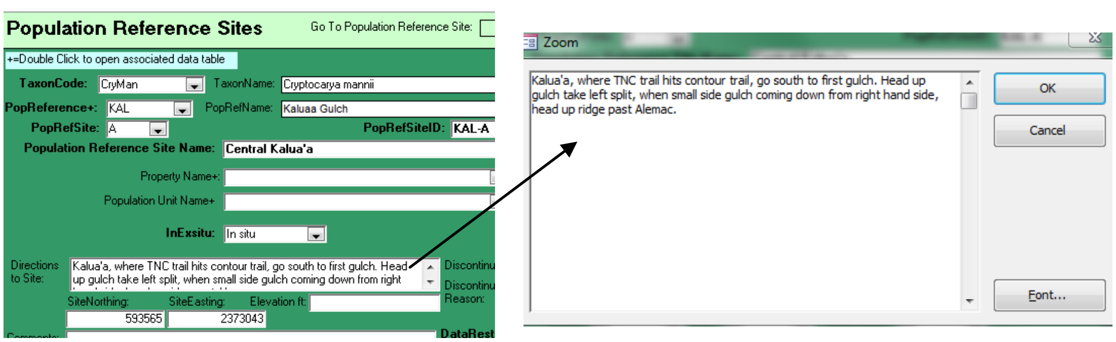


Using the * (asterisk), in a Find Form represents a wild card. Such as Organization *= Search for all Sources with any Organization. In this case, we will just search for the Last Name = Yoshinaga.

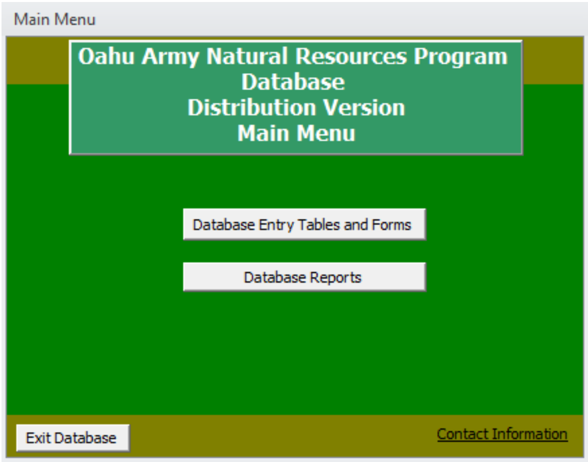


On the bottom of each Data entry form (such as the Sources Form), there are a set of Navigation buttons. These buttons allow you to go to the previous or next record. Pressing the tab or enter keys moves from one data field to another.

Short cuts: *Shift + F2* in any text field (within a data entry form or datasheet) will bring up the Zoom window. The Zoom window will allow you to view the complete text entered in that data field. See example below.



II. Main Menu



Open the **OARNPDatabase_DV.mdb** either by double clicking the file, creating a shortcut on your desktop, or by opening MS Access and opening the file. The database will open to the Main Menu.

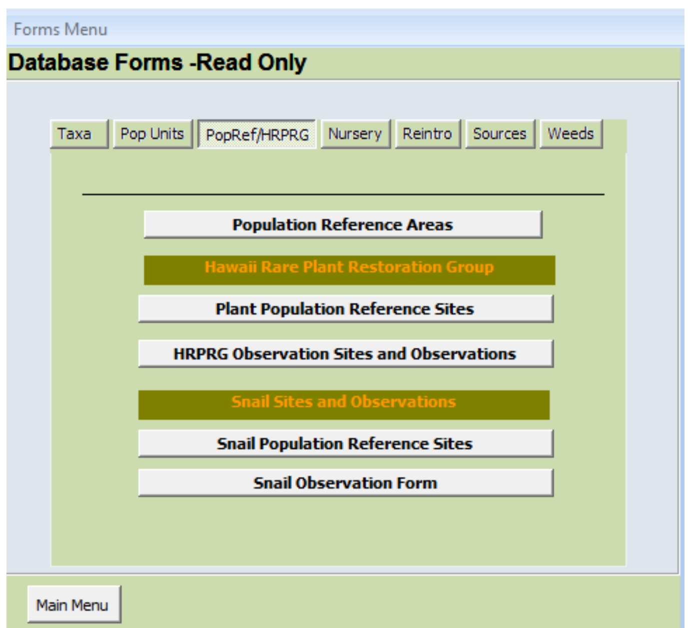
The database is broken up into 2 parts, Database Forms and Database Reports. We will primarily cover the Database reports. Database Forms are self-explanatory and is only for viewing purposes. The forms are provided for detailed review of individual observations. Only pertinent data fields will be discussed in detail.

III. Database Forms

The **Database Forms menu** is broken up into several sections. They are Taxa, Pop Units, PopRef/HRPRG, Reintro, Sources, and Weeds.

Most buttons under each tab will open a "Find" form that will allow you to find existing database record.

For the purpose of this tutorial, we will discuss forms of the PopRef/HRPRG tab with comprise of the Population Reference and Population Reference Sites. All other sections are supplemental and self-explanatory.

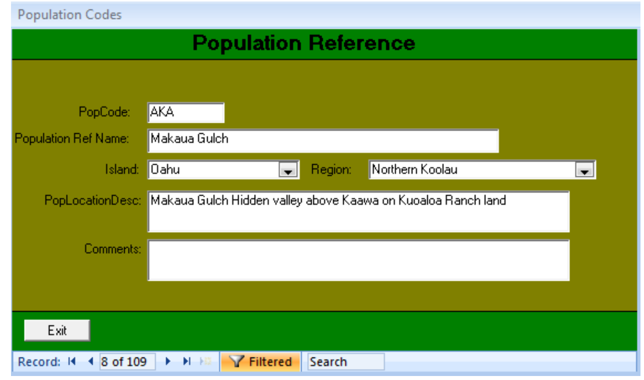


an

PopRef, Sites, and Observations

Population information is broken up into three sections, Population Reference Areas (PopRef), Population Reference Sites (PopRefSite) and Observations. Both In situ and Reintro observations will be covered in this section.

Population Reference Areas (PopRef)



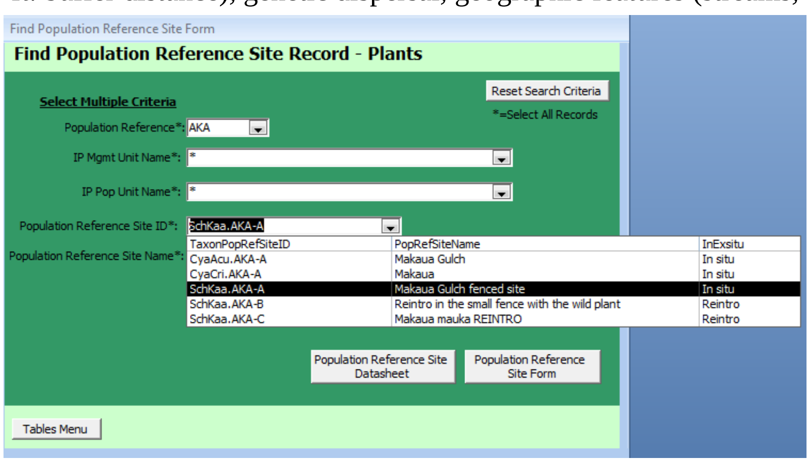
Population Reference, also known as PopRef for short, is a boundary system that allows a consistent identification of plant or animal populations. The PopRef is normally valleys, summits, ahupuaa, bogs, or areas that biologists have continuously acknowledged within observations from past decades.

It should be noted that the Population Reference is not necessarily the name for any given population. It is only used as an identifier to compile different plant or animal populations within a given area. For example: Makaua on the Windward Koolau of Oahu (highlighted in blue). The GIS boundary is based upon Makaua's ahupuaa as AKA's PopRef. But a plant population within Makaua PopRef, its population name may be named something different like a puu, or other landmark within Makaua.

Population Reference Site (PopRefSite)

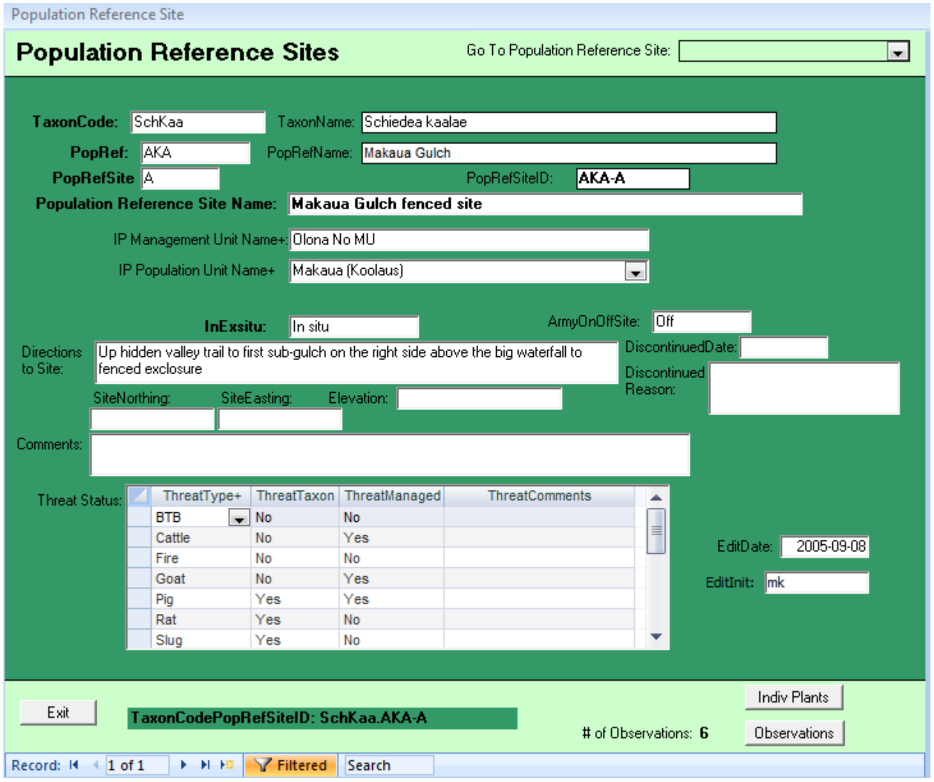
The Population Reference Site (PopRefSite) is the primary data table in establishing plant or animal population sites. The PopRefSite identifies the Population Name, whether it is In situ, Ex situ or Reintro, and provides directions to the site, etc. The PopRefSite is only site information; observation information from various surveys is kept in the observation section discussed later.

Determining what is a population or Population Reference Site is always very difficult and can vary by taxon. Normally populations are determined by the botanist in the field. Population determination criteria normally used is topography, distance from one population to another (Army normally uses 1000 ft. buffer distance), genetic dispersal, geographic features (streams, veg. type changes), etc.



To view an existing PopRefSite record, from the menu click on the Population Reference Sites button, a Find Population Reference Site Record form will appear and select AKA under the PopRef drop down as in the example. From that, you could also see all of the AKA Populations under the Population Reference Site ID Drop down. Select SchKaa.AKA-A.

Within the PopRefSite record, **TaxonCode, PopRef, and PopRefSite (Site Letter)** are kept. All three data fields build the TaxonCodePopRefSiteID (aka PopRefSiteID or PopRef Code). The PopRefSiteID is found on the bottom of the form in this case SchKaa.AKA-A. The PopRefSiteID is the unique key field that provides consistent population identification. The format of the PopRefSiteID is always TaxonCode**.**PopRef**-**<u>SiteLetter</u>.



Population Reference Site Name (PopRefSiteName) is the name used to identify the population. It is normally be a brief descriptive name. Detailed directions or descriptions are entered in the Directions to Site field.

IP Management Unit Name: Management Unit commonly known from.

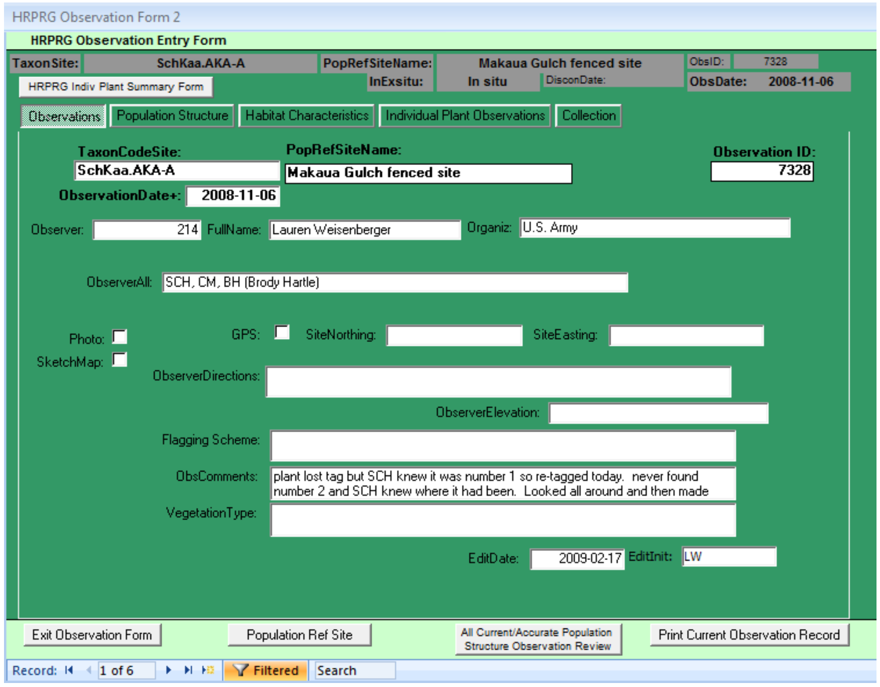
IP Population Unit Name (PopUnit): The PopUnit is used when several PopRefSites need to be tracked together. Such as a taxon with several sites throughout the Northern Waianae Mountains, Northern Waianae could be used as a PopUnit Name.

InExsitu: Identifies whether the PopRefSite is a naturally occurring wild (In situ), or Reintroduction (Reintro), etc.

Directions to Site: Detailed directions to locate the population.

Threat Control Status: What the threat control is being conducted (Yes, No, Partial)

Observations

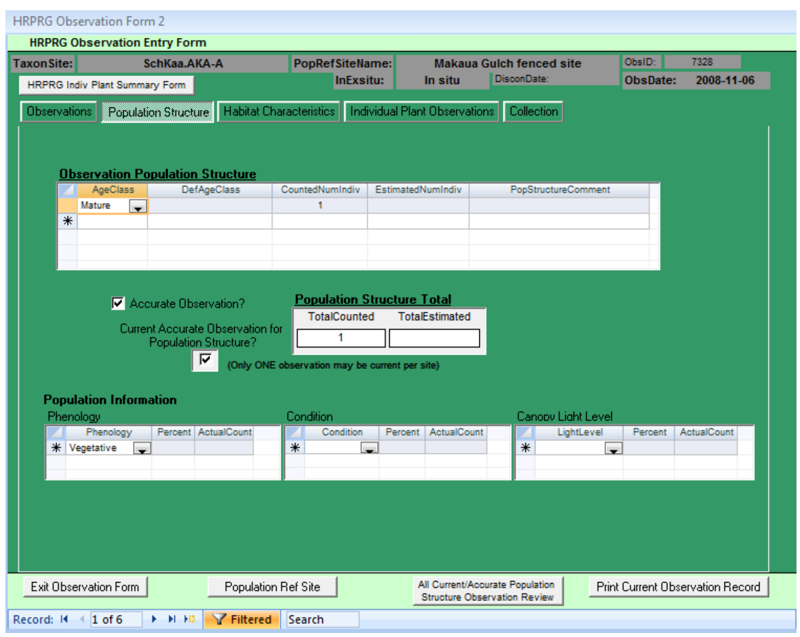


Clicking the Observations button on the bottom of the PopRefSite Form will open up the corresponding Observations.

ObservationDate: Observations of the Population Reference Site are entered by the ObservationDate. Observation Date is normally the day that the Population Site was surveyed. If the individual(s) were not found during the survey, the observation date and record is still be filled out. If the survey took several observation days, then the start date is entered in the ObservationDate.

Observer Directions may be entered if it is different from the PopRefSite Directions. Observer Directions may be a different route or situation that would represent the directions for that survey day.

Population Structure

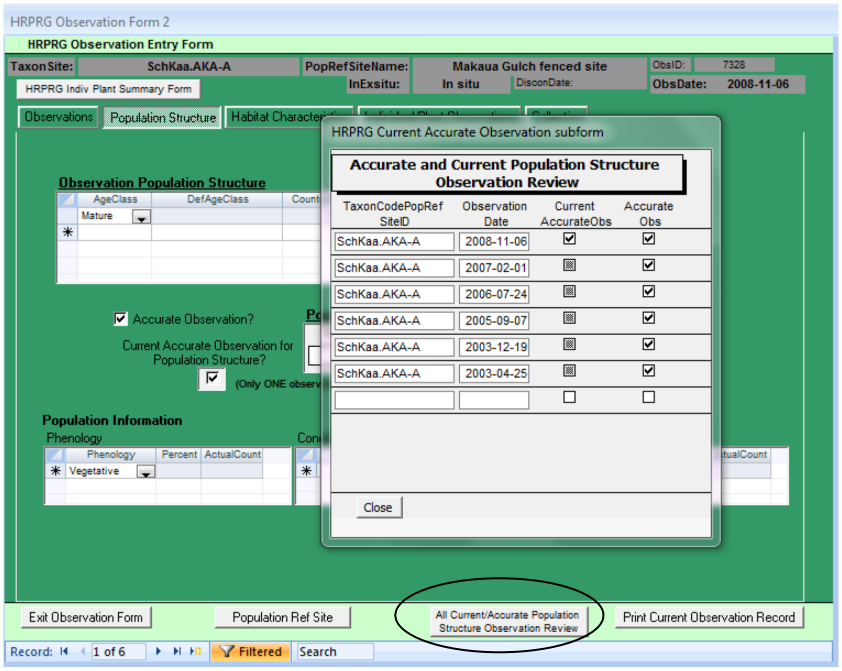


The Population Structure should are always entered for any observations, even if the number of plants observed are incomplete (not all plants observed).

Age Class always is required, where **CountedNumIndiv** (Counted Number of Individuals) is considered a more accurate count of the number of plants. **EstimatedNumIndiv** (Estimated Number of Individuals) may be entered only when the CountedNumIndiv is not entered. EstimatedNumIndiv is used when the number of plants is numerous. EstimatedNumIndiv should not be entered when the number of plants can be counted.

EstimatedNumIndiv may not be a number range, if a range such as 100-200 is provided, the conservative number 100 is entered, and 100-200 may be entered in the PopStructureComment.

Accurate Observation is checked off when the Population Structure's Age Classes and CountedNumIndiv/ EstimateNumIndiv contain an accurate and representative count of the PopRefSite population. Many observations over different survey dates may have the Accurate Observation checked off.

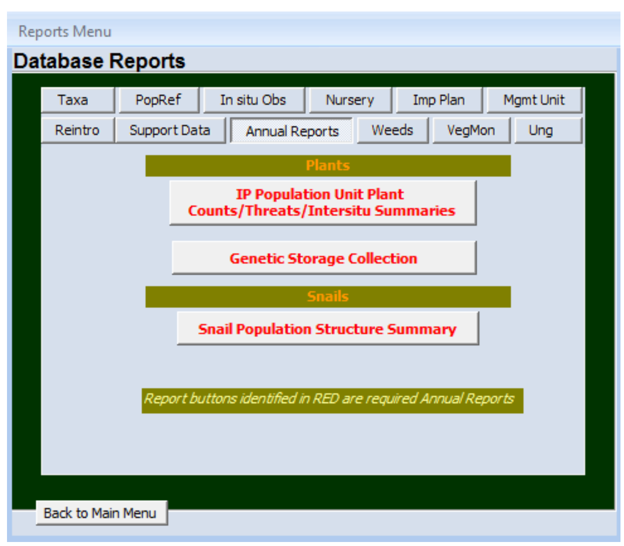


As opposed to the Accurate Observation check box, the <u>**Current Accurate Observation** check off box may only have one observation checked</u>. The Current Accurate represents the population structure that is considered both current and accurate. The most recent observation may not always be the Current Accurate observation, thus the Current Accurate is used to identify the proper Population Structure numbers that currently represents the population in reports and queries.

Clicking on the button on the bottom "All Current/Accurate PopStruc Obs Review" will pull up a review form to show all observations for the site and which ones were Accurate, and which one is tagged as the Current/Accurate.

IV. <u>Database Reports</u>

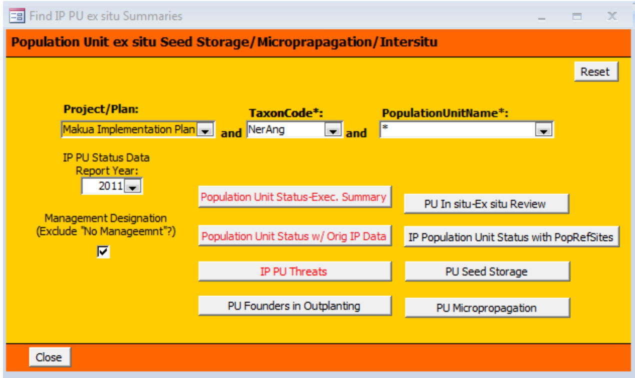
Starting from the Main Menu, click on the Database Reports button. The Database Reports menu provides reports for various sections of the database.



Similar to the Database Entries, clicking on a button within the Database Reports will open a Find Form that will assist in selecting data records for the report.

For the purpose of this document, we will cover the reports normally generated for the Year-End Annual report.

There are three sections consisting of four reports that are normally printed annually. The sections are IP Populations, Genetic Storage, and Snail Population as shown in the figure to the right.



Taxon Status and Threat Summaries

Under the IP Population Unit button, the menu has threat reports (in red) Exec. Summary, Taxon Status (Population Unit Status) and the Threat Summary (IP PU Threats). Buttons with red text will signify it is a report used in the year-end annual report. Project/Plan and Report Year must be selected for the reports to run. In the Report Year Field, select 2012. Report Year is defined below under Total Mature, Immature and Seedling 2012.

Executive Summary

The Executive Summary database report combines data derived from the Taxon Status Summary Report, Genetic Summary Report and Threat Summary. See below for further details.

Makua Implementation Plan - Executive Summary - Plants

# of Stable IP Population Units: 43 of 100

[shaded] = Ungulate Threat to Taxon within Population Unit

No Shading = Absence of Ungulate threat to Taxon within Population Unit

Plant Taxon	Target # Matures	Population Unit Name	Total Current Mat.+Imm.	Total Current Mature	Total Current Immature	Total Current Seedling	# Plants In 2012	# Plant In Original Report	% Completed Genetic Storage Requirement	% of Plants Protected from Ungulates	PU Met Goal?	# PU Met Goal
Neraudia angulata	100											
		Kaluakauila	134	65	69	0	164	0	N/A	100%	No	
		Makua	133	117	16	1	39	29	46%	17%	Yes	
		Manuwai	57	52	5	0	0	12	100%	100%	No	
		Waianae Kai Mauka	65	27	38	0	20	46	26%	100%	No	
		Neraudia angulata Total:	389	261	128	1	223	87				1 of 4

Taxon Status Summary

Makua Implementation Plan - Population Unit Status

Action Area: In

TaxonName: Neraudia angulata Target # of Matures: 100 # MFS PU Met Goal: 1 of 4

Population Unit Name	Management Designation	Total Mature Original IP	Total Imm Original IP	Total Seedling Original IP	Total Mature 2012	Total Immature 2012	Total Seedling 2012	Total Mature Current	Total Immature Current	Total Seedling Current	Wild Mature Current	Wild Immature Current	Wild Seedling Current	Outplanted Mature Current	Outplanted Immature Current	Outplanted Seedling Current	PU LastObs Date	Population Trend Notes
Kaluakauila	Manage reintroduction for stability				164	0	0	**65**	**69**	**0**	0	0	0	65	69	0	2013-05-21	Many of the outplants were observed dead in the last year and new immature plants were observed in the outplanting site
Kapuna	Genetic Storage	1	0	0	0	0	0	**0**	**0**	**0**	0	0	0	0	0	0	2013-03-27	The last remaining plant was observed dead in the last year
Makua	Manage for stability	29	0	22	24	15	1	**117**	**16**	**1**	19	15	1	98	1	0	2013-07-11	Many plants were added to a new reintroduction site
Punapohaku	Genetic Storage				1	0	0	**4**	**0**	**0**	4	0	0	0	0	0	2013-09-04	New plants were discovered during surveys
	In Total:	30	0	22	189	15	1	**186**	**85**	**1**	23	15	1	163	70	0		

Action Area: Out

TaxonName: Neraudia angulata Target # of Matures: 100 # MFS PU Met Goal: 1 of 4

Population Unit Name	Management Designation	Total Mature Original IP	Total Imm Original IP	Total Seedling Original IP	Total Mature 2012	Total Immature 2012	Total Seedling 2012	Total Mature Current	Total Immature Current	Total Seedling Current	Wild Mature Current	Wild Immature Current	Wild Seedling Current	Outplanted Mature Current	Outplanted Immature Current	Outplanted Seedling Current	PU LastObs Date	Population Trend Notes
Halona	Genetic Storage	15	0	0	30	4	0	**30**	**4**	**0**	30	4	0	0	0	0	2006-05-22	No monitoring in the last year
Leeward Puu Kaua	Genetic Storage	3	0	0	9	0	0	**9**	**0**	**0**	9	0	0	0	0	0	2006-11-21	No monitoring in the last year
Makaha	Genetic Storage	56	14	0	6	7	0	**4**	**2**	**0**	4	2	0	0	0	0	2012-12-18	Thorough monitoring

The Taxon Status Summary, shown above, displays the current status of the wild and outplanted plants for each PU next to the totals from the previous year for comparison. The report also depicts the original IP Totals for the different age classes. The PUs are grouped into those with plants that are located inside the MIP or OIP AA (In) and PUs where all plants are outside of both AAs (Out).

Population Unit Name: Groupings of Population Reference Sites. Only PUs designated to be 'Manage for Stability' (MFS), 'Manage Reintroduction for Stability/Storage,' or 'Genetic Storage' (GS) are shown in the table. Other PUs with 'No Management' designations are not managed and will not be reported. "No Management" PUs may be shown by not checking the "Exclude No Management" box on the report menu.

Management Designation: For PUs with naturally occurring (*in situ*) plants remaining, the designation is either 'Manage for Stability' or 'Genetic Storage'. Some MFS PUs will be augmented with outplantings to reach stability goals. When reintroductions alone will be used to reach stability, the designation is 'Manage Reintroduction for Stability.' When a reintroduction will be used for producing propagules for genetic storage, the designation is 'Manage Reintroduction for Storage'.

Total Original IP Mature, Immature, Seedling: These first three columns display the original population numbers as noted in the first Implementation Plan reports of MIP (2005) and OIP (2008). When no numbers are displayed, the PU was not known at the time of the IPs

Total Mature, Immature and Seedling 2012: This displays the **SUM** of the number of *wild and outplanted* mature, immature plants and seedlings from the previous year's report. These numbers should be compared to those in the next three columns to see the change observed over the last year.

Total Current Mature, Immature, Seedling: The **SUM** of the *current* numbers of *wild and outplanted* individuals in each PU. This number will be used to determine if each PU has reached stability goals. These last three columns can be compared with the NRS 2010 estimates to see the change observed over the last year.

Wild Current Mature, Immature, Seedling: These set of three columns display the most up to date population estimates of the wild (in situ) plants in each PU. These numbers are generated from OANRP monitoring data, data from the Oahu Plant Extinction Prevention Program (OPEP) and Oahu NARS staff. The estimates may have changed from last year if estimates were revised after new monitoring data was taken or if the PUs have been split or merged since the last reporting period. The most recent estimate is used for all PUs, but some have not been monitored in several years. Several PU have not been visited yet by OANRP and no plants are listed in the population estimates. As these sites are monitored, estimates will be revised.

Outplanted Current Mature, Immature, Seedling: The third set of three columns display the numbers of individuals OANRP and partner agencies have outplanted into each PU. This includes augmentations of in situ sites, reintroductions into nearby sites and introductions into new areas.

PU LastObs Date: Last Observation Date of the most recent Population Reference Site observed within a PU. Where thorough monitoring was done, the estimates were updated. Although, there are sites that may have been observed more recently, but a complete monitoring was not done.

Population Trend Notes: Comments on the general population trend of each PU is given here. This may include notes on whether the PU was monitored in the last year, a brief discussion of the changes in population numbers from the previous estimates, and some explanation of whether the change is due to new plants being discovered in the same site, a new site being found, reintroductions or augmentations that increased the numbers or fluctuations in the numbers of wild plants. In some cases where the numbers have not changed, NRS has monitored the PU and observed no change. When the PU has not been monitored, the same estimate from the previous year is repeated.

Threat Control Summary

Action Area: In

TaxonName: Cenchrus agrimonioides var. agrimonioides

PopulationUnitName	ManagementDesignation	# Mature Plants	Ungulates Managed	Weeds Managed	Rats Managed	BTB Managed	Slugs Managed	Fire Managed
Kahanahaiki and Pahole	Manage for stability	320	Partial 100%	Partial 86%	Partial 30%	No	No	No
Kuaokala	Genetic Storage	1	No	No	No	No	No	No

Action Area: Out

TaxonName: Cenchrus agrimonioides var. agrimonioides

PopulationUnitName	ManagementDesignation	# Mature Plants	Ungulates Managed	Weeds Managed	Rats Managed	BTB Managed	Slugs Managed	Fire Managed
Central Ekahanui	Manage for stability	161	Yes	Partial 100%	Yes	No	No	No
Makaha and Waianae Kai	Manage for stability	12	Partial 58%	Partial 100%	No	No	No	No
South Huliwai	Genetic Storage	17	No	No	No	No	No	No

= Threat to Taxon within Population Unit
No Shading = Absence of threat to Taxon within Population Unit
Ungulate Managed = Culmination of Cattle, Goats, and Pig threats
Yes=All PopRefSites within Population Unit have threat controlled
No=All PopRefSites within Population Unit have no threat control
Partial% =Percent of mature plants in Population Unit that have threat controlled
Partial 100% = All PopRefSites within Population Unit have threat partially controlled

The Threat Control Summary summarizes the threat status for each Taxon Population Unit. Yes, No or Partial is used to indicate the level of threat management. Partial management has additional percentage based upon the number of mature plants being protected.

Population Unit Name: Groupings of Population Reference Sites. Only PUs designated to be 'Manage for Stability' (MFS), 'Manage Reintroduction for Stability/Storage,' or 'Genetic Storage' (GS) are shown in the table.

Management Designation: Designations for PUs with ongoing management are listed. Population Units that are MFS are the first priority for complete threat control. PUs that are managed in order to secure genetic storage collections receive the management needed for collection (ungulate and rodent control) as a priority but may be a lower priority for other threat control.

 # Mature Plants: Number of Mature Plants within the Population Unit.

Threat Columns: The six most common threats are listed in the next columns. To indicate if the threat is noted at each PU, a shaded box is used. If the threat is not present at that PU, it is not shaded.

Threat control is defined as:
Yes = All sites within the PU have the threat controlled
No = All sites within the PU have no threat control
Partial %= Percent of mature plants in Population Unit that have threat controlled
Partial 100%= All PopRefSites within Population Unit have threat partially controlled
Partial (with no %) = All PopRefSites within Population Unit have threat partially controlled and only immature plants have been observed.

Ungulates: This threat is indicated if pigs, goats or cattle have been observed at any sites within the PU. This threat is controlled (Yes) if a fence has been completed and all ungulates removed from the site. Most PUs are threatened by pigs, but others are threatened by goats and cattle as well. The same type of fence is used to control for all three types of ungulates on Oahu. Partial indicates that the threat is controlled for some but not all plants in the PU.

Weeds: This threat is indicated at all PUs for all IP taxa. This threat is controlled if weed control has been conducted in the vicinity of the sites for each PU. If only some of the sites have had weed control, 'Partial' is used.

Rats: This threat is indicated for any PUs where damage from rodents has been confirmed by OANRP staff. This includes fruit predation and damage to stems or any part of the plant. The threat is controlled if the PU is protected by snap traps and bait stations. For some taxa, rats are not known to be a threat, but the sites are within rat control areas for other taxa so the threat is considered controlled. In these cases, the box is not shaded but control is 'Yes' or 'Partial.' Partial indicates that the threat is fully controlled over part of the PU.

BTB: BTB stands for the Coffee Black Twig Borer (*Xylosandrus compactus*). This threat is indicated for any PUs where damage from BTB has been confirmed by OANRP staff. This is known to be a threat for all *Alectryon macrococcus* var. *macrococcus* and *Flueggea neowawraea*. Other MIP/OIP taxa may be affected and will be monitored for damage. Effective control methods do not exist at this time.

Slugs: This threat is indicated for several IP taxa as confirmed by OANRP staff. Currently, slug control is conducted under an Experimental Use Permit from Hawaii State Department of Agriculture, which permits the use of Sluggo® around the recruiting seedlings of *Cyanea superba* subsp. *superba* in Kahanahaiki Gulch on Makua Military Reservation. Until the label is changed to allow for application in a forest setting, all applications must be conducted under this permit. Partial indicates that the threat is fully controlled over part of the PU.

Fire: This threat is indicated for PUs that occur on Army lands within the high fire threat area of the Makua AA, and some PUs within the Schofield West Range AA and Kahuku Training Area that have been threatened by fire within the last ten years. Similarly, PUs that are not on Army land were included if there is a history of fires in that area. This includes the PUs below the Honouliuli Contour Trail, the gulches above Waialua where the 2007 fire burned including Puulu, Kihakapu, Palikea, Kaimuhole, Alaiheihe, Manuwai, Kaomoku iki, Kaomoku nui and Kaawa and PUs in the Puu Palikea area that were threatened by the Nanakuli fire. Threat control conducted by OANRP includes removing fuel from the area with pesticides, marking the site with Seibert Stakes for water drops, and installing fuel-breaks in fallow agricultural areas along roads. 'Partial' means that the threat has been partially controlled to the whole PU, not that some plants are fully protected. Firebreaks and other control measures only partially block the threat of fire which could make it into the PU from other unprotected directions.

Genetic Storage Summary

Genetic Storage Summary

		# of Potential Founders			Partial Storage Status				Storage Goals				Storage Goals Met	
Population Unit Name	Management Designation	Current Mature	Current Imm.	Dead and Repres.	# Plants >= 10 in SeedLab	# Plants >= 10 Est Viable in SeedLab	# Plants >=1 Microprop	# Plants >=1 Army Nursery	# Plants >= 50 in SeedLab	# Plants >= 50 Est. Viable in SeedLab	# Plants >=3 in Microprop	# Plants >=3 Army Nursery	# Plants that Met Goal	% Completed Genetic Storage Requirement
Action Area: In														
Neraudia angulata														
Kapuna	Genetic Storage	0	0	2	2	2	0	2	2	0	0	2	2	100%
Makua	Manage for stability	19	15	71	2	2	0	23	1	0	0	23	23	46%
Punapohaku	Genetic Storage	4	0	0	0	0	0	2	0	0	0	1	1	25%
Action Area: Out														
Neraudia angulata														
Halona	Genetic Storage	30	4	0	0	0	0	7	0	0	0	7	7	21%
Leeward Puu Kaua	Genetic Storage	9	0	0	0	0	0	1	0	0	0	1	1	11%
Makaha	Genetic Storage	4	2	8	2	1	0	13	1	0	0	12	12	86%
Manuwai	Manage for stability	0	0	2	0	0	0	2	0	0	0	2	2	100%
Waianae Kai Makai	Genetic Storage	45	35	0	0	0	0	0	0	0	0	0	0	0%
Waianae Kai Mauka	Manage for stability	16	4	14	0	0	0	9	0	0	0	9	9	26%
		Total Current Mature	Total Current Imm.	Total Dead and Repres.	Total # Plants w/ >=10 Seeds in SeedLab	Total # Plants w/ >=10 Est Vaible Seeds in SeedLab	Total # Plants w/ >=1 Microprop	Total # Plants w/ >=1 Army Nursery	Total # Plants w/ >=50 Seeds in SeedLab	Total # Plants w/ >=50 Est Viable Seeds in SeedLab	Total # Plants w/ >=3 in Microprop	Total # Plants w/ >=3 Army Nursery	Total # Plants that Met Goal	
		127	60	97	6	5	0	59	4	0	0	57	57	

The Genetic Storage Summary estimates of seeds remaining in genetic storage have been changed this year to account for the expected viability of the stored collections. The viability rates of a sample of most collections are measured prior to storage. These rates are used to estimate the number of viable seeds in the rest of the stored collection. If the product of (the total number of seeds stored) and (the initial percentage of viable seeds) is >50, that founder is considered secured in genetic storage. If each collection of a species is not tested, the initial viability is determined from the mean viability of (preference in descending order):

1. other founders in that collection
2. that founder from other collections
3. all founders in that population reference site
4. all founders of that species

Number (#) of Potential Founders: These first columns list the current number of live *in situ* immature and mature plants in each PU. These plants have been collected from already, or may be collected from in the future. The number of dead plants from which collections were made in the past is also included to show the total number of plants that could potentially be represented in genetic storage for each PU since collections began. Immature plants are included as founders for all taxa, but they can only serve as founders for some. For example, for *Hibiscus brackenridgei* subsp. *mokuleianus*, cuttings can be taken from immature plants for propagation. In comparison, for *Sanicula mariversa*, cuttings cannot be taken and seed is the only propagule used in collecting for genetic storage. Therefore, including immature plants in the number of potential founders for *S. mariversa* gives an over-estimate. The 'Manage reintroduction for stability/storage' PUs have no potential founders. The genetic storage status of the founder stock used for these reintroductions is listed under the source PU.

Partial Storage Status: To meet the IP genetic storage goal for each PU for taxa with seed storage as the preferred genetic storage method, at least 50 seeds must be stored from 50 plants. This year, the number of seeds needed for each plant (50) accounts for the original viability (Estimate Viability) of seed collections. In order to show intermediate progress, this column displays the number individual plants that have collections of >10 seeds in storage. For taxa where vegetative collections will be used to meet storage goals, a minimum of three clones per plant in either the Lyon Micropropagation Lab, the Army nurseries or the State's Pahole Mid-elevation Nursery is required to meet stability goals. Plants with one or more representatives in either the Lyon Micropropagation Lab or a nursery are considered to partially meet storage goals. The number of plants that have met this goal at each location is displayed.

 # Plants that Met Goal: This column displays the total number of plants in each PU that have met the IP genetic storage goals. As discussed above, a plant is considered to meet the storage goal if it has 50 seeds in storage or three clones in micropropagation or three in a nursery. For some PUs, the number of founders has increased in the last year; therefore, it is feasible that NRS could be farther from reaching collection goals than last year. Also, as seeds age in storage, plants are outplanted, or explants contaminated, this number will drop. In other PUs where collections have been happening for many years, the number of founders represented in genetic storage may exceed the number of plants currently extant in each PU. In some cases, plants that are being grown for reintroductions are also being counted for genetic storage. These plants will eventually leave the greenhouse and the genetic storage goals will be met by retaining clones of all available founders or by securing seeds in storage. This column does not show the total number of seeds in storage; in some cases thousands of seeds have been collected from one plant.

% Completed Genetic Storage Requirement: Describes the percent of Founder Plants that have met Genetic Storage goals. Genetic storage of at least 50 seeds each from 50 individuals, or at least three clones each in propagation from 50 individuals, is required for each PU. If there are fewer than 50 founders for a PU, genetic storage is required from all available founders. For example, if there are at least 50 seeds from five individuals, or at least three clones in propagation from five individuals, then listed in the tables is 10%.

See Taxon Status Summary above for details on In/Out Action Area, Population Units, and Management Designation.

Snail Population Status Summary

Number of Snails Counted

Population Reference Site	Management Designation	Total Snails	Date of Survey	Size Classes: Large	Medium	Small	Unk	Threat Control: Ungulate	Weed	Rat	Euglandina rosea	Jackson's Chameleon
Achatinella mustelina												
ESU: A — Pahole to Kahanahaiki												
MMR-A Kahanahaiki Exclosure	Manage for stability	58	2013-05-13	32	12	14	0	Yes	Yes	Yes	Yes	No
MMR-C Maile Flats	Manage for stability	99	2012-05-17	68	23	8	0	Yes	Yes	Yes	No	No
PAH-B Pahole Exclosure	Manage for stability	42	2013-05-13	24	16	2	0	Yes	Yes	Yes	Yes	No
	ESU Total:	199		124	51	24	0					

Size Class Definitions

SizeClass	DefSizeClass
Large	>18 mm
Medium	8-18 mm
Small	< 8 mm

[shaded] = Threat to Taxon at Population Reference Site
No Shading = Absence of threat to Taxon at Population Reference Site
Yes=Threat is being controlled at PopRefSite
No=Threat is not being controlled at PopRefSite
Partial=Threat is being partially controlled at PopRefSite

Table shows the number of snails, size classes, and threats to the snails in the ESU sites. Yes = threat is being controlled; In some cases the threat may be present but not actively preying on A. mustelina.

The Snail Population Status Summary describes the current population size and threat control. Size Classes varies by snail taxon and definitions are listed on the lower left corner of the report. Threat Control consists of Yes, No, or Partial. Partial is where only some of the threat is being controlled at the site.

Population Reference Site: The first column lists the population reference code for each field site. This consists of a three-letter abbreviation for the gulch or area name. For example, MMR stands for Makua Military Reservation. Next, a letter code is applied in alphabetic order according to the order of population discovery. This coding system allows NRS to track each field site as a unique entity. This code is also linked to the Army Natural Resource geodatabase. In addition, the "common name" for the site is listed as this name is often easier to remember than the population reference code.

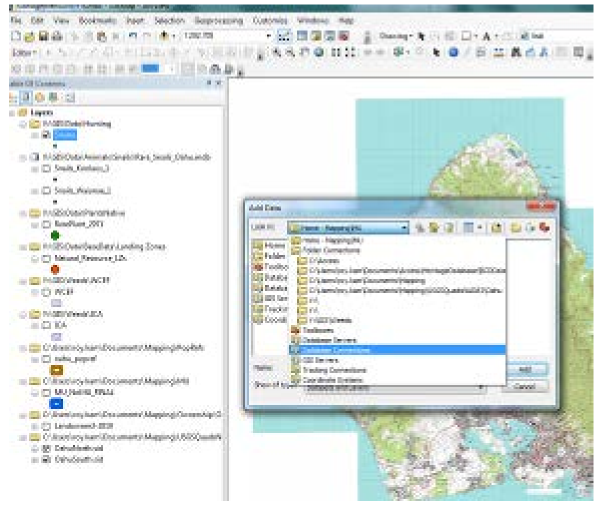
Management Designation: In the next column, the management designation is listed for each field site. The tables used in this report only display the sites chosen for MFS, where NRS is actively conducting management. These sites are generally the most robust sites in terms of snail numbers, habitat quality, and manageability. Other field sites where NRS has observed snails are tracked in the database but under the designation 'no management.' In general, these sites include only a few snails in degraded habitat where management is logistically challenging. The combined total for sites designated as MFS should be a minimum of 300 total snails in order to meet stability requirements.

Population Numbers: The most current and most accurate monitoring data from each field site are used to populate the 'total snails' observed column and the numbers reported by 'size class' columns. In some cases, complete monitoring has not been conducted within this reporting period because of staff time constraints, therefore, older data are used.

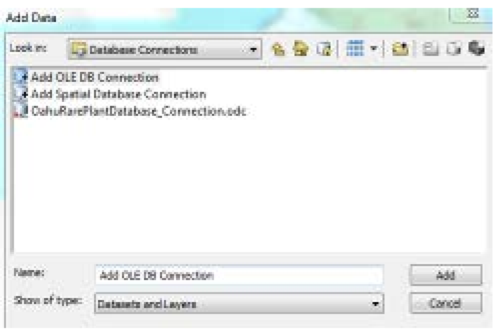
Threat Control: It is assumed that ungulate, weed, rat and Euglandina threats are problems at all the managed sites. If this is not true of a site, special discussion in the text will be included. If a threat is being managed at all in the vicinity of A. mustelina or affecting the habitat occupied by *A. mustelina* a "Yes" designation is assigned. The "No" designation is assigned when there is no ongoing threat control at the field site.

Linking Access Database Query into ArcGIS –Distribution Database Version

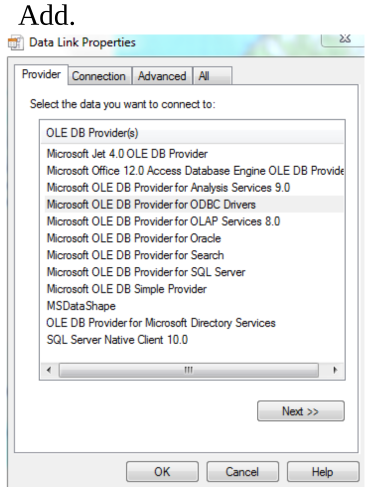
There may be times that information found in the Access database is needed in a GIS map. The following shows you how to link a query from Access into an ArcGIS project. The Population Reference Site query will be used as an example. Note there are several steps needed to bring in an Access Database query. If you don't feel comfortable in doing this, contact Roy Kam (rkam@hawaii.edu) and he will walk you through.



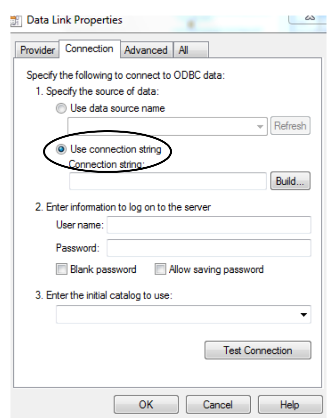
In your ArcGIS Project, make sure you have the Rare Plants or Rare Snails shapefile (or whatever shapefile you are linking) as one of your layers. Click on the Add Button, and choose *Database Connections*.



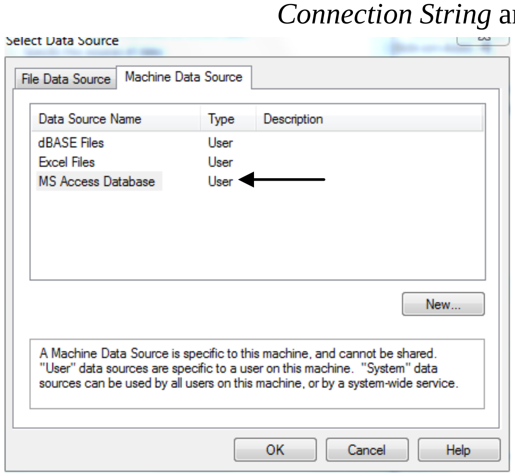
Then select *Add OLE Database Connection*, and click on Add.



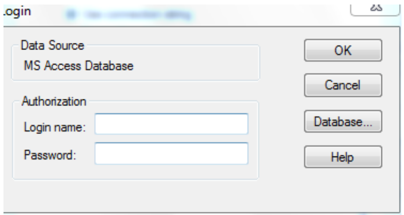
A Data Link Properties window will appear. Select *Microsoft OLE DB Provider for ODBC Drivers*.



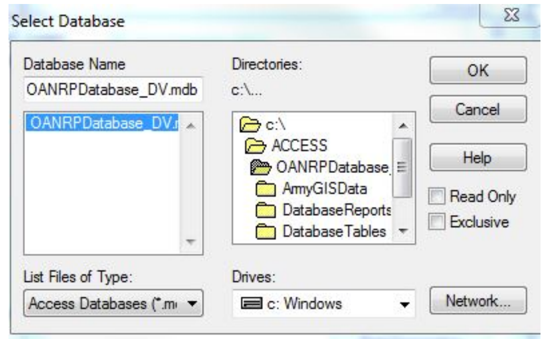
Then in the Data Link Properties window, select the *Connection tab*. Under the Connection Tab, select *Use Connection String* and click on the button *Build*.



In the Select Data Source window, select the *Machine Data Source* tab, and select *MS Access Database then* click *OK*.

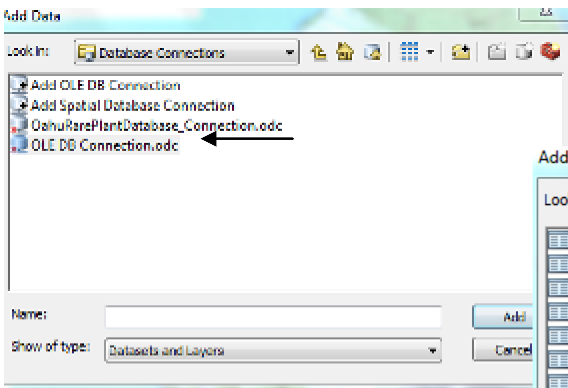


In the Login Window, Click on the *Database* button (leave Login Name and Password blank).

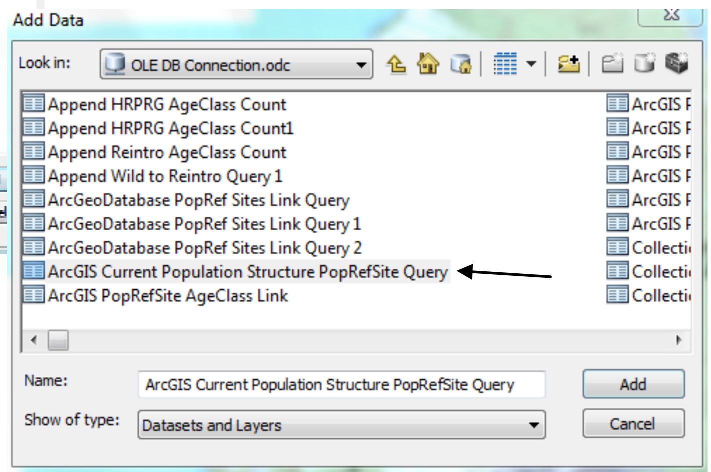


In the Select Database window, change the Drives to C: and browse to C:\Access\OANRPDatabase_DistributeVersion\ OANRPDatabase_DV.mdb

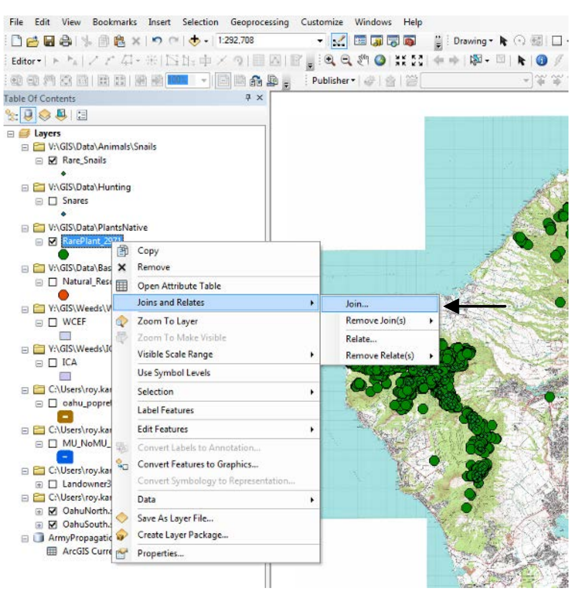
Click Ok to close the windows, until you are back at the Add Data window. You will now see a new OLE DB Connection.odc listed.



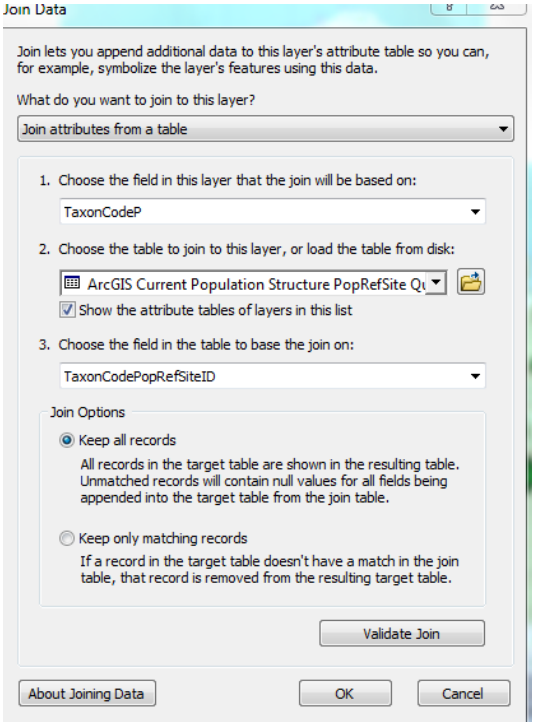
Double click on the OLE DB Connection.odc. The window will then open the Access Database and list all tables and queries.



Browse through the list until you find *ArcGIS Current Population Structure PopRefSite Query*. This query in the Access Database lists all of the Rare Plants and Rare Snails with their current Population Structure and whether the site is In situ or Ex situ. Click Add. The query will now appear as a Layer in your map project.



Go to the shapefile, right click and select Join under the Joins and Relates.



The last procedure is to join the Rare Plant shapefile with the Access Query. Select TaxonCodeP from the Rare Plant GIS Shapefile, and TaxonCodePopRefSiteID from the Access database query. The data will now appear together in the Snare shapefile attribute table.

Attribute Table from ArcGIS. Example of Rare Plant shapefile joined to Access Database Query.

← Rare Plants GIS Shapefile table data → Access Database data

RarePlants

OBJ	ID	SPECIES	POPULATION	TaxonCodeP	LOCATION	SOU	FULL_SCIEN	X	Y	NATU	Statu	TaxonCode	PopRefName
1	0	AleMacMac	SBW-A	AleMacMac.SBW-A	Mohiakea gulch	JL	Alectryon macrococcus macrococcus	590515.562	2376426.50004	Yes	E	AleMacMac	Schofield Barracks Mil
2	0	AleMacMac	SBW-C	AleMacMac.SBW-C	Puu Kumakalii	JL	Alectryon macrococcus macrococcus	590981.875	2375960.25005	Yes	E	AleMacMac	Schofield Barracks Mil
3	0	AleMacMac	SBW-D	AleMacMac.SBW-D	Puu Kumakalii	JL	Alectryon macrococcus macrococcus	591323.250	2375402.75002	Yes	E	AleMacMac	Schofield Barracks Mil
4	0	SchTri	ALA-C	SchTri.ALA-C	Kaala	JL	Schiedea trinervis	589030.703	2378443.74343	Yes	E	SchTri	Mt. Kaala NAR
5	0	SchTri	SBW-G	SchTri.SBW-G	Puu Kalena	JL	Schiedea trinervis	589641.375	2376627.49997	Yes	E	SchTri	Schofield Barracks Mil
6	0	CyaAcu	ALA-B	CyaAcu.ALA-B	Kaala	JL	Cyanea acuminata	589083.312	2378560.75002	Yes	E	CyaAcu	Mt. Kaala NAR
7	0	CyaGriOba	SBW-A	CyaGriOba.SBW-A	Kaala 2400'	JL	Cyanea grimesiana obatae	590057.000	2378433.99994	Yes	E	CyaGriOba	Schofield Barracks Mil
8	0	CyaCal	NA	CyaCal.ALA-A	Kaala	JL	Cyanea calycina	588965.812	2378293.99994		E	CyaCal	Mt. Kaala NAR
9	0	CyaCal	NA	CyaCal.ALA-A	Kaala	JL	Cyanea calycina	588996.187	2378697.74996		E	CyaCal	Mt. Kaala NAR
10	0	CyaCal	NA	CyaCal.ALA-A	Kaala	JL	Cyanea calycina	589218.125	2378491.00001		E	CyaCal	Mt. Kaala NAR
11	0	CyaCal	NA	CyaCal.SBW-A	Kaala	JL	Cyanea calycina	589493.687	2377636.75002	Yes	E	CyaCal	Schofield Barracks Mil
12	0	CyaCal	NA	CyaCal.SBW-A	Kaala	JL	Cyanea calycina	589268.312	2377825.24999	Yes	E	CyaCal	Schofield Barracks Mil
13	0	CyaCal	SBW-A	CyaCal.SBW-A	Kaala	JL	Cyanea calycina	588881.999	2378048.50004	Yes	E	CyaCal	Schofield Barracks Mil
14	0	CyaCal	SBW-C	CyaCal.SBW-C	Puu Kalena 2300'	JL	Cyanea calycina	590479.812	2376867.99994	Yes	E	CyaCal	Schofield Barracks Mil
15	0	CyaCal	SBW-C	CyaCal.SBW-C	Puu Kalena 2800'	JL	Cyanea calycina	590307.312	2376571.74996	Yes	E	CyaCal	Schofield Barracks Mil

→ Access Database data joined query →

RarePlants

PopRefName	FedStat	TaxonCodePopRefSit	PopRefSiteName	InExsitu	ObservationDate	AccObs	CurAccObs	Immature	Large	Mature	Medium
Schofield Barracks Milita	E	AleMacMac.SBW-A	Mohiakea	In situ	2013-05-20	Yes	Yes	<Null>	<Null>	2	<Null>
Schofield Barracks Milita	E	AleMacMac.SBW-C	North of Puukumakalii (Dead)	In situ	2012-04-04	Yes	Yes	0	<Null>	0	<Null>
Schofield Barracks Milita	E	AleMacMac.SBW-D	Southeast of Puukumakalii	In situ	2012-06-27	Yes	Yes	0	<Null>	0	<Null>
Mt. Kaala NAR	E	SchTri.ALA-C	Lower 2 Poles Ridge	In situ	2002-10-23	Yes	Yes	5	<Null>	5	<Null>
Schofield Barracks Milita	E	SchTri.SBW-G	Kalena, in notch	In situ	2007-08-20	Yes	Yes	0	<Null>	0	<Null>
Mt. Kaala NAR	E	CyaAcu.ALA-B	Kaala, one gulch N of Alstri ridge	In situ	2008-03-13	Yes	Yes	<Null>	<Null>	19	<Null>
Schofield Barracks Milita	E	CyaGriOba.SBW-A	North Haleauau	In situ	2005-10-03	Yes	Yes	0	<Null>	0	<Null>
Mt. Kaala NAR	E	CyaCal.ALA-A	Kaala	In situ	2013-06-06	Yes	Yes	<Null>	<Null>	3	<Null>
Mt. Kaala NAR	E	CyaCal.ALA-A	Kaala	In situ	2013-06-06	Yes	Yes	<Null>	<Null>	3	<Null>
Mt. Kaala NAR	E	CyaCal.ALA-A	Kaala	In situ	2013-06-06	Yes	Yes	<Null>	<Null>	3	<Null>
Schofield Barracks Milita	E	CyaCal.SBW-A	North Haleauau, Below ALA-O populati	In situ	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
Schofield Barracks Milita	E	CyaCal.SBW-A	North Haleauau, Below ALA-O populati	In situ	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
Schofield Barracks Milita	E	CyaCal.SBW-A	North Haleauau, Below ALA-O populati	In situ	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
Schofield Barracks Milita	E	CyaCal.SBW-C	Kaala-Kalena	In situ	2006-10-25	Yes	Yes	<Null>	<Null>	1	<Null>
Schofield Barracks Milita	E	CyaCal.SBW-C	Kaala-Kalena	In situ	2006-10-25	Yes	Yes	<Null>	<Null>	1	<Null>
<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>

DEPARTMENT OF THE ARMY
HEADQUARTERS, 25TH INFANTRY DIVISION AND US ARMY HAWAII
SCHOFIELD BARRACKS, HAWAII 96857-6000

REPLY TO
ATTENTION OF

APVG-CG

FEB 27 2014

MEMORANDUM FOR DISTRIBUTION

SUBJECT: USARHAW Washrack Utilization Policy to Control Invasive Species

1. References:

2. Purpose. Enforce the use of washracks to prevent the spread of invasive species.

3. Applicability. All USARHAW units, Army tenant units on Hawaii installations, U.S. Pacific Command Component Commands, and external entities that utilize Army ranges. This policy applies to all category of personnel: service members, civilians, contractors, and authorized civilian guests utilizing USARHAW ranges.

4. Responsibilities. All units, agencies, and organizations conducting training or activities that involve movement between USARHAW ranges are required to ensure that vehicles utilized are not carrying seeds or plant material to prevent the spread of noxious or invasive plant species.

5. Background.

a. In January 2011, the Natural Resource Program (NRP) discovered a population of the highly invasive plant Chromolaena in the Kahuku Training Area (KTA). This plant is native to Central America and is a highly invasive plant found on Guam. The Chromolaena is designated a noxious weed in the state of Hawaii. This species has the potential to negatively impact training at KTA if it were to become established as it can cause respiratory problems in humans.

b. In November 2011, February 2012, and April 2012, the Natural Resource Program found incipient populations of Fountain Grass, a major invasive grass species at Pohakuloa Training Area (PTA), Makua Military Reservation (MMR), KTA, and Schofield Barracks East Range. Fountain Grass has the potential to exacerbate the already high threat to endangered species on Army lands caused by fires.

c. In February 2012, the NRP found a population of *Schizachrium Condesatum*, Bush Beard Grass at Schofield Barracks East Range. This species is also on the state noxious weed list and is a known threat to natural resources.

6. USARHAW Policy to Control Invasive Species.

a. Leadership Involvement and Education. All leaders and supervisors (military and civilian) must be made aware of the potential to danger of spreading invasive species. USARHAW Range Division is directed to include and maintain a short briefing for all range users to assist in the preventing the spread of noxious or invasive species. The briefing will be given to the organization's Range OIC in charge of the training or activity. The OIC will be required to complete range checklist which includes confirmation equipment and vehicles are clean (backside of checklist that range operations provides to unit on day of training event).

b. Washing of Vehicles and Gear.

(1) All personnel, units, and organizations conducting training on USARHAW ranges are required to ensure vehicles and equipment are clean prior to use on ranges. If the vehicle(s) were deployed to PTA, Guam, or other out-of-state location, units are responsible for conducting an inspection, determine risk, and take corrective action.

(2) All personnel, units, and organizations conducting training on USARHAW ranges are required to ensure vehicles and equipment moving between geographically separate locations are clean prior to departing.

(a) Clean, wash, and inspect vehicles and equipment prior to movement to/from off island locations.
(b) Clean, wash, and inspect vehicles and equipment prior to movement from KTA to Schofield Barracks.
(c) From SBMR East Range clean, wash, and inspect vehicles and equipment prior to movement. Note that McCarthy Flats has Devil Weed on the roads – therefore vehicles must be washed after using MF ranges.
(d) At other training locations commanders can clean, wash, and inspect at his or her discretion.

7. Specific procedures will be developed to ensure compliance and reflected in the USARHAW Range SOP.

8. POCs for this policy are Mr. Tom Haywood, USARHAW TSS, thomas.j.haywood.civ@mail.mil, (808)-655-7353; LTC Britton London, 25 ID G3T, britton.t.london.mil@mail.mil, (808) 655-5351; Steven M. Araki, MSE-HI G3, steven.m.araki.civ@mail.mil, (808) 655-7341; Mr. Victor Garo, Range Officer, victor.garo.civ@mail.mil, (808) 655-1404.

KURT FULLER
Major General, US Army
Commanding

DEPARTMENT OF THE ARMY
US ARMY INSTALLATION MANAGEMENT COMMAND, PACIFIC REGION
HEADQUARTERS, UNITED STATES ARMY GARRISON, HAWAII
851 WRIGHT AVENUE, WHEELER ARMY AIRFIELD
SCHOFIELD BARRACKS, HAWAII 96857-5000

REPLY TO
ATTENTION OF:

IMHW-ZA

0 7 JAN 2014

MEMORANDUM FOR All Military Personnel and Department of Defense Civilian Employees within United States Army Garrison, Hawaii (USAG-HI) Installations

SUBJECT: Policy Memorandum USAG-HI-63, Landscaping with Native Plants

1. References.

a. Army Regulation (AR) 200-1, Environmental Protection and Enhancement, 13 December 2007.

b. Department of Defense Instruction (DODI) 4715.03, 18 March 2011.

c. Executive Order 13112, Invasive Species, 3 February 1999.

d. Presidential Memorandum, "Environmentally and Economically Beneficial Practices on Federal Landscaped Grounds," 26 April 1994

e. Paragraph 5h, Office of the Assistant Secretary of the Army Installations, Energy and Environment Memorandum, "Sustainable Design and Development Policy Update (Environmental and Energy Performance)," 27 October 2010.

2. Applicability. This policy applies to all Soldiers, civilians, family members, contractors, and other personnel who work on, reside on, or visit any U.S. Army installation, facility, or work site in the State of Hawaii.

3. Policy.

a. Protecting our environment is one of the most important aspects of accomplishing the USAG-HI mission. USAG-HI is committed to utilizing environmentally beneficial landscape practices that will enhance the local Hawaiian environment while minimizing any adverse effects that the landscaping will have on it. Specifically, USAG-HI aims to use locally adapted native plants and avoid using invasive species. Planting of native species in the landscape reduces water resource requirements, provides habitat for native animals, and creates a Hawaiian cultural landscape on post.

b. To achieve this end, all new USAG-HI construction and land management projects will require the use of native Hawaiian plant species for landscaping to the extent practical.

c. If use of native Hawaiian plants is not practical, then non-invasive, non-native plants may be used after a justification memorandum explaining why using native Hawaiian plants is not practical has been concurred by the Environmental Division of the Directorate of Public Works, USAG-HI.

d. The enclosures to this policy memorandum contain information about native plants that have been used on USAG-HI installations as well as information about appropriate non-invasive, non-native plants that may be used. These enclosures should be referenced when planning for USAG-HI landscape projects.

e. The following websites also provide information on suitable native Hawaiian species for landscaping:

(1) http://www.boardofwatersupply.com/cssweb/display.cfm?sid=1360. Produced by the Honolulu Board of Water Supply, this guide divides up Oahu into Zones, and recommends native plants for each zone. For Schofield Barracks and Wheeler Airfield, the appropriate zones are 2, 3, and 4. The plants listed in zones 1 and 5 may also be appropriate; the plants in Zones 8 and 9 would not.

(2) www.plantpono.org. Produced by the Coordinating Group on Alien Pest Species, the Hawaii Invasive Species Council, and other experts, this provides a concise list of plants which should never be planted, and good native or ornamental alternatives.

4. Proponent. The proponent for administration of the Landscaping with Native Plants Policy is DPW, Environmental Division, at 655-9189.

DANIEL W. WHITNEY
COL, SF
Commanding

3 Encls
1. Recommended Native Plants
2. Non-Invasive Plants Authorized
3. Native Hawaiian Plant Poster

Native Hawaiian Plants (Recommended List)

Scientific Name	Common Name
TREES	
Acacia koa	Koa
Metrosideros polymorpha	Ohia
Pandanus tectorius	Hala
Pipturus albidus	Mamaki
Prichardia remota	Loulu
Psydrax odoratum	Alahe'e
Sapindus oahuensis	Lonomea
SHRUBS/HEDGES	
Abutilon menziesii	Ko'oloa'ula
Dodonaea viscosa	A'ali'i
Gardenia brighamii	Na'u
Gossypium tomentosum	Ma'o
Hibiscus arnotianus	White hibiscus, Kokio ke'oke'o
Hibiscus spp.	various native Hawaiian Hibiscus
Nototrichium sandwichense	Kulu'i
Osteomeles anthyllidifolia	ulei
Plumbago zeylanica	Ilie'e
Scaevola taccada	Naupaka kahakai/Beach Naupaka
Vitex rotundifolia	Pohinahina
Wikstroemia uva-ursi	Coastal Akia
GROUND COVER	
Carex wahuensis	sedge
Chenopodium oahuense	Aweoweo
Dianella sandwicense	Uki'uki
Ipomea pes-caprae subsp. brasiliensis	pohuehue
Jacquemontia sandwicensis	pa'u o hi'iaka
Melanthera integrifolia	nehe
Microlepia strigosa	Palapalai
Sida fallax	Ilima papa

Non-Native, Non-Invasive Plants (Authorized List)

Scientific Name	Common Name
TREES	
Albizia saman	Monkey Pod
Aleurites moluccana	Kukui
Bauhinia x blakeana	Orchid tree
Cassia x nealiae	Rainbow Shower Tree
Cordia subcordata	Kou
Delonix regia	Royal Poinciana
Dracaena spp.	Money tree
Fagraea berteriana	Puakenikeni
Lagerstroemia indica	Crape myrtle
Magnolia grandiflora	Magnolia
Plumeria spp.	Plumeria
Swietenia mahagoni	Cuban Mahogany
Calophyllum inophyllum	Kamani
Tabebuia ochracea	Golden Shower
SHRUBS	
Alpinia purpurata	Red and pink ginger
Bixa orellana	Lipstick plant
Camelia japonica	Camelia
Crinum asiaticum	Spider lily
Croton spp.	Croton
Gardenia angusta	Gardenia
Gardenia taitensis	Tahitian Gardenia
Ixora spp.	Ixora
Plumbago auriculata	Plumbago
Russelia equisetiformis	Firecracker plant
Saccharum officinarum	Ko, Sugarcane
Strelitzia reginae	Bird of paradise
HEDGES	
Bougainvillea spp.	Bougainvillea
Chrysalidocarpus lutescens	Areca palm
Cordyline fruticosa	Ti leaf
Hibiscus spp.	Hibiscus
Murraya paniculata	Mock orange
Nandina domestica	Heavenly bamboo
Pittosporum tobira	Pittosporum
Polyscias guilfoylei	Panax
GROUND COVER	
Arachis glabrata	Perrenial peanut
Mesembryanthemum crystallinum	Ice plant
Phymatosorus grossus	Lauae fern, maile-scented fern

Enclosure 2

LANDSCAPE INDUSTRY COUNCIL OF HAWAI'I

BUY NATIVE · IT MATTERS
IT'S EVERYONE'S KULEANA

Department of Agriculture STATE OF HAWAII

- Dry
- Wet
- Full Sun
- Partial Sun
- Shade
- Endemic
- Indigenous
- Pollinators
- Salt & Wind Tolerant
- E Endangered Species

LICH Landscape Industry Council of Hawaii

Funding provided by the State of Hawaii Department of Agriculture

FSC certified paper comes from trees that are grown for the express purpose of BEING paper, precluding the need for harsh chemicals and bleaches

WWW.HAWAIISCAPE.COM

LANDSCAPE INDUSTRY COUNCIL OF HAWAI'I

GROW NATIVES • IT MATTERS

1. Golden rule: Use of native plants should never endanger their wild populations 2. Do not collect native plants from the wild without a Department of Hawai'i Land and Natural Resources collection permit (http://hawaii.gov/dlnr/dofaw/permit_info). Threatened and endangered plants are not to be collected from the wild. 3. Cultivated/landscape stock of threatened and endangered (T&E) plants require a license from the Hawai'i Dept. of Land and Natural Resources - Division of Forestry and Wildlife. A red T&E plant tag must accompany each listed plant. 4. Collect native plants only if you are a trained individual. Native ground cover vegetation can be damaged very easily. Avoid unnecessary damage to collection sites by staying on or near established trails. 5. When collecting common species with a permit, collect less than 5 percent of total seeds from each plant. 6. When collecting, propagating and planting native plants, replicate nature's genetic diversity. Ideally, collect from 8-10 plants per population and a total of 3-5 populations. Keep good records of the location and description of parent plants. Note provenance of plants throughout propagation to installation. 7. Use native plants from your island even if the species distribution is statewide. 8. Avoid moving native plants interisland. 9. Do not import native plants from outside of Hawai'i. 10. Purchase native plants from an established plant nursery. 11. Use native plants in your landscaping only and do not outplant them in natural areas.

VINES, GRASSES & GROUNDCOVERS

0 – 3 Feet Height

Pā'ū-o-Hi'iaka | Nehe | Dwarf Naupaka | 'Ae'ae | Palapalai | Kupukupu

3 – 6 Feet

Pili Grass | Kāwelu | 'Uki'uki | Pōhinahina | 'Ilie'e | O'ahu Sedge

SHRUBS

2½ – 10 Feet

Maiapilo | 'Āweoweo | 'Akoko | 'Ākia | Ma'o | 'Ilima

10 – 15 Feet

Ko'oloa'ula | 'Ūlei | Ma'o hau hele | Kulu'ī | 'A'ali'i | Naupaka Kuahiwi

TREES & PALMS

15 – 30 Feet

Nā'ū | 'Iliahialo'e | Koai'a | Kou | Hāpu'u | Māmaki

30+ Feet

Wiliwili | Hō'awa | Alahe'e | Milo | Loulu | 'Ōhi'a lehua

Dry | Wet | Full Sun | Partial Sun | Shade | Endemic | Indigenous | Pollinators | Salt & Wind Tolerant | Endangered Species

Department of Agriculture STATE OF HAWAII

LICH

WWW.HAWAIISCAPE.COM

Enclosure 3, Pg 2 of 2

Assessment of Vegetation Response to Ungulate Removal
Utilizing High Resolution Remotely Sensed Data

Qi Chen and Lalasia Bialic-Murphy
University of Hawaii at Manoa

Abstract - Understanding the impact of exotic predators on native ecosystems is critical to effectively preserve and manage natural areas. The primary objective of this study was to develop an efficient and cost effective methodology, utilizing high-resolution remotely sensed imagery, to monitor the spatial and temporal dynamics of vegetation recovery following fencing and feral pigs (*Sus scrofa*) control. Four years after the release of top-down stressors, vegetation conditions in the fenced site increased at a greater proportional rate compared to the vegetation conditions in the control site, indicating ecosystem recovery following feral pig suppression.

1. Introduction

Feral pigs are one of the most pervasive threats to terrestrial ecosystems. The introduction of feral pigs can have direct and indirect effects on native vegetation, which can ultimately lead to the decline of ecosystem function (D'Antonio & Vitousek 1992; Didham et al. 2005; Vitousek 1996). Feral pigs uproot native vegetation, disperse non-native seeds, create disturbed areas that are more vulnerable to invasive species establishment (Ickes et al. 2001; Spear & Chown 2009), and alter nutrient cycling (Dunkell et al. 2011) and fire regimes (D'Antonio & Vitousek 1992). Feral pigs also have a significant effect on erosion and hydrology (Vitousek 1986), converting vegetation groundcover to bare ground pits (i.e., wallows).

The impact of feral ungulates is thought to be particularly destructive to remote island ecosystems. This is in part due to the absence of shared evolutionary history (Gillespie & Clague 2009). With lack of diverse herbivore and predator communities island plants often have lower mechanistic and physiologic tolerance to the introduction of exotic pests (Gillespie & Clague 2009; Whittaker & Fernández-Palacios 2007).

In Hawaii, feral pigs are among the most pervasive threats to native ecosystem. To protect natural resources and healthy watersheds, fencing and feral pig eradication has become a primary step taken by conservation organizations.

Previous studies suggest that the response in vegetation conditions to feral pig eradication is highly variable, even between comparable habitat and spatially proximal forest stands (Loope & Scowcroft 1985). While many studies found that vegetation cover and species richness increased following feral pig exclusion, other studies found that vegetation conditions did not rebound significantly (Loope & Scowcroft 1985).

Many of the previous studies that have been conducted in Hawaii to assess vegetation response to feral ungulate control have been criticized as lacking a control site, being conducted over a relatively short timeframe, and covering small geographical study areas (Nogueira-Filho et al. 2009). It has been argued that, given those concerns, many of the previous studies did not accurately represent ecological processes at the landscape scale (Loope & Scowcroft 1985; Nogueira-Filho et al. 2009).

In Hawaii, the most commonly used approach to study vegetation response to feral pig exclusion has been standard field based monitoring (i.e., belt transects and point intercepts). For assessing ecosystem level vegetation response to the suppression of top-down stressors, there are several drawbacks of field based monitoring, such as: 1) Natural resources management and watershed recovery actions often cover large geographic areas, making data collection relatively time intensive. For example, the average data collection time that Oahu Army Natural Resources Program (OANRP) takes to monitor ecosystem health is a total of 480 field hours. Data entry, analysis, and synthesis require additional staff time. 2) Field based data collection can also be challenging to perform in landscapes exhibiting rugged terrain and can have an unintentional negative impact on fragile ecosystems with dense understory vegetation. Given these challenges, it is often cost prohibitive to monitor vegetation response to feral pig exclusion across large geographical areas using field based monitoring techniques.

Given the constraints of using field based monitoring techniques, there is a critical need to develop a cost effective, efficient, and low impact monitoring technique to map the spatial distribution of vegetation impacted by feral ungulates and monitor vegetation recovery over time. Recent advancement of remotely sensed imagery has made it a viable tool to use for this purpose. Currently there are a wide variety of sensors that are available, such as airborne LiDAR, hyperspectral, and conventional spaceborne optical sensors. Airborne LiDAR and optical sensors provide the most detailed data, allowing for assessment of vertical and horizontal vegetation structure. In remote places such as Hawaii, however, using airborne data to map vegetation may be impractical because of the high upfront costs of mobilizing airplanes and sensors (usually from the mainland) and the persistent cloud cover (a company usually has to wait for weeks, if not months, to collect cloud-free imagery for certain mountainous areas). For these reasons airborne imagery has often been found to be a less cost effective method for monitoring vegetation conditions, relative to traditional field monitoring techniques.

The one underexplored option to map vegetation is very high spatial resolution (VHR) satellite imagery, which is both cost effective (typically 10 times less expensive than airborne data) and has the expected spatial and spectral imagery quality needed (e.g., Nagendra 2001; Clark et al. 2005; Larsen et al. 2007; Warner et al. 2009; Immitzer et al. 2012).

The primary objective of this study was to develop a monitoring methodology that would reduce the cost and increase the efficiency of assessing vegetation response to ungulate removal on a coarse scale across large geographical areas.

The monitoring protocol that we developed utilized VHR imagery to compare the spatial (i.e. fenced and unfenced) and temporal (i.e. before and after fencing) changes in vegetation conditions following ungulate suppression. Our hypothesis was that vegetation conditions would recover, relative to an un-fenced control site, following feral pig eradication.

2. Study System

Our study covered two large natural areas located along the summit of the Koolau Mountain Range on the island of Oahu. These areas have been actively managed by OANRP staff for over a decade as part of a larger mitigation effort to offset the potential impact of military training operations on natural resources. The plant community at the study sites is a wind-swept wet forest, dominated by native short-statured vegetation.

One of the study sites, Upper Opaeula, is a 122-acre management unit (MU) that is located between 2,600 and 2,800 feet elevation (Figure 1). The mean monthly rainfall ranges from 358–518 mm (Giambelluca et al. 2013). In 2001, Upper Opaeula was fenced and feral pigs were eradicated. The Upper Opaeula control site (i.e., un-fenced area) that we selected for this study is a 40-acre area directly to the north of the Upper Opaeula MU (Figure 1).

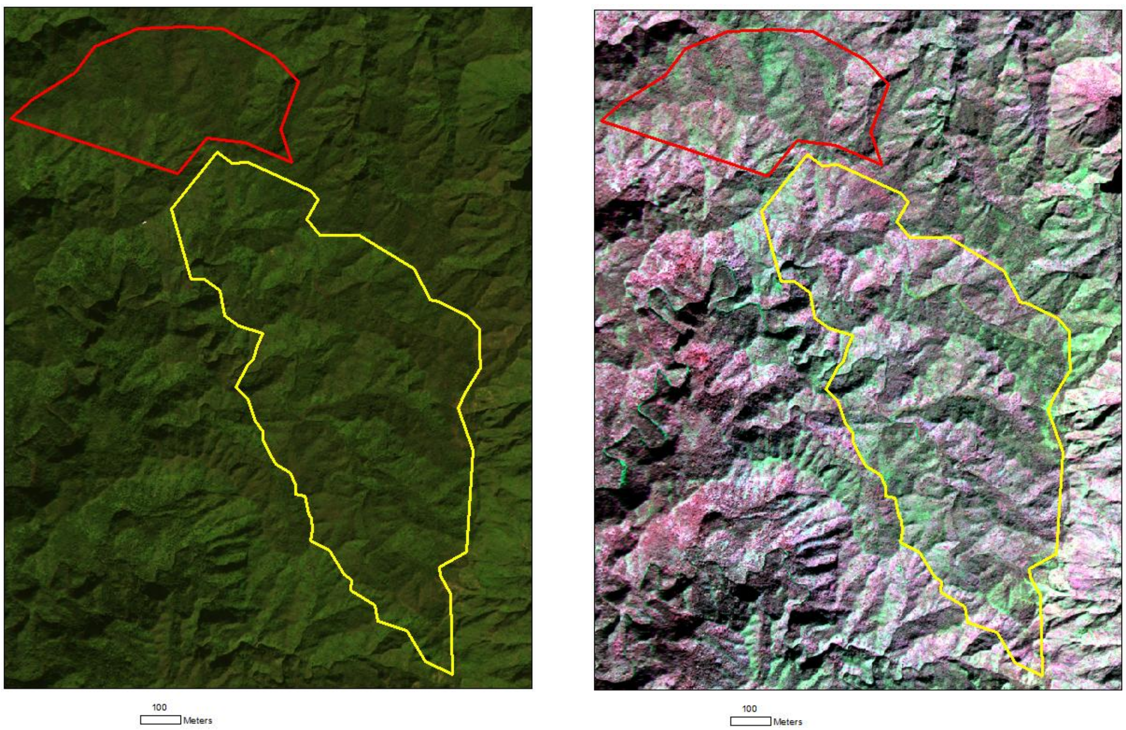


Figure 1: Upper Opaeula MU (outlined in yellow) and the control site (outlined in red) shown in the true-color (left) and false-color (right) images. In the false-color image, the pink and red pixels correspond to dense vegetation (i.e., high NDVI); the green pixels correspond to areas covered by short statured vegetation (e.g., ferns, grass, and shrubs).

The dominant native canopy species in the Upper Opaeula MU and control site include *Metrosideros spp.*, *Cheirodendron spp.*, *Cibotium spp.*, *Ilex anomala*, *Myrsine sandwicensis*, and *Perrottetia sandwicensis*. The dominant native understory species are *Dicranopteris linearis*, *Melicope spp.*, *Cibotium chamissoi*, *Machaerina angustifolia*, *Coprosma granadensis*, *Kadua centranthoides*, *Nothoperanema rubiginosa*, *Sadleria sp.*

and *Broussaisia arguta*. The dominant invasive canopy in the Upper Opaeula MU and control site is strawberry guava (*Psidium cattleianum*). The distribution of strawberry guava is patchy but high-density hotspots are often found in areas previously disturbed by ungulates.

Figure 2: Tree canopy vegetation type.

Figure 3: Open grass vegetation type.

The second study site, Koloa, is a 164-acre MU located in the northern Koolau Mountains at an elevation of 1950 - 2400 feet. The mean monthly rainfall ranges from 316 mm – 488 mm (Giambelluca et al. 2013). The native canopy and understory species at the Koloa MU are the same as the native species that occur in the Opaeula MU. In 2011, OANRP constructed the Koloa MU fence and, by the beginning of 2012, it was complete (Figure 4). Ungulate suppression started in 2011, prior to fence completion. By the beginning of 2012, no signs of ungulate activity were detected within the fence.

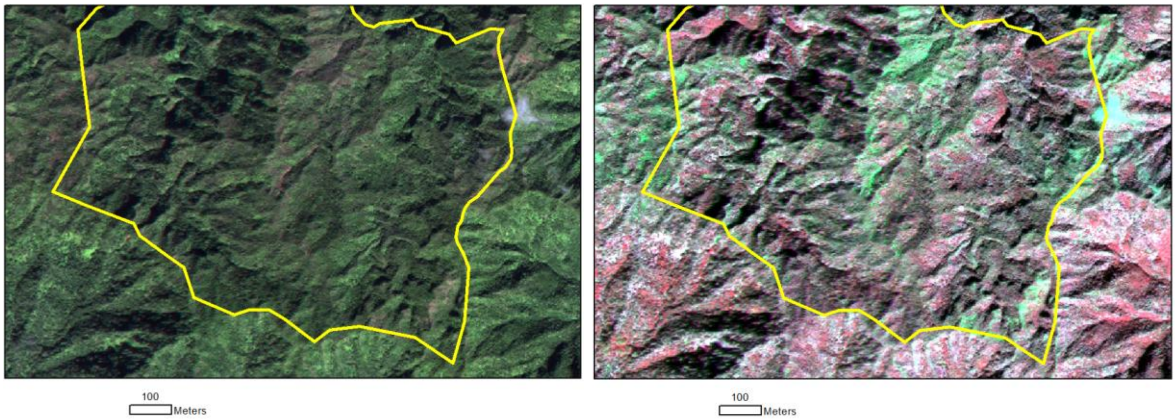


Figure 4: Koloa MU shown in the true-color (left) and false-color (right) images. In the false-color image, the pink and red pixels correspond to dense vegetation (i.e., high NDVI); the green pixels correspond to areas covered by short statured vegetation (e.g., ferns, grass, and shrubs).

3. Data

The data that we used for this study were satellite imagery from IKONOS and WorldView-2 (WV2), which were launched on September 24, 1999 and October 8, 2009, respectively. The satellites have a sun-synchronous orbit with a period of ~100 minutes. IKONOS and WV2 are both pushbroom sensors that map the earth one row at a time with linear detector arrays. WV2 has a total of 8 multispectral (MS) bands and one panchromatic (PAN) band while IKONOS has only 4 MS bands and one PAN band.

Image type	Date	Local time	Spatial resolution
IKONOS	May 15, 2000	9:57 am	3.4 m
IKONOS	Jan 22, 2005	10:26 am	3.4 m
WorldView-2	Jan 25, 2011	10:21 am	1.8 m

Table 1. The high spatial resolution satellite imagery used for vegetation change analysis.

We purchased the IKONOS and QuickBird imagery that was used for this study from Apollo Mapping (https://apollomapping.com/), a reseller of imagery from DigitalGlobe Inc. The total cost of the IKONOS and QiuckBird imagery was $630 (Table 2). The QuickBird image was not used for analysis, however, because of the extensive cloud cover. The WV2 image used was obtained from USDA free of charge.

Description	Qty	Unit $
25 Sq Km, IKONOS DGL, Oahu Final 2000, 4-Band Bundle 80cm/3.2 CC, 5/15/2000	1	$175
25 Sq Km, IKONOS DGL, Oahu Final 2005, 4-Band Bundle 80cm/3.2m CC, 1/22/2005	1	$175
25 Sq Km, QuickBird DGL, Oahu Final 2005, QB, 4-Band Bundle 60cm/2.4m MTF, 12/31/2005	1	$280
Total		$630

Table 2. Imagery purchase cost.

4. Methods

4.1. NDVI

We used NDVI (Normalized Difference Vegetation Index) derived from the remotely sensed imagery to quantify spatial and temporal differences in vegetation condition. NDVI is an index based on near-infrared (NIR) and red reflectance values and it is commonly used to quantify vegetation cover and density (Jensen 2009). NDVI can be intuitively understood as a greenness index. Green vegetation has higher near-infrared reflectance and low red reflectance, which leads to high NDVI values. Therefore, higher NDVI values are associated with more green vegetation cover and density. Dense vegetation canopy has a high NDVI value (from 0.3 to 0.8) and bare ground soil substrate has a low NDVI value (from 0.1 to 0.2).

In addition to vegetation cover and structure, NDVI is also related to leaf chlorophyll content and leaf water content. Therefore, NDVI decreases when vegetation is at the senescence stage or under environment-induced stress (e.g., drought or disease). Such variations need to be considered when the NDVI change is used to assess the vegetation growth and recovery.

4.2. Experimental design

To establish a baseline of the vegetation conditions, we produced NDVI images for each MU, using satellite imagery captured prior to ungulate control, in the year 2000 for the Upper Opaeula MU and in the year 2011 for the Koloa MU.

To assess vegetation conditions following feral pig control at the Upper Opaeula MU, we calculated NDVI using a time series of imagery that were captured five and ten years following ungulate suppression. We used the same time series of imagery to calculate the NDVI values for the Upper Opaeula MU control site (Figure 1). Feral pig suppression had not been actively managed at the control site. However, due to the occasional recreational hunting that likely occurred throughout the area, the results of our study may not fully reflect the extent of ungulate activity across the broader geographical range.

For the Koloa MU, time series analysis was not conducted. The primary purpose of calculating the NDVI value for the Koloa MU was to provide OANRP staff with a baseline NDVI map of vegetation conditions. We recommend calculating the NDVI value of the Koloa MU and the adjacent control site in 2016 because it would provide a five-year assessment of vegetation conditions following ungulate exclusion, in order to keep the monitoring interval consistent with the interval used for the Upper Opaeula MU.

4.3. Imagery Preprocessing

- **Orthorectification**

A raw remotely sensed image is usually geometrically distorted because of topographic relief and off-nadir imaging geometry. The geometric errors of our raw IKONOS images can be seen by a visual comparison between the raw IKONOS images and a geometrically corrected one, which appear to be as large as ~100 m (Figure 5).

To remove such geometric distortion and errors, we orthorectified the IKONOS images using a RPC (Rational Polynomial Coefficients) model to define the mathematical model of the imaging geometry and relate image coordinates (in rows and columns) to map coordinates (x, y, and elevation z). The coefficients were provided by the satellite company and are based on satellite orbital position, orientation, and the rigorous model for the sensor. The RPC coefficients were stored in the ancillary file for our IKONOS imagery. With the image geometry defined by RPC and an ancillary DEM (Digital Elevation Model), the map coordinates of each pixel was calculated.

The RPC model was created using information about the satellite altitude (or elevation) above a mathematically-defined geometry called ellipsoid (e.g., WGS84). We used a 10-m DEM from the University of Hawaii at Manoa Coastal Geology website http://www.soest.hawaii.edu/coasts/data/oahu/dem.html. The DEM represented elevation above mean sea level, which, if extended to land at the geopotential, corresponds to a geoid. The ellipsoid and geoid did not coincide. For this reason, the difference between ellipsoid and geoid over the study area had to be reconciled during orthorectification. The ellipsoid and geoid elevation difference (i.e., geoid height) that we used was based on Cooper et al. (2014). The horizontal datum of the DEM is NAD83, which was converted to WGS84 using ArcGIS, so that it was compatible to the satellite images.

The Worldview-2 image used for this study had already been orthorectified by the data provider. We did not know the specific approach that was used for orthorectifying the Worldview-2 image. It is possible that different inputs (e.g., DEM and geoid height) were used. Thus, some discrepancy might exist between the orthorectified WorldView-2 and IKONOS images. We checked any discrepancy among the orthoimages and, when needed, used additional control points to refine the image registration quality.

- **Radiometric Calibration**

The native data format of the raw IKONOS and WorldView-2 imagery is in Digital Numbers (DN). The specific value of a pixel DN is dependent on not only the surface reflectance but also the sensor type, image acquisition time, and imaging geometry. Since the calculation of NDVI requires surface reflectance as inputs, we had to be removed the DN variations that were caused by factors not related to surface reflectance.

To remove the DN variations caused by the use of different sensors, we conducted radiometric calibration. According to Taylor (2005), the calibration coefficients are different for IKONOS images taken after Feb 22, 2001 (Table 3). We used the following equation to derive IKONOS spectral radiance $L_{IKONOS,\lambda}$ in W/(m^2*sr*µm) for each band.

$$L_{IKONOS,\lambda} = \frac{10^4 DN_\lambda}{CalCoef_\lambda \times Bandwidth_\lambda}$$

where DN_λ is the IKONOS pixel DN, $CalCoef_\lambda$ is the calibration coefficient (in unit DN(mW/(cm^2* sr))), and $Bandwidth_\lambda$ is the bandwidth of spectral band in nm, respectively, for each spectral band λ.

Band (λ)	$CalCoef_\lambda$ (Pre 2/22/01) (in DN(mW/(cm^2*sr)))	$CalCoef_\lambda$ (Post 2/22/01) (in DN(mW/(cm^2*sr)))	$Bandwidth_\lambda$ (nm)
Pan	161	161	403
Blue	633	728	71.3
Green	649	727	88.6
Red	840	949	65.8
NIR	746	843	95.4

Table 3: Radiometric calibration coefficients for IKONOS images.

The WorldView-2 spectral radiance $L_{WV2,\lambda}$ in W/(m^2*sr*µm) was calculated as follows:

$$L_{WV2,\lambda} = \frac{K_\lambda \times DN_\lambda}{Bandwidth_\lambda}$$

where DN_λ is the WorldView-2 pixel DN, K_λ is the calibration coefficient in unit W/(m^2* sr*DN), and $Bandwidth_\lambda$ is the bandwidth of spectral band in µm, for each spectral band λ (Table 4).

Band (λ)	K_λ (in W/(m^2* sr*DN))	$Bandwidth_\lambda$ (µm)
Pan	0.05678345	0.2846
Coastal	0.009295654	0.0473
Blue	0.01260825	0.0543
Green	0.009713071	0.0630
Yellow	0.005829815	0.0374
Red	0.01103623	0.0574
Red Edge	0.005188136	0.0393
NIR1	0.01224380	0.0989
NIR2	0.009042234	0.0996

Table 4: The calibration coefficients and bandwidths of WorldView-2.

- **Planetary Reflectance**

With the spectral radiance calculated from the previous step, we further calculated planetary reflectance based on the following formula:

$$\rho = \frac{\pi \times L_\lambda \times d^2}{Esun_\lambda \times \cos\theta_s}$$

where $Esun_\lambda$ is the mean solar exoatmospheric irradiance in W/(m^2* μm), *d* is the Earth-Sun distance in astronomical units, and θ_s is the solar zenith angle. Essentially, by calculating planetary reflectance ρ from the spectral radiance L_λ, we reduced the image-to-image illumination differences caused by the sensor bands' spectral settings (the spectral response curve of a band affects $Esun_\lambda$), Earth-Sun distance (*d*), and solar zenith angle (θ_s).

1) $Esun_\lambda$

We used the mean solar exoatmospheric irradiance $Esun_\lambda$ values listed in Tables 5 and 6 for the IKONOS and WorldView-2 bands.

IKONOS Band (λ)	$Esun_\lambda$ (W/(m^2* μm))
Pan	1375.8
Blue	1930.9
Green	1854.8
Red	1556.5
NIR	1156.9

Table 5. $Esun_\lambda$ values for IKONOS bands.

Worldview-2 Band (λ)	$Esun_\lambda$ (W/(m^2* μm))
Pan	1580.8
Coastal	1758.2
Blue	1974.2
Green	1856.4
Yellow	1738.5
Red	1559.5
Red Edge	1342.1
NIR1	1069.7
NIR2	861.3

Table 6. $Esun_\lambda$ values for Worldview-2 bands.

Note that even though IKONOS and WorldView-2 have some common bands (Blue, Green, Red, and NIR), their $Esun_\lambda$ values are not exactly the same. This is because the spectral response curves of the corresponding bands between the two sensors are different. This causes spectral radiance (thus pixel brightness) difference even if the two sensors are imaging the same target from the same position and at the same time. By including $Esun_\lambda$ in the calculation of reflectance, the spectral radiance variations due to the optical properties of sensors are minimized.

2) Earth-Sun distance *d*

Another factor that can cause illumination difference is the Earth-Sun distance *d*. The solar irradiance reaching the earth varies with *d*, which again depends on the date and time of year for acquiring the images. Therefore, precise information on the image acquisition time and accurate approaches to calculate Earth-Sun distance were needed. The image metadata file usually stores the data acquisition time in UTC format.

The first step to calculate *d* was to obtain the decimal Universal Time (UT) from the hours (hh), minutes (mm), and seconds (ss) of image acquisition.

UT = hh + mm/60 + ss/3600

Next, the Julian Day (JD) was calculated as follows:
JD = int(365.25 * (year + 4716)) + int(30.6001 * (month + 1)) + day + UT/24 + B - 1524.5
where
A = int(year/100)
B = 2 - A + int(A/4)

Note that for images that were taken in January or February, the year and month were revised:
year = year - 1
month = month + 12

The last step was to calculate *d*:
d = 1.00014 - 0.01671 * cos(g) - 0.00014 * cos(2*g)
where
g = 357.529 + 0.98560028 * (JD - 2451545.0)

Although a table from NASA (http://landsathandbook.gsfc.nasa.gov/excel_docs/d.xls) was available to estimate *d* based on Day of the Year (DOY), it was not as precise as the equation that we calculated, which was based on the exact time when the image was taken.

3) Solar zenith angle θ_s

The solar zenith angle θ_s is 90^o minus sun elevation angle, the latter of which was obtained from the image metadata files. The solar zenith angles θ_s of the three images are summarized in (Table 7).

Image	Sun Elevation Angle (deg)	Sun Zenith Angle (deg)
IKONOS (2000/05/15)	68.6	21.4
IKONOS (2005/01/22)	45	45
WorldView2 (2011/01/25)	44.9	45.1

Table 7. The sun zenith angles of the satellite images.

Note that the 2005 IKONOS and 2011 WorldView-2 images were acquired at the similar day of the year (DOY), so the sun zenith angle was very similar.

4.4. NDVI Calculation

The NDVI was calculated as follows:

$$NDVI = \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red}}$$

where ρ_{NIR} and ρ_{red} are the near infrared and red planetary reflectance that we calculated from section 4.1, respectively.

The image processing and analysis software that we used to conduct remote sensing and GIS analysis were ENVI version 5.1 and ArcGIS version 10.2.

5. Results

5.1. Orthorectification

A comparison between the raw and orthorectified images indicated that distortion existed in the raw image and the distortion was not constant in terms of direction and magnitude across the whole image (Figure 5). The distortion varied according to terrain relief. Therefore, the usual rubber-sheeting geometric correction approach that uses Ground Control Points (GCPs) to create a statistical model was not sufficient. Instead, we used the photogrammetric approach because it allowed us to correct the geometric distortion based on topographic variation (i.e., DEM) pixel-by-pixel.

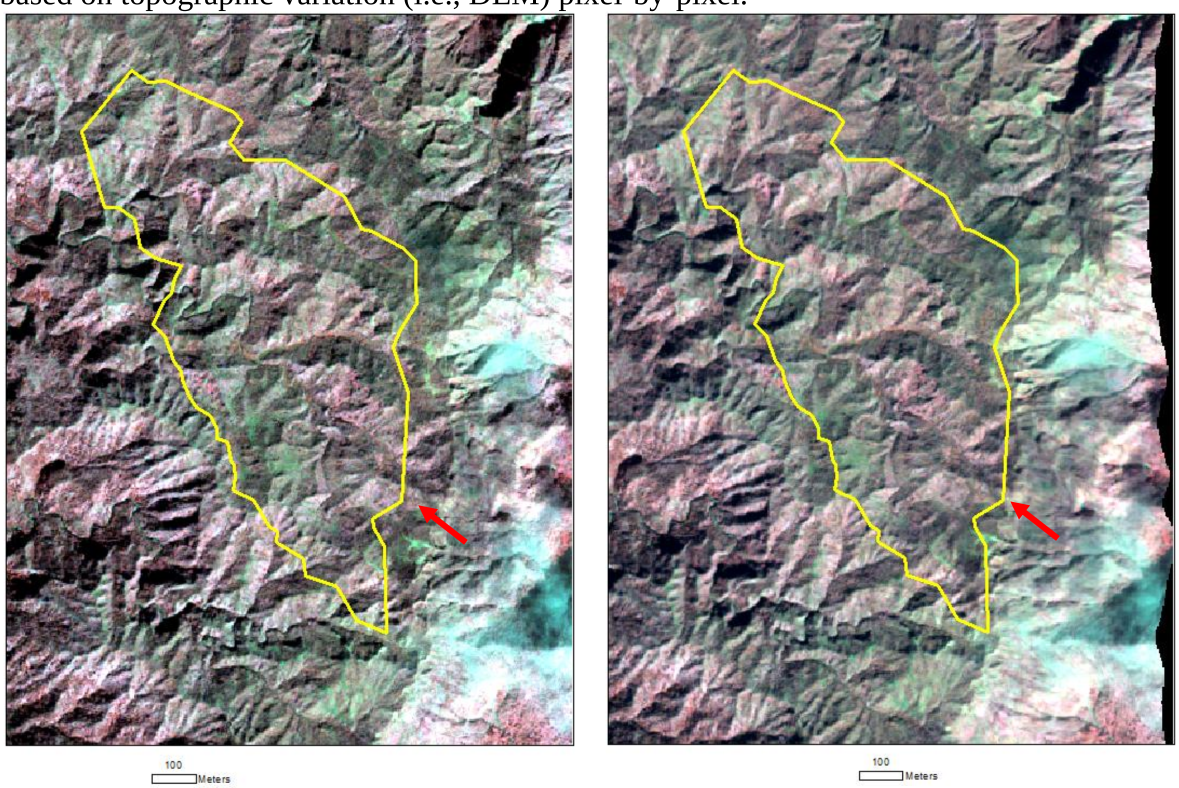


Figure 5: Orthorectification of the IKONOS (Jan 22, 2005) images (before: left image; after: right image). Note the polygon shapefile matches with the ridgeline better after orthorectification. The red arrows point to the ridgeline.

5.2. Radiometric calibration and reflectance calculation

The calibration of image DN to radiance and the calculation of planetary reflectance (Figure 6) enabled us to compare the three images and study the spatial-temporal changes of vegetation, despite that the images were collected by different sensors at different times with different imaging geometries. The reflectance is the required physically meaningful variable to further calculate NDVI.

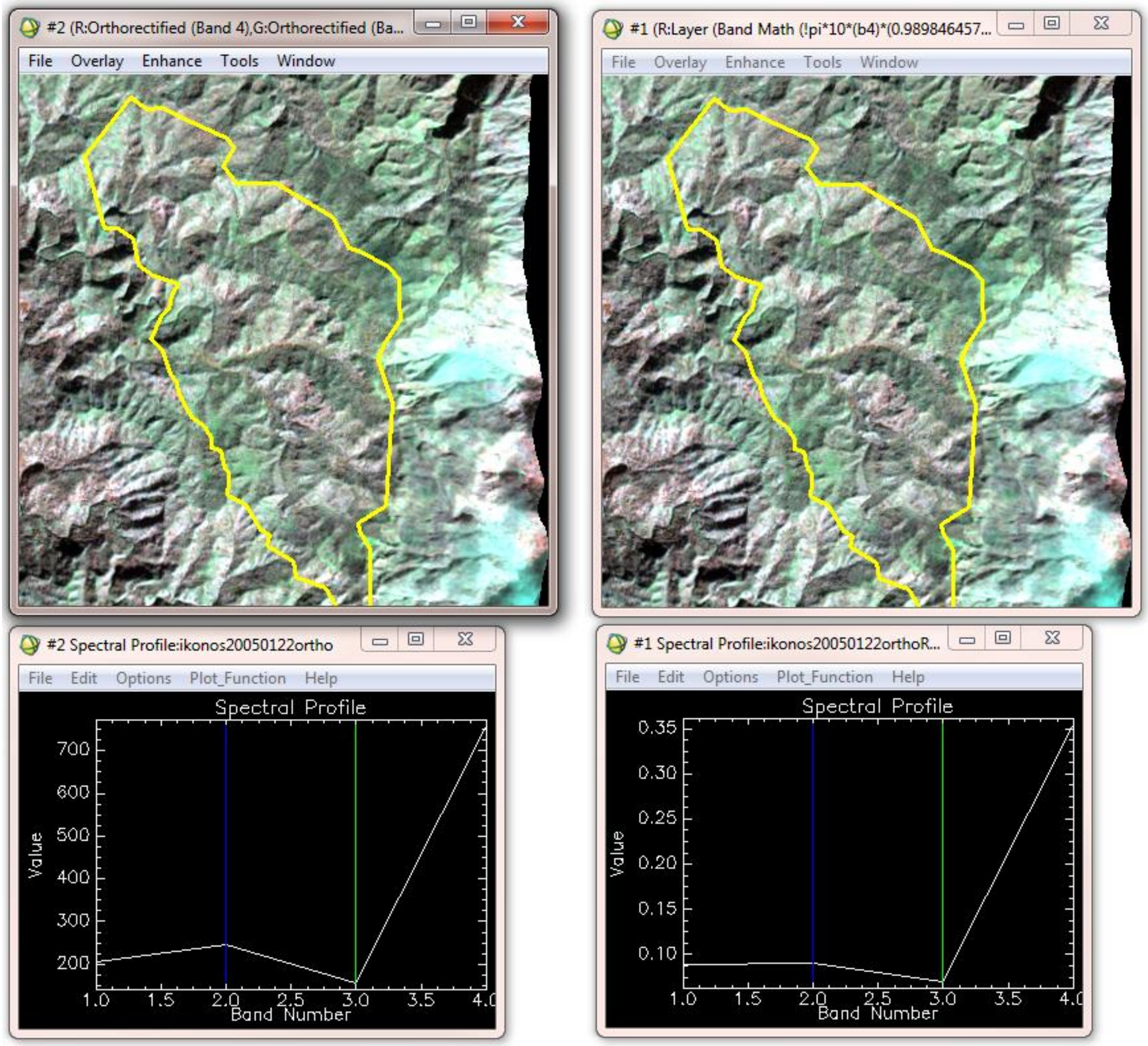
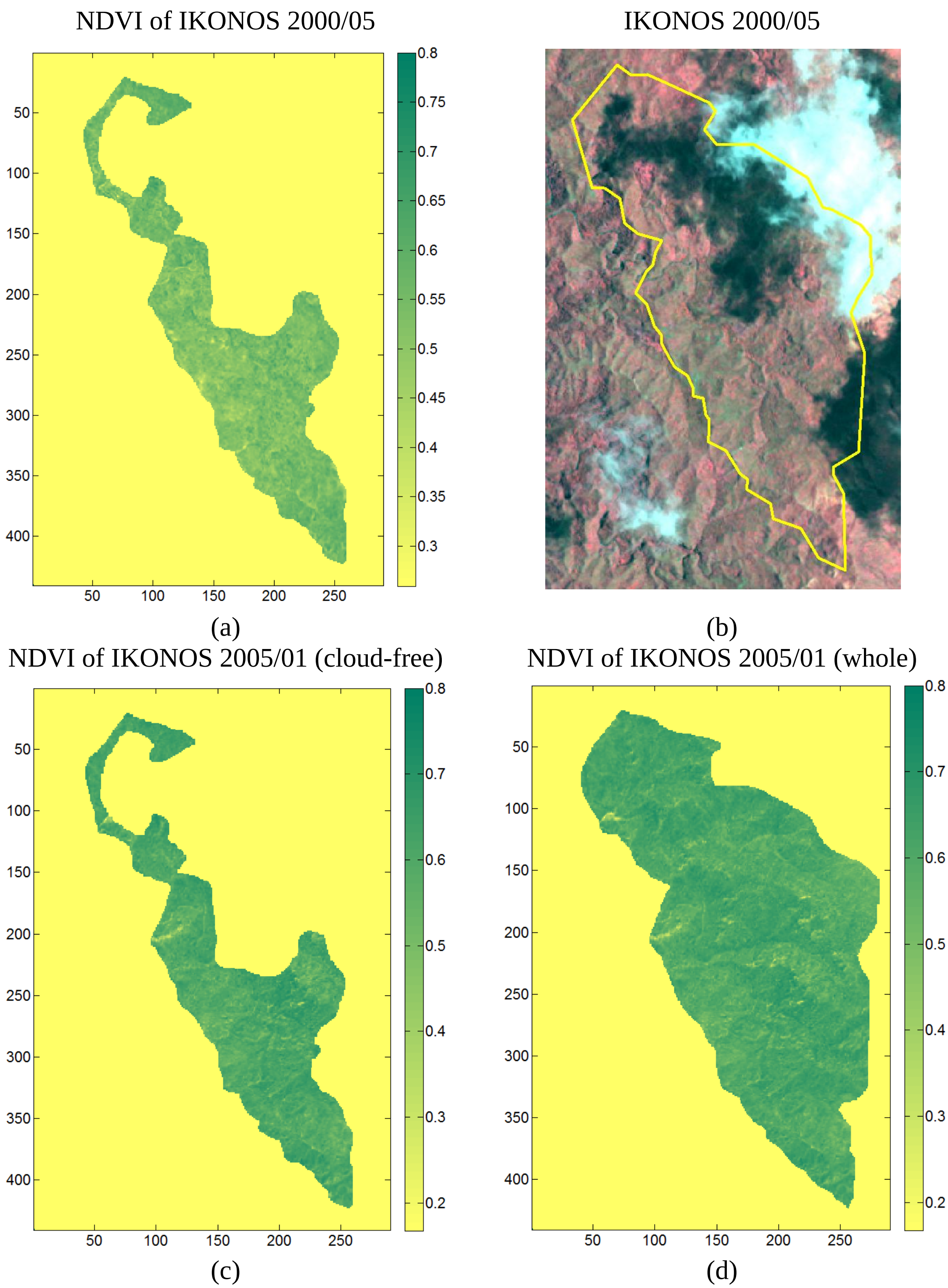


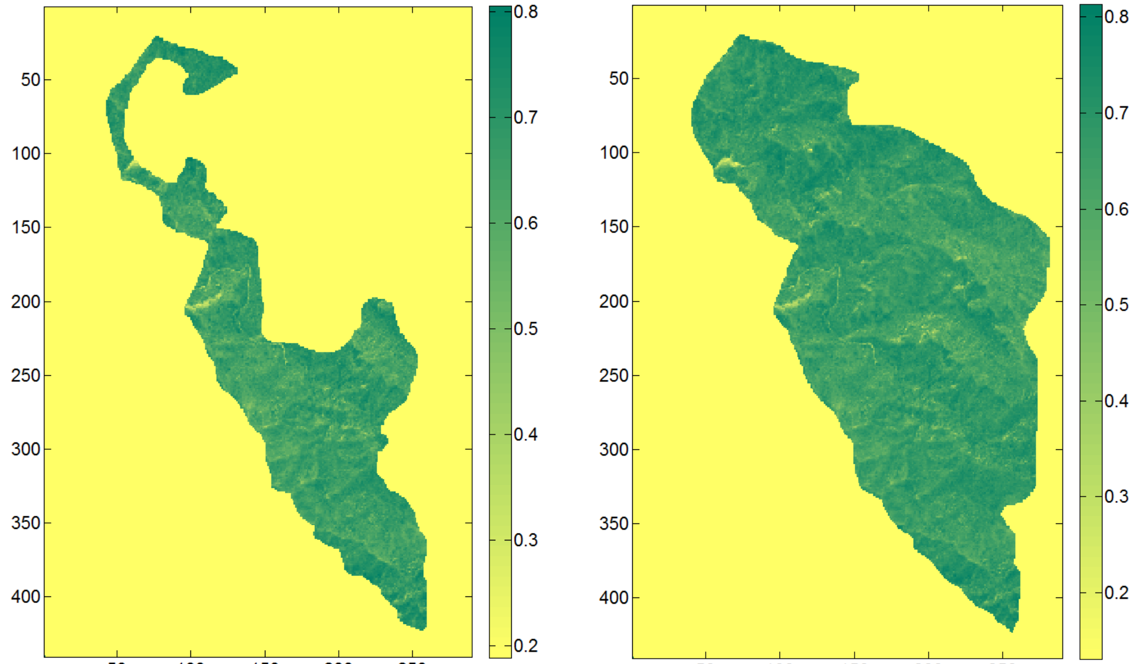
Figure 6: Calculation of reflectance from NDVI. Top row: the false color images of DN (left) and reflectance (right). Bottom row: the spectral profiles of DN (left) and reflectance (right) of a vegetated pixel in the image.

5.3. Spatial and temporal distributions of NDVI

The NDVI of both the Upper Opaeula MU (Figure 7) and its control site (Figure 8) varies around 0.3-0.8. For the Upper Opaeula MU, the 2000 IKONOS image was partially covered by clouds. Therefore, we conducted the time series analysis by masking the clouds and shadows.

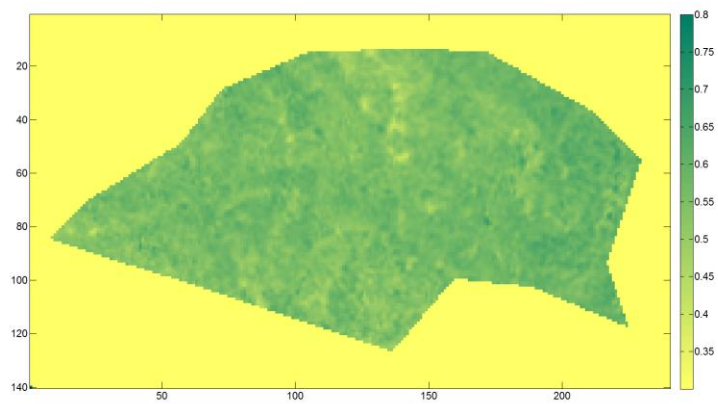


NDVI of IKONOS 2011/01 (cloud-free) NDVI of IKONOS 2011/01 (whole)

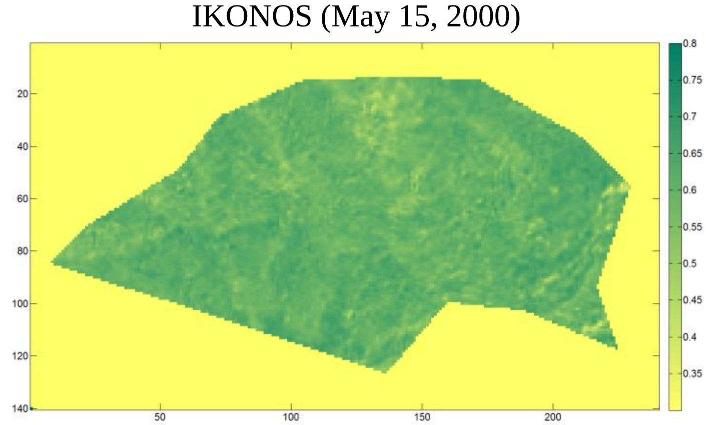


(e) (f)

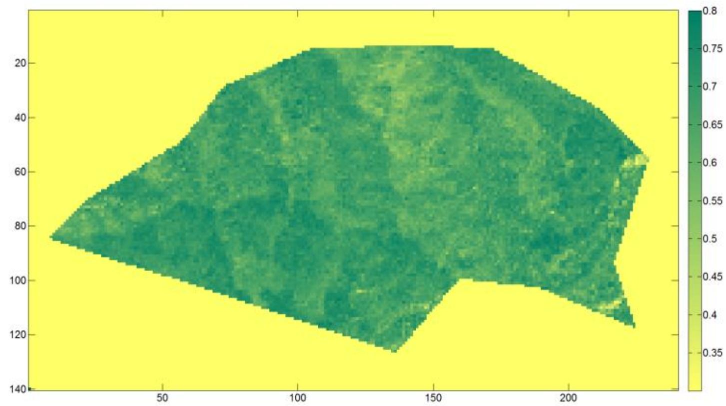
Figure 7: NDVI maps of the Upper Opaeula MU (cloud-free).



IKONOS (May 15, 2000)



IKONOS (Jan 22, 2005)



Worldview-2 (Jan 25, 2011)

Figure 8: NDVI maps of the control site calculated from three satellite images.

For the Koloa MU, the NDVI has a larger dynamic range (Figure 9). The baseline mean NDVI value in 2011 was 0.6442.

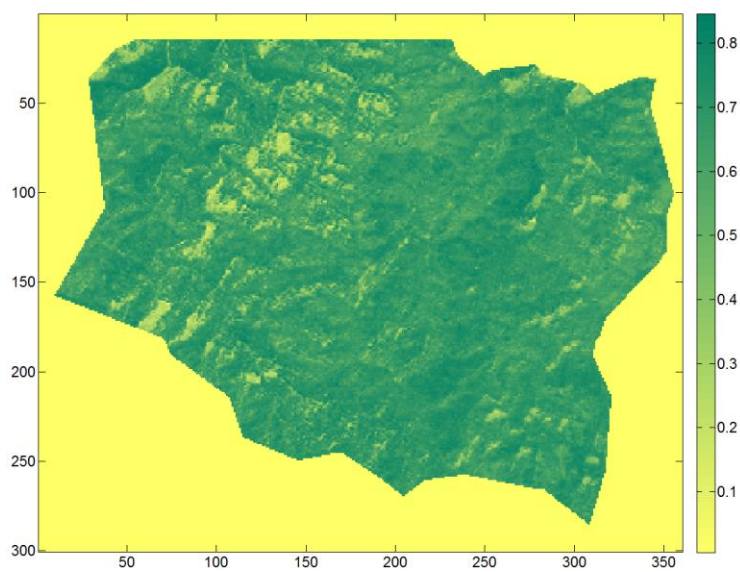


Figure 9: The NDVI maps of the Koloa MU using the Worldview-2 (Jan 25, 2011) image.

5.4. Linkage between NDVI changes and vegetation response to ungulate removal

In 2000, the NDVI value was lower for the Upper Opaeula MU, relative to the control site, which implies that the vegetation in the Upper Opaeula MU was more severely impacted by ungulates prior to fencing. From 2000 to 2005, the rate of increase in the NDVI value was greater for the Upper Opaeula MU than it was for the control area, illustrating there was a positive response in vegetation conditions to ungulate eradication (Figure 10). From 2005 to 2011, the NDVI value increased at relatively the same rate, indicating that there was a minimal response in vegetation conditions to ungulate control from 2005 to 2011.

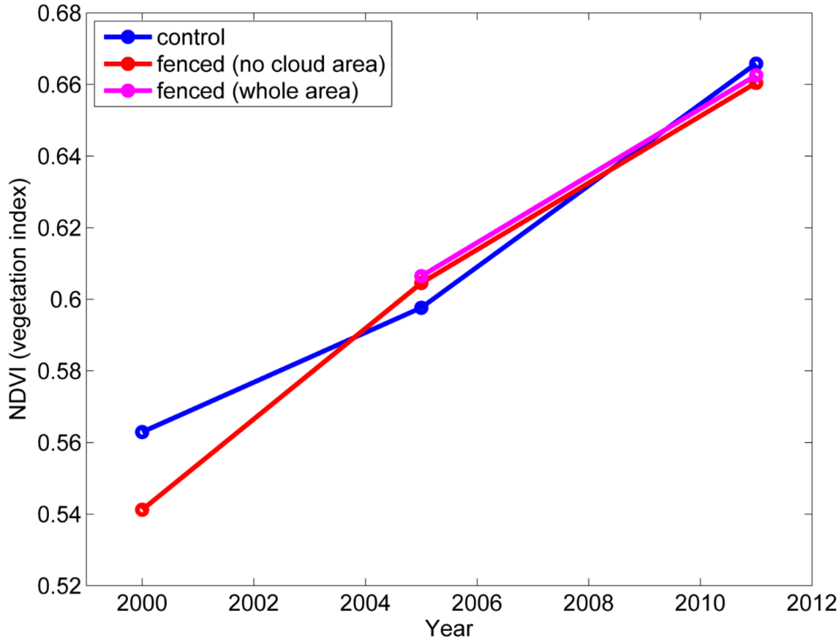


Figure 10: Mean NDVI values of the fenced and control areas for the 2000, 2005, and 2011 images.

5.5.Effects of image preprocessing on NDVI

To demonstrate the effects of image preprocessing (geometric calibration, radiometric calibration, and reflectance calculation, we calculated an ad-hoc “NDVI” that is based on the DN (i.e., $(DN_{nir}-DN_{red})/(DN_{nir}-DN_{red})$) for all the pixels in the image and compared with NDVI based on reflectance (Figure 11). Overall, the image preprocessing changed the NDVI ordinal relationship between fenced and control areas (Figures 10 and 11).

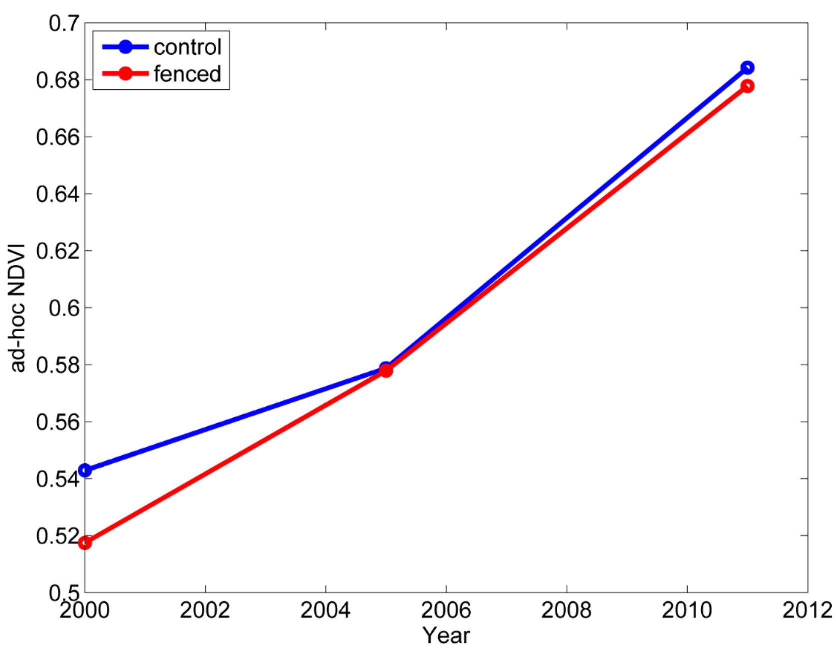


Figure 11: The mean ad-hoc “NDVI” value (calculated based on NIR and red DN) of Upper Opaeula (red) and the control area (blue) for 2000, 2005, and 2011.

6. Discussion

The relatively greater increase in vegetation conditions at the Upper Opaeula MU over time, relative to the control site, was consistent with our original hypothesis (i.e., vegetation recovery occurred following ungulate suppression). However, the continuous increase of the NDVI value over an eleven-year span at both the Upper Opaeula and the control site was not expected. A change in the NDVI can be caused by several factors: 1) conversion of land cover from one vegetation type to another (i.e., from bare ground to vegetated area), 2) successional change of vegetation from one stage (e.g., grass) to another (e.g., shrub and trees), and 3) vegetation vigor caused by environmental conditions (such as soil water content and temperature).

The relatively large increase in the NDVI value over time at our study sites may be partially explained by the temporal differences in precipitation. Heavy rainfall events can cause grass to establish in previously disturbed areas (i.e wallows, etc.) and vegetation to flush. For our study, the mean monthly rainfall and the NDVI values were significantly correlated ($p < 0.05$) (Table 8). The total rainfall over the three-month span, prior to when the satellite imagery taken in 2000, was the lowest (5.9"). The total rainfall over the three-month span, prior to when the satellite imagery was taken in 2011, was the highest (27.82") (Western Regional Climate Center, 2014)

Date Range	Total rainfall (in inches)
Feb. 15th – May 15th of 2000	5.9
Oct. 22nd of 2004 – Jan. 22nd of 2005	22.35
Oct. 25nd of 2010 – Jan. 25nd of 2011	27.82

Table 8: The total rainfall over the three-month span, prior to when the satellite imagery for our study was captured.

The positive relationship between precipitation and vegetation conditions was supported by the findings of a prior study. Kellner et al. (2011) found that the enhanced vegetation index (EVI), which is a similar value to NDVI, and rainfall were strongly correlated with vegetation cover <1m in height. The relationship between EVI and vegetation in the "higher" canopy (>1m) were not significantly correlated. Those results illustrated that EVI strongly tracked temporal changes in groundcover vegetation. The results of the Kellner et al. (2011) study also indicated that the magnitude of difference in vegetation cover of natural areas following feral ungulate control, relative to a control site, was greatest during the dry season. Thus, it was easier to detect vegetation response to ungulate eradication using remote sensing data during the dry season. Based on the finding of Kellner et al. (2011), we recommend future studies using remotely sensed data to monitor vegetation response to feral ungulate removal also utilize imagery captured during the dry season.

Remote sensing of vegetation degradation and its recovery is a challenging issue because degradation often occurs at small spatial scales. This makes the widely used approach of classifying a landscape into different vegetation categories not applicable. Instead, the NDVI approach used in this project, which quantifies vegetation conditions at the continuous scale, is more suitable for capturing subtle vegetation changes. The key of successfully applying such an approach is to make sure the images collected by different sensors and from different times are precisely geometrically and radiometrically corrected. As such, the calculated image difference can be attributed to actual vegetation change happening in the field. Given that VHR satellite images are relatively new, the sensor parameters and the image metadata are usually not well documented. We devoted much of our time to search the sensor-specific calibration parameters, validate the data-specific information, test different approaches for image processing, and finally establish a methodology for the whole project. Although the development of such methodology took time, it can be easily adapted to another geographic area and time if the same type of sensors is used for similar applications. For projects of similar geographic size, the estimated time for replicating analysis using the methodology could vary from days to weeks, depending on the analyst's level of skills in remote sensing.

7. Conservation Application

The developed monitoring framework provides a useful tool for conservation practitioners to quantify vegetation recovery to the release of top-down stressors over large geographical areas. The generated spatial distribution maps of ungulate impact may also provide conservation practitioners with a useful tool to identify areas highly impacted by ungulate, which are likely primary hotspots for the establishment of undesirable invasive vegetation.

One limitation of satellite imagery is detecting succession at the species level. Combining the remote sensed data analysis techniques that we developed for this study with fine-scale field based plots would be ideal for capturing vegetation recovery over time at the landscape scale and documenting species level succession following feral pig eradication. Utilizing these two monitoring techniques together would address the concerns of previous pig exclusion studies that have been conducted in Hawaii.

In 2013, twenty plots were installed in the Koloa MU by OANRP staff and David Bybee (a biology professor at Brigham Young University). The plots were installed in areas that were easily accessible in order to avoid unintentional negative impact to fragile habitat. This study will allow for analysis of forest succession, following ungulate removal, at the species level. Continuing this project, in combination with remote sensing NDVI mapping and monitoring, would allow OANRP staff to capture vegetation recovery at the spatial scale (i.e., MU level) and resolution (i.e., to identify if a change in the vegetation conditions at the landscape level was dominated by native or non-native species) of interest in an efficient and effective manner.

References:

Cole, R. J., C. M. Litton, M. J. Koontz, and R. K. Loh. 2012. Vegetation Recovery 16 Years after Feral Pig Removal from a Wet Hawaiian Forest. Biotropica **44**:463-471.

D'Antonio, C. M., and P. M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual review of ecology and systematics:63-87.

Didham, R. K., J. M. Tylianakis, M. A. Hutchison, R. M. Ewers, and N. J. Gemmell. 2005. Are invasive species the drivers of ecological change? Trends in Ecology & Evolution **20**:470-474.

Dunkell, D. O., G. L. Bruland, C. I. Evensen, and C. M. Litton. 2011. Runoff, Sediment Transport, and Effects of Feral Pig (Sus scrofa) Exclusion in a Forested Hawaiian Watershed 1. Pacific Science **65**:175-194.

Eckhardt, R. C. 1972. Introduced plants and animals in the Galapagos Islands. Bioscience **22**:585-590.

Giambelluca, T. W., Q. Chen, A. G. Frazier, J. P. Price, Y.-L. Chen, P.-S. Chu, J. K. Eischeid, and D. M. Delparte. 2013. Online Rainfall Atlas of Hawai‘i. Bull. Amer. Meteor. Soc.

Gillespie, R. G., and D. A. Clague 2009. Encyclopedia of islands. Univ of California Press.

Ickes, K., S. J. Dewalt, and S. Appanah. 2001. Effects of native pigs (Sus scrofa) on woody understorey vegetation in a Malaysian lowland rain forest. Journal of Tropical Ecology **17**:191-206.

Jensen, J. R. 2009. Remote Sensing of the Environment: An Earth Resource Perspective 2/e. Pearson Education India.

Kellner, J. R., G. P. Asner, K. M. Kinney, S. R. Loarie, D. E. Knapp, T. Kennedy-Bowdoin, E. J. Questad, S. Cordell, and J. M. Thaxton. 2011. Remote analysis of biological invasion and the impact of enemy release. Ecological Applications **21**:2094-2104.

Loope, L. L., and P. G. Scowcroft. 1985. Vegetation response within exclosures in Hawaii: a review. Hawaii's terrestrial ecosystems: preservation and management:377-402.

Nogueira-Filho, S. L., S. S. Nogueira, and J. M. Fragoso. 2009. Ecological impacts of feral pigs in the Hawaiian Islands. Biodiversity and Conservation **18**:3677-3683.

Spear, D., and S. L. Chown. 2009. Non- indigenous ungulates as a threat to biodiversity. Journal of Zoology **279**:1-17.

Taylor, M. 2005. IKONOS Planetary Reflectance and Mean Solar Exoatmospheric Irradiance; Space Imaging Inc.: Thornton, Colorado. URL: http://www.spaceimaging.com/whitepapers_pdfs/Esun1.pdf.

Vitousek, P. M. 1986. Biological invasions and ecosystem properties: can species make a difference? Pages 163-176. Ecology of biological invasions of North America and Hawaii. Springer.

Vitousek, P. M. 1996. Biological invasions and ecosystem processes: towards an integration of population biology and ecosystem studies. Pages 183-191. Ecosystem Management. Springer.

Western Regional Climate Center. http://www.wrcc.dri.edu/. accessed date. Web.15 Sept. 2014

Whittaker, R. J., and J. M. Fernández-Palacios 2007. Island biogeography: ecology, evolution, and conservation. Oxford University Press.

Annual Progress Report for "Makaha Valley Vegetation Mapping Analysis"
Project Update: January 1, 2014 – September 30th, 2014

Evaluation of Three Very High Resolution Remote Sensing Technologies for Vegetation Monitoring in Makaha Valley

William Weaver wweaver@hawaii.edu
Tomoaki Miura <tomoakim@hawaii.edu>
Department of Natural Resources and Environmental Management
University of Hawaii at Manoa

This report serves to update the progress of this project from the start in January of 2014 through September 30th, 2014. Progress was made with respect to gear research, procurement and testing, imagery acquisition and procurement of classification software tools.

Project Overview

The main objective of this project is to evaluate three different remote sensing technologies to expand the set of monitoring tools and develop a methodology for an accurate, cost effective method to map target plant species and track Management Unit change over time. One application of this tool will be to use it in sensitive areas that may otherwise be difficult to monitor using ground surveying techniques. These areas include the northern and central Ko'olau mountain summits. The foundation work for this project has been conducted in a portion of Makaha Valley (Figure 1). The study site is relatively accessible and vegetation monitoring data has been gathered with the use of belt line transect sampling.

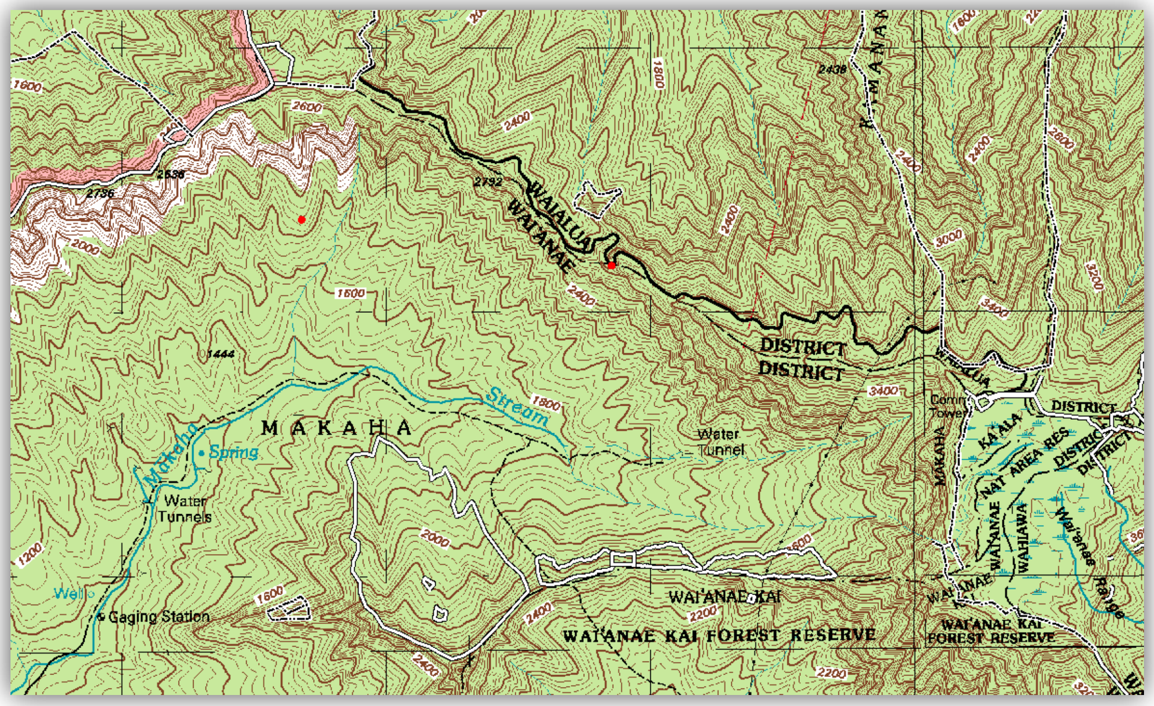


Figure 1. Topographic map portraying the back of Makaha Valley with Subunits I and II and the Ka'ala road.

Proposed Imagery Technologies

1. The Gigapan Epic Pro robotic unit will be utilized to obtain a very high resolution mosaic panorama of the target area. Resolution of the Gigapan imagery may serve to be accurate to less than 1cm. A compliment of the imagery will be the use of a laser rangefinder remote GPS system for geo-referencing.
2. High resolution orthorectified aerial imagery will also be taken of Makaha Valley utilizing an Unmanned Aerial Vehicle (UAV). Resolution may be less than 5cm.
3. Multi spectral satellite imagery from WorldView-2 will be acquired for the Makaha Valley. WV2 offers high resolution 8-band multispectral imagery with a multispectral resolution of 1.85m.

Image Analysis

A number of methods of analyzing imagery for the three technologies will be examined, which include visual inspections and object based classification with eCognition software from Trimble Navigation Ltd. eCognition uses a hierarchy of image objects to group and classify related pixels on digital images focusing on the spectral and shape characteristics of the data.

Target Species

- Psidium cattleianum (Strawberry guava)
- Coffea arabica (Coffee)
- Grevillea robusta (Silky oak)
- Toona ciliata (Australian cedar)
- Fraxinus uhdei (Tropical ash)
- Acacia koa (Koa)
- Metrosideros polymorpha (Ohia)
- Diospyros sp. (Lama)

Work Accomplished

Gigapan

- We researched various camera and lens options for the Gigapan equipment, and developed a cost-effective Gigapan hardware configuration.
- We successfully established good photo-taking protocols (i.e., exposure settings, ideal sky conditions, etc.) through a number of testing at various locations including Tantalus and UH Manoa Campus.
- A good sample Gigapan image was acquired of the study site.
- We found and concluded that the conventional unsupervised classification method was ineffective in classifying Gigapan images of vegetation formation.

Below, we describe in detail our Gigapan experiment conducted at Makaha on March 27, 2014.

Methods

Imagery was obtained of the central portion of Makaha Subunit II on March 27, 2014 between 12 and 1p.m. from a turnout on the Federal Aviation access road leading up to the summit of Mount Ka'ala. The vantage point has an elevation of approximately 850 meters, (see Figure 1) and is located at the UTM coordinates 04Q0586840, 2379164. The exact setup location was marked with pink surveyors flagging to allow for return to the same location.

The Gigapan Epic Pro was mounted on a tripod and levelled using the bubble level on the device. A Canon 60D and a Canon 100-400mm 4.5-6.3L lens with a Canon 2x extender was then mounted to the Gigapan unit and zoomed to its full extent (see Fig. 2). A remote shutter switch was attached between the Gigapan and camera body to reduce camera shake.

Figure 2. The Gigapan Epic Pro and Canon 60D setup used for image acquisition

The camera was set to manual mode, manual focus, ISO400, F11 with a shutter speed of 1/125 of a second. Focus was set manually about 1/3 above the center of the study area. The top left and bottom right corners of the panorama were selected. It was important to note the number of columns and rows of images for later image processing. The Gigapan unit was initiated to take the images of the study area starting at the top left corner panning from top to bottom. Once the unit had taken the images in a certain column it moved up to the adjacent row with a 30% overlap in between images. The unit took approximately 40 minutes to complete the panorama image capture.

Post processing of the images was conducted to create the gigapixel panorama of the study site using GigaPan Stitch 2.3.0307. The image was loaded into ENVI 5.1. and an individual file taken by the camera was selected. It represented an area near known landmarks with vegetation representative of the study area as a whole. Visual classification of a subset of the image was undertaken to be used as a comparison using visual cues, such as tone, texture, shape, pattern, and relationship to other objects. Isodata image analysis was run with ENVI 5.1 utilizing 10-25 classes with a maximum of 10 iterations. The red, green and blue bands of the image were loaded with ENVI.

Results

The area of interest was captured by a panoramic image stitched together from 244 images, resulting in a single file 1.77GB in size (See Figure 3). The distance from the vantage point to the center of Subunit II was measured using the ArcGIS 10.1 measuring tool and determined to be approximately 1100m. The resulting gigapixel image had a spatial resolution of 0.6cm.

This was determined using the following formula:

GSD=distance/focal length x CCD pixel size

Where GSD is the ground surface distance, the distance is measured from the camera to the survey location, the focal length is the length of the lens and CCD pixel size is the size of the camera sensor.

Figure 3. Gigapixel resolution panorama of a portion of Makaha Subunit II

The resulting imagery produced by the isodata classification could not be used to generate a useful vegetation map. Vegetation classes could not be combined or split as noticeable changes in canopy classes were not readily discernable from the array of colors displayed (see Figure 4).

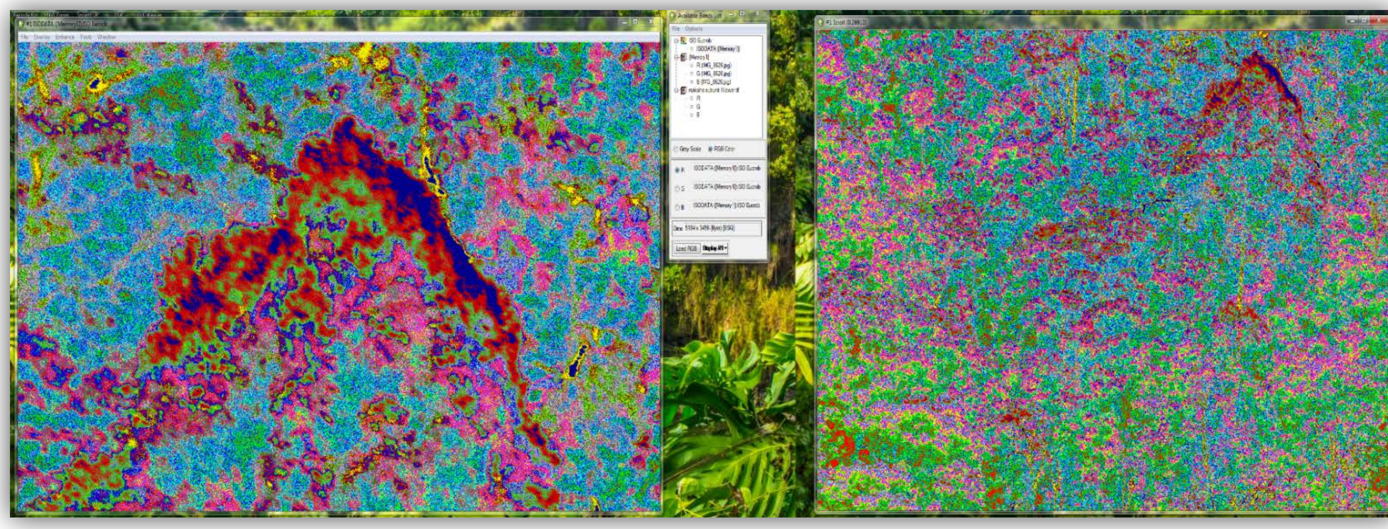


Figure 4. Imagery with the application of ENVI isodata classification analysis tool

Discussion and Summary

Initially, the goal was to capture the entire subunit II in a mosaic of images to be created into a gigapixel panorama. However a subset of the unit was chosen due to operational constraints with the memory cards on hand. Some of the memory cards available on the field day did not have a writing speed to match the speed of image capture and the two cards that did have the writing capacity did not have enough memory to hold the 1,000+ images required to capture the area in its entirety.

There were issues with the sharpness and clarity of the images taken of Makaha. This may be attributed to several factors:

> 1) The tripod used was not steady under the weight of the gigapan unit and camera setup and could have contributed to camera shake.
>
> 2) The focus had to be set up manually due to the 2x extender on the lens. A 1.4x extender may be beneficial to obtain for future use as one can utilize automatic focus with the initial setup. Some of the spatial resolution will be lost with the shorter lens focal length but may be offset by better picture clarity.

3) A faster shutter speed than 1/125 may help with clarity issues and a sunnier day could help to facilitate this. As a general rule the shutter speed should match the focal length of the lens (GigaPan Systems LLC pers. comm., 2014)

The weather conditions on the day of image acquisition seemed to be favorable with clean air, light winds and an even cloud cover. It would be interesting to recreate the imagery on a day with mostly sunny conditions for a comparison analysis. As stated earlier, a sunnier day may result in better imagery due to the ability to use a faster shutter speed. The color saturation will also have some variability from imagery taken on a cloudy day. The gigapan unit will need to be tended to in order to pause the image capture as clouds shade the study area.

Visual Classification coupled with ground truthing may be feasible for vegetation mapping with gigapixel imagery due to its very high spatial resolution but is time consuming and subject to user error. Isodata classification was not an effective tool with the vegetation found in upper Makaha. This is probably due to the homogenous nature of the canopy vegetation. The difference in reflectance values of the individual pixels of vegetation was not significant enough to separate out vegetation classes.

Next Steps

Further testing was done from Tantalus and other equipment was researched. The 2x extender was determined to be the cause of the image clarity issue. Short term Canon gear rentals may be used in the future for sharper images and enhanced resolution. A sturdy tripod was purchased for the project. Field work was also conducted to find other vantage points from lower down in Makaha Valley. A suitable vantage point was found for subunit I. Research was conducted and inquiries were made with several companies in order to locate a device that would enable the user to gather remote GPS points to be coupled with the Gigapan imagery for georeferencing purposes. Lasertech is a surveying company that carries several products that match this application. Pacific GPS on Oahu, is able to bring in the equipment needed and make it available for rental.

In the next year further Gigapan imagery will be acquired coupled with a laser rangefinder and Trimble GPS unit. Canon gear will be rented from Camera HI for several days during the field campaign. The laser rangefinder and gps trimble unit will be rented from Pacific GPS.

Unmanned Aerial Vehicle

With respect to the high resolution aerial platform, correspondence and project specifics were discussed with Remap HI and a site visit was made. Another researcher, Aaron Woods, with a German engineered UAV system was also consulted with for a project estimate and plans to visit the research target area. Image acquisition will be made during the Spring of 2015 with one of these two options. Leading up to this, a field campaign will be established to demark ground calibration points for image classification.

World View Satellite Imagery

Inquiries were made to acquire current World View 2 satellite imagery of Makaha. In addition, an eCognition license was obtained from Trimble ltd. This involved some licensing and installation troubleshooting. The next step will be to take an online training on running the software and start image analysis.

Next Year

October 1st 2014 to September 30th, 2015

- Field campaign to establish ground calibration points
- Additional imagery acquisition of Gigapan
- New image acquisition of High Res UAV Aerial and WV2
- Imagery analysis and protocol development
- Accuracy check of imagery with field component
- Vegetation map creation of target species

Schofield-Kaukonahua Fire
October 16-November 5, 2013

MEMORANDUM FOR RECORD

These notes were compiled on November 13, 2013 to document Oahu Army Natural Resource Program (OANRP) response for the fire, the damage to State and Federal natural resources, safety concerns, and lessons learned to improve fire plans and responses.

Summary

OANRP is not well informed on the ignition of this fire but believe it started near MF5 during a detonation/disposal operation conducted by EOD on October 16th. The fire burned in the range until October 23rd when the fire broke out to the North and onto lands owned by Dole Food Company Inc. and leased by a local rancher. *Hibiscus brackenridgei* on the Dole parcel were at risk from the fire. At mid morning on October 23rd, OANRP became involved. OANRP assisted Army Wildland Fire with OANRP personnel on site at the IC (Incident Command) and with contract helicopter support for nine days. Five of those days were full days assisting and managing helicopter operations. The other four days were only partial days. On the remaining days, no assistance was requested of OANRP and thus OANRP did not support fire response operations. In the end, there was no impact to MIP taxa though it burned within 1,180 m of *H. brackenridgei*. Property losses were limited to livestock fence lines and waterlines because of fire and some crop losses due to rotor wash from responding helicopters. While this appears to be a distance of some magnitude, the flashy fuels involved and experience from the Waialua fire of 2007 justified OANRP involvement. OANRP management gained some valuable lessons which are reviewed in the lessons learned section at the end of this document.

The fire burned approximately 420 acres of mixed fuels. Some sections were of dry fuels dominated by *Panicum maximum*, *Leucaena leucocephala*, and other alien grasses. In the higher elevations the heavier fuels consisted of weedy trees. A partial species list includes; *Eucalyptus spp, Acacia confusa, Psidium cattleianum, Syzygium cuminii, Schinus terebinthifolius, Casuarina spp, Cupressus spp. and Pinus spp*. The weather over the course of the week was mainly dry (40-75% RH), hot (>70-80˚ F) and, for the most part, winds were calm and variable (0-5 +mph) mainly out of the south. There was a significant rain that occurred on October 19th and November 6th. There have been no flares up since then.

Figure 1: Map showing the extent of the burn on October 23, 2013 and proximity to *H. brackenridgei*. This map was generated from the ground observations.

<u>October 16-23</u>

Before OANRP became involved, the fire had been burning on the slopes of Kaukonahua gulch to the east of the ignition point. No resources were threatened during that first week of the fire, and the fire appeared to be entirely contained by the night of October 20th when it rained. On Monday and Tuesday of October 21-22nd, the fire re-ignited and continued to spread further down gulch. According to Army Wildland Fire staff, limited helicopter support was available during this time and OANRP did not send our contract helicopter as support was not requested.

Figure 2: Extent of fire before mid morning on the 23th. No OANRP involvement had been initiated as there was no resource threat.

Wednesday October 23, 2013

Staff	Time	Total Hours
Joby Rohrer	~1000-1800	8.0
Kapua Kawelo	~1100-1800	7.0
Michelle Mansker	~1100-1MD 500	4.0
Mike Walker	~1100- 1800	7.0
Kala Asing	~1:00-1800	7.0
Dan Sailer	~1100- 1800	7.0

Company & Pilot	Time	Total Hours
9PA Airborne Aviation (Steve Aiu)	11:00-5:30 pm	5.6 Hobbs meter time

Sequence of Events

~0900: The fire somehow crossed to the north of the drainage at the location labeled "jump" in Figure 1. This is an approximate location on the map. Army Wildland Fire suspect there was a "roll out". When this occurs ignited fuel rolls down slope and into unburned fuels. Once at the bottom of the slope the fire spread aggressively up through flashy fuels. Large smoke plumes and flames were visible from West base and OANRP staff began contacting PCSU and DPW management for direction.


Figure 3: Fire actively spreading to the North. Photo credit, Clay Trauernicht

~1100-17:30+: OANRP staff assist Army Wildland Fire posted at Kaukonahua and at MF3 range tower. Airborne Aviation helicopter arrives on scene with pilot Steve Aiu in the Hughes MD 500 and begins bucket drops. Steve Aiu also provides direction to less experienced pilots and prioritizes bucketing operations based on his experience and reconnaissance. Military air support continues throughout the day with two or more Blackhawks, one U.S. Marine Sea Stallion, Army National Guard Chinook, Evergreen Helicopters, and Air One from HFD. Army Wildland fire kept logs on helicopters time on scene.

Time	Hobbs	Note
~ 1100	973.5	Steve Aiu arrives at Dragon X LZ, pulls doors, bucket set up, gear test and water drops begin
1300	975.0	Bucket pulled and Steve heads to Hot POL, refueling depot at Wheeler Army Airfield. Returns in about 25 minutes and resumes water drops
1MD 500	976.8	Second refuel as above
1700	978.3	Third refuel as above
1830	979.1	Steve back at Dragon X. Bucket stored and held for the night by OANRP. Doors returned to ship and Steve heads back to HNL. Plans are made for the following day.

Fire Behavior

Fire spreads aggressively up slope and is unmanageable on initial run. Southerly winds also push the fire downgulch toward Kaukonahua Road and northward. Helicopter drops are unable to contain the fire spread toward the north and the fire burns approximately 30-40 acres per hour on the northern fireline with some fire spotting and extreme fire behavior at times. Helicopter water drops slow spread once the fire reaches the main crestline along the western fireline. Drops are also directed to prevent spread across slopes to the north as directed by OANRP to prevent threats to the *H. brackenridgei*. No ground resources are used because of concerns with UXO. In addition, there are no access points nor escape routes or safety zones. Thick smoke hinders bucketing operations as ships are unable to fly low into the gulch to create an effective 'anchor' near the gulch bottom to slow or prevent the fire from spreading northward.

Figure 4: Fire actively spreading across slope to the North. U.S. Army Blackhawk dropping water on advancing front. Photo credit, Clay Trauernicht

Safety Concerns

On the 23rd as well as throughout the incident, helicopter coordination is the paramount safety concern. All operations are directed by Scott Yamasaki (Army Wildland Fire). Frequency 122.925 is used by all aircraft ensuring seamless communication. Dip pond usage is spread across multiple ponds to avoid conflicts. Army Wildland Fire staff reported that given the rotor wash from the large military aircraft, they needed to be alerted ahead of time before ships landed at Dragon X so they could retreat to a safe location.

Thursday October 24, 2013

Staff	Time	Total Hours
Joby Rohrer	0700 – 1800	11
Mike Walker	0700 – 1800	11
Kala Asing	0700 – 1800	11
Kapua Kawelo	0730 – 1800 (at MF-3 tower or supporting in office)	10
Michelle Mansker	0800-1200 (same as Kawelo)	4

Company & Pilot	Time	Total Hours
9PA Airborne Aviation (Steve Aiu	0700 – 1740	7.0 Hobbs (breaks for refueling and a1.5 hour standby)

Sequence of Events

Water drops started early in the morning and ran all day. There was no significant spread on the perimeter. For the second day there was strong showing of air support with all groups mentioned above on site with the exception of HFD. All air operations are run by Scott Yamasaki. Focus continued on perimeter and northern edge.

0705: S. Yamasaki, Mike Walker and Kala Asing perform an aerial reconnaissance and map with GPS the perimeter of the fire.

0730: 9PA Steve Aiu begins bucket work and provides direction to other less experienced pilots.

1400-1545: 9PA down on standby so that he could do another round of bucketing late in the day. Flight time limitations are 8 hours of flight time per OAS and 12 per duty day (NEED TO CONFIRM THIS). This should be considered when operations start early as these restrictions can be limiting. Breaks can be taken to ensure availability later in the day.

Time	Hobbs	Note
0705	979.7	Scott Yamasaki, Mike Walker and Steve Aiu perform aerial recon and mapping
0725	980.0	Recon finished and bucket drops begin
0835	980.9	First refueling cycle at Wheeler
0902	981.1	Return from Wheeler
1050	982.7	Second fuel run
1127	982.9	Back from refuel. Slow return due to having to wait for a Sea Stallion to be fueled (37 minute turn around).
1300	984.4	To Dillingham to refuel as Wheeler is unavailable
1400	984.9	Back from Dillingham. Refueling takes a full hour, and 0.5 Hobbs. Steve put on break due to daily flight time constraints.
1545	984.9	Bucket drops resume
1715	986.4	Back to dragon pull bucket replace doors and debrief. Steve heads to Wheeler at 1740 for gas then to HNL

Fire Behavior

Light winds and heavy air support hold the fire from additional spread.

Figure 5: Map produced by helicopter mapping on the morning of October 24.

Safety Concerns

Flight managers need to assist pilots in keeping track of flight time and duty day limitations and strategically plan the best use of their time on long days.

Figure 6: Sea Stallion and crew form Kaneohe Marine base. These large helicopters provided valuable support during the incident. Photo credit, Clay Trauernicht

Friday October 25, 2013

Staff	Time	Total Hours
Michelle Mansker	0700-1100	4.0
Joby Rohrer	0800 – 1800	11.0
Mike Walker	0800-1030	2.5

Company & Pilot	Time	Total Hours
9PA Airborne Aviation (Alan Olmos)	0840-1700	4.5 Hobbs breaks for refueling and a 2.0 hour standby

Sequence of Events

Water drops started early in the morning and ran all day. Sometime around 3 am in the morning, the fire began actively burning on the northern end of the fire. For the third day there was strong showing of air support with all groups mentioned above on site. All air operations are run by Scott Yamasaki. Focus continues on the Northern edge to stop the spread.

0730: Michelle Mansker reports active fire on the Northern edge and request air support ASAP.

0800: Mike Walker responds from Waialua to size up the fire threat and report to Michelle and Joby.

0840: Alan Almos from Airborne Aviation on scene in 9PA. Takes radios to Mike and then begins bucket drops.

1000: Michelle and Joby report to IC at Kaukonahua and relieve Mike. Operations are run out of this location for the duration of the day.

Time	Hobbs	Note
0840	986.9	Alan on scene with 9PA. Takes radios to Mike and starts bucket drops
1035	988.4	Drops bucket at Kaukonahua LZ and goes to Wheeler for fuel
1106	988.6	Back from fuel starts bucket drops
1233	990.0	Second fuel run
1302	990.2	Back for bucket
1415	991.2	Bucket malfunction, set down at Kaukonahua LZ then to Wheeler for fuel
1456	991.4	Back from Wheeler, shut down at Dragon X for break
1700	991.4	Released from fire headed to HNL

Fire Behavior

Light winds and heavy air support prevent any additional spread to the north after the early morning run.

Safety Concerns

When OANRP pilots are flying in the vicinity of the larger ships extra caution should be taken to ensure that there is no impact of rotor wash. On one occasion Alan reported rotor wash from one of the Sea Stallions causing instability to his ship.

The bucket on a couple of occasions pulled out the electrical three pin because the length of the extension cord did not leave adequate slack as compared to the 50' cable. Airborne should ensure that the extension cord supplied for the electrical release on the bucket is long enough to ensure there is enough slack. OANRP staff had to continually pull slack up toward to the top of the line to ensure that the cord would not get pulled out by the cable.

Saturday October 26, 2013

Staff	Time	Total Hours
Jon Sprague	0800-1800	10
Joby Rohrer	0900-1100 (phone communication)	2
Stephanie Joe	0930-1030 (research time at home)	1

Company & Pilot	Time	Total Hours
9PA Airborne Aviation (Steve Aiu)	1000 - 1730	5.2 Hobbs time. Steve sat on the ground for about an hour in the afternoon.

Sequence of Events

0800: Jon (JS) arrived at Schofield West base yard to prep for Steve. JS met Steve at ~1000 at Dragon X to hook on the water bucket. After doing so, JS transited to the IC off of Kaukonahua road to observe the fire, coordinate with Wildland Fire staff, and tend 8PA. Steve dropped buckets for most of the day, and directed aerial drops for about an hour (see below). He also shut down for about an hour to clear some air space for the larger helicopters. As noted below, helicopters stopped pulling from one of the catchments early in the morning due to the presence of anti-algae in the water.

Time	Hobbs	Note
1000	991.6	Begin water drops.
~1400	994.7	Begin aerial recon. Steve directed water drops by the larger helicopters with JS and one Wildland Firefighter.
~1500	995.5	Resume water drops.
1730	996.6	End ops for the day

Fire Behavior

The fire stayed low all day, with occasional flare-ups in the black that were quickly extinguished. Steve directed the larger helicopters to drop primarily on the northern most extend of the fire line to prevent the fire from breaking out while he doused some of the smaller, smoldering logs.

Safety Concerns

On the morning of October 26th Army Wildland Fire reported that a local farmer used the chemical copper sulfate in one of the dip ponds being used. The copper sulfate was added by the farmer to decrease moss and algal growth in the pond. OANRP Research Specialist Stephanie Joe was tasked with determining the environmental hazards of using water from this pond. After one hour of research she indicated that it would be best not to use the water. This chemical has a danger label and is a risk to aquatic organisms. In addition, there is no application method listed on the label that covered use in fire suppression equipment (see attachment MSDS and label at the end of the document). Stephanie reported this to Joby who called Chief Freeman and Scott Yamasaki. With this new information Army Wildland Fire immediately stopped using the pond. Wildland fire was very timely in reporting the information they received from the farmer and adapted their fire response as recommended.

Sunday October 27, 2013

Staff	Time	Total Hours
Dan Sailer	0600-1400	8

Company & Pilot	Time	Total Hours
9PA Airborne Aviation (Alan Olmos)	0630-12:15	2.2 Hobbs time (1 hour break and left due to lightning activity)

Sequence of Events

Time	Hobbs	Note
0630	996.9	Alan arrives for aerial reconnaissance with Jake Favor and Dan S.
0740	997.7	End of aerial recon and directing drops using hovering MD 500 as a target
0745	997.7	Departs for first refueling at Hot POL at Wheeler AAF, needs to wait at Wheeler until depot opens
0825	997.9	Returns to pickup bucket and begin bucketing operations
0950	998.9	Drops bucket for second fueling at Wheeler AAF
1035	999.1	Returns to ranch land LZ but sets down for a break as no active flames detected or targets identified. Army Wildland fire conducts a planning meeting reviewing options for direct ground attack.
		Thunderstorms break out in the area but provide only negligible rain onto the fire itself.
1217	999.1	Due to nearby lightning, Alan departs for HNL and remainder of aircraft cease operations for the day due to inclement weather.

Fire Behavior

During the reconnaissance flight, numerous burning logs along the western and northern firelines are noted but the majority of the fireline was cold with a 70% fire containment declared at the start of operations. No active flames reported all morning and the fire did not increase in size. Operations focused on burning logs at the northern and western perimeter to prevent rollouts and some interior areas to prevent chimneys (burning standing trees and snags) from spreading fire to incompletely burned areas should the winds increase. Misting rain greatly decreased any fire activity from noon onwards into the evening.

Safety Concerns

Significant air turbulence from military rotor wash was again noted during the latter part of the reconnaissance flight when Alan was signaling to military ships where to direct their water drops. A very low level flight was done to find an appropriate landing zone where fire crews could be inserted but all the semi-level and cleared areas were burned over and covered with ash which would clog the helicopter’s engine. The only other LZ in the black was a discontinued artillery firing point, but this was not chosen due to UXO concerns. Puu Pane LZ was also considered but not chosen due to safety concerns about hiking through unburnt fuels with no good escape route to reach the fireline. Vehicular access to the fireline was possible but also not chosen due to the same issue of having to drive through unburnt fuels in front of the fire to reach the fireline and then have the problem of no good escape route. Basket dropping fire crews onto the fireline was also considered but not chosen as a safe option given their dependency on a helicopter for evacuation with limited landing zone options or a very difficult hike out.

Lightning activity in the vicinity of the fire prevented air operations from continuing after 1200 hrs.

Monday October 28, 2013

Staff	Time	Total Hours

Joby Rohrer	1400-1630	2.5
Jake Faber	1400-1630	2.5

Company & Pilot	**Time**	**Total Hours**
9PA Airborne Aviation (Steve Aiu)	1400-1MD 500	0.8 Hobbs time

Sequence of Events

Steve came to Dragon X LZ to conduct an aerial survey of the fire and to get GPS points to direct military ships. Jake and Joby inspected the perimeter and mapped hot spots with GPS.

Time	Hobbs	Note
1400	1002.0	Start Aerial recon from Dragon X
1MD 500	1002.8	Complete recon

Fire Behavior

Fire was not very active on this day. Some small hotspots marked on or near the perimeter. These points were converted to 10 digit military grids and relayed to military pilots by Army Wild land fire. The fire boundary was again mapped with GPS to update the area that burned to the north.

Figure 7: Extent of burn as of October 28. Note extension to the north from the last map.

Safety Concerns

No concerns on this day.

Tuesday October 29, 2013

Staff	Time	Total Hours
Joby Rohrer	1400-1530	1.5
Jon Sprague	1640-1740	1.0

Company & Pilot	Time	Total Hours
9PA Airborne Aviation (Alan Olmos)	1400-1530	1.2 Hobbs time
9PA Airborne Aviation (Alan Olmos)	1700-1740	0.9 Hobbs time

Sequence of Events

Alan came to Dragon X LZ to conduct an aerial survey of the fire to help direct military ships. After the initial recon at 1400-1530 Army Wildland Fire requested additional support as it had been a very effective operation. Alan left to extract OANRP crews then returned at 1630 to assist again for another hour.

Time	Hobbs	Note
1400	1006.1	Start Aerial recon from Dragon X
1530	1007.3	Complete recon
1630	1007.8	Start second Aerial recon from Dragon X
1730	1008.7	Complete recon

Fire Behavior

Fire is not very active some small hotspots marked on or near the perimeter. On this operation the MD 500 acted a visual reference for the military ships dropping water. This was very effective as there were small spots that were difficult for the larger helicopter to line up.

Safety Concerns

There were no incidents on this day. However, when performing an operation like this there must be good communication and care taken to ensure that both pilots have a plan before the smaller ship acts as a visual reference. Alan communicated well with the military pilots and used his strobe light to signal them and confirmed over the radio which way he would break away as they approached.

Tuesday October 29, 2013- Wednesday November 4, 2013

There was no significant fire behavior over this period at times there was smoking in the black burned out area. Army Wildland Fire kept a watch on the fire and occasionally called in military support.

Wednesday November 5, 2013

Staff	Time	Total Hours
Joby Rohrer	1400-1800	4 hours

Company & Pilot	Time	Total Hours
9PA Airborne Aviation (Steve Aiu)	1434-1745	2.3 Hobbs time

Sequence of Events

About 1300 there was active fire on the western edge of the Schofield boundary. Flames were visible from the OANRP baseyard crowing in the tops of *Eucalyptus* trees with flame lengths of up to 40 feet. The active spread slowed before any helicopter resources were on scene. Once helicopters arrived they drenched the area of the flare up. This flare up did not reach the ridge top although it looked like it had.

Time	Hobbs	Note
1434	1019.9	Start bucket ops from Dragon X
1730	1022.2	Complete bucket drops

Fire Behavior
Very active flare-up died down quickly and then was drenched with bucket drops. There were no additional flare-ups.

Safety Concerns
No concerns on this date

Thursday November 6, 2013

Staff	Time	Total Hours
Kapua Kawelo	6 hours	
Clay Trauernicht	2 hours	
Scott Yamasaki	1 hour (time for aerial survey only)	

Company & Pilot	Time	Total Hours
9PA Airborne Aviation (Alan Olmos)	1400-1430	0.6 Hobbs time

Sequence of Events

Time	Hobbs	Note
1434	1019.9	Start bucket ops from Dragon X
1730	1022.2	Complete bucket drops

Fire Behavior
Two spots with smoke were observed during aerial reconnaissance and were mapped for Wildland fire use. During the helicopter survey heavy rain began. Heavy rain fell on the fire area for the remainder of the day.

Safety Concerns
None

Figure 8: Extent of burn as of November 6. Note extension on the southwestern edge.

<u>Lessons Learned</u>

1- **Coordination of air operations:** Wildland Fire Crew Boss S. Yamasaki coordinated all air operations using I-Com radios on 122.925. This way he controlled the circular flight paths of ships around the fire and in and out of dip ponds. All ships also were able to speak to each other throughout the incident. This was a major improvement from other fires.

2- **Steve Aiu:** Currently a half time pilot with Airborne Aviation, Steve Aiu is a retired Chief from HFD. With his years of aerial firefighting experience he is a valuable asset to both the IC on the ground as well as the other pilots on the incident. On this fire he was greatly appreciated by Army Wildland Fire and the military pilots.

3- **Advantages of the Hughes MD 500 or similar ships:** While the Hughes MD 500 only carries about 90 gallons in its bucket compared to hundreds, even 2,000 gal. for the Chinook, there are a couple of advantages of the smaller ship.

    a. **Dropping from a hover:** The larger ships do not stop while dropping water. If they did the resulting down-draft could be very damaging. Therefore the water they deliver is always spread across the sweep of the flight path. In contrast the Hughes MD 500 can stop, lower the bucket down through the trees and right on top a target before releasing the 90 gallons of water. For hotspot work in heavy fuels (tall trees/burning logs) this is a great advantage.

   b. **Aerial recon:** Similar to above, the MD 500 can be used to survey the fire. The small aircraft can hover close to the ground and slowly survey to find small hotspots. These can then be mapped and used to direct resources. The large military ships cannot survey close to the ground due to rotor wash.

4- **Dip ponds:** A variety of dip ponds were available for use during the incident. Agricultural ponds in Helemano, Kaukonahua and Poamoho. The dip pond at Dragon X was also heavily utilized.

5- **Dip pond damage:** The dip pond at Dragon X had the liner damaged and had to be drained and repaired. The damage was caused by the heavy down draft from the larger Sea stallions. There was also damage to crops around dip ponds caused by rotor wash from larger ships.

6- **Agricultural chemical concerns:** There was copper sulfate being used in one of the Kaukonahua ponds. (see attached documents MSDS and label) OANRP staff investigated the label and hazard concerns then advised wild land fire to terminate use of the water. Use was terminated immediately. The presence of this chemical in agricultural water should be considered in future incidents.

7- **Grids for military ship direction:** Once the actively spreading fire stopped, OANRP used hand-help GPS to record hot spot locations. These UTM locations were then translated into 10 digit military grids. Army Wildland fire passed these on to the military ships and they used then to direct water drops. It takes some time to do these conversions as there is no computer program that can convert these.

8- **Aerial reference for military ships:** As mentioned in 3b the MD 500 can identify hotspots that are missed by the large military ships. The MD 500 was also used to hover over these locations and act as a visual guide to the larger ships as they approached with a water drop. This was an effective technique when the fire stopped actively burning and there were just small isolated hotspots.

9- **UAS/UAV:** Unmanned reconnaissance ships (Shadows) were used to identify hot spots with infrared cameras. UAVs were flown at high elevation and produced grid targets for the military ships. UAVs flew above helicopter bucket operations and did not interfere with ongoing fire fighting work.

10- **Refuleing at Hot POL:** Refueling at Hot POL, Wheeler Army Airfield fuel depot, greatly reduced turn-around time. It is a good idea to time fuel cycles such that multiple ships do not head to the depot at the same time. This could slow things down greatly if a pilot has to wait in line. OANRP must ensure that the CALP, Fuel Purchase Agreement, and valid fuel cards are in place throughout the year. Fueling even at Dillingham Airfield can take a pilot away from the incident for more than an hour and refueling is not available during non business hours (e.g. before 7 am and after 5 pm). This can be critical time lost.

Revised 3-22-06 by notification to restore original language to Specific Instructions---control algae in irrigation conveyance systems
1-31-2006 Bordeaux, storage and disposal, Florida septic systems---changes and additions (Bordeaux) are indicated

50 LBS. NET WEIGHT (22.7 KILOS)

COPPER SULFATE CRYSTALS

ACTIVE INGREDIENT BY WEIGHT
COPPER SULFATE PENTAHYDRATE………………………………… 99.0%
OTHER INGREDIENTS…………………………………………………………. 1.0%
TOTAL ………………………………………………………………………. 100.0%
CAS #7758-99-8
COPPER AS METALLIC NOT LESS THAN 25%

See back panel for specific pesticidal use directions.

Also for non-pesticidal uses of copper sulfate including but not limited to:
• For Non-Pesticidal Manufacturing and Industrial Uses.
• For manufacturing, repackaging, formulation of algaecides and fungicides.
• For use as foot baths to control hoof rot in cattle.
• For use in preparing Bordeaux mixture.
• For use as a trace mineral for mixing in animal feeds at levels in accord with good feeding and feed manufacturing practices.
• For use as a fertilizer trace mineral for plant growth and used in accord with recommended agronomic practices.

(NOTE: For the states of Wisconsin, California, Oregon and Washington fertilizer recommendations and information, refer to back panel.)
When this product is used as a feed or fertilizer ingredient:
Guaranteed Analysis: Copper (Cu) = 25.0% Derived from Copper Sulfate

KEEP OUT OF REACH OF CHILDREN

DANGER - PELIGRO

Si usted no entiende la etiqueta, busque a alguien para que se la explique a usted en detalle.
(If you do not understand the label, find someone to explain it to you in detail.)

FIRST AID

If on skin or Take off contaminated clothing.
clothing: Rinse skin immediately with plenty of water for 15-20 minutes.
Call a poison control center or doctor for treatment advice.
If inhaled: Move person to fresh air.
If person is not breathing, call 911 or an ambulance, then give artificial respiration, preferably by mouth to mouth, if possible.
Call a poison control center or doctor for further treatment advice.
If in eyes: Hold eye open and rinse slowly and gently with water for 15-20 minutes.
Remove contact lenses, if present, after the first 5 minutes, then continue to rinse eye.
Call a poison control center or doctor for treatment advice.
If swallowed: Call poison control center or doctor immediately for treatment advice.
Have person sip a glass of water if able to swallow.
Do not induce vomiting unless told to do so by the poison control center or doctor.
Do not give anything by mouth to an unconscious person.
Notes: Have the product container or label with you when calling a poison control center or doctor, or going for treatment.
In the event of a medical emergency, you may also contact the National Pesticide Information Center at 1-800-858-7378.

CHEM ONE LTD.

This product manufactured for EPA REG. NO. 56576-1
CHEM ONE LTD. EPA EST. NO. 52117-MX-001
HOUSTON, TEXAS 77040-6519
TEL. (713) 896-9966

PRECAUTIONARY STATEMENTS

HAZARDS TO HUMANS AND DOMESTIC ANIMALS

DANGER - PELIGRO

CORROSIVE: Causes eye damage and irritation to the skin and mucous membranes. Harmful or fatal if swallowed. Do not get in eyes, on skin or on clothing. Do not breathe dust or spray mist. May cause skin sensitization reactions to certain individuals.

PERSONAL PROTECTIVE EQUIPMENT

Applicators and other handlers must wear: Long-sleeved shirt and long pants, chemical-resistant gloves made of any waterproof material, shoes plus socks, and protective eyewear. Some materials that are chemical-resistant to this product are listed below. If you want more options, follow the instructions for category A on an EPA chemical resistance category selection chart. Discard clothing and other absorbent materials that have been drenched or heavily contaminated with this product's concentrate. Do not reuse them. Follow manufacturer's instructions for cleaning/maintaining PPE. If no such instructions for washables, use detergent and hot water. Keep and wash PPE separately from other laundry.

USER SAFETY RECOMMENDATIONS:

Users should: Wash hands before eating, drinking, chewing gum, using tobacco or using the toilet. Remove clothing immediately if pesticide gets inside. Then wash thoroughly and put on clean clothing Remove PPE immediately after handling this product. Wash the outside of gloves before removing. As soon as possible, wash thoroughly and change into clean clothing.

ENVIRONMENTAL HAZARDS

This product is toxic to fish. Direct application of Copper Sulfate to water may cause a significant reduction in populations of aquatic invertebrates, plants and fish. Do not treat more than one-half of lake or pond at one time in order to avoid depletion of oxygen from decaying vegetation. Allow 1 to 2 weeks between treatments for oxygen levels to recover. Trout and other species of fish may be killed at application rates recommended on this label, especially in soft or acid waters. However, fish toxicity generally decreases when the hardness of water increases. Do not contaminate water by cleaning of equipment or disposal of wastes. Consult your local State Fish and Game Agency before applying this product to public waters. Permits may be required before treating such waters.

STORAGE AND DISPOSAL

PROHIBITIONS: Do not contaminate water, food or feed by storage or disposal. Open burning and dumping is prohibited. Do not re-use empty container.

STORAGE: Keep pesticide in original container. Do not put concentrate or dilutions of concentrate in food or drink containers.

PESTICIDE DISPOSAL: Pesticide wastes are acutely hazardous. Improper disposal of excess pesticide, spray mixture, or rinsate is a violation of Federal law. If these wastes cannot be disposed of by use according to label instructions, contact your State Pesticide or Environmental Control Agency, or the Hazardous Waste representative at the nearest EPA Regional Office for guidance.

CONTAINER DISPOSAL: Completely empty bag into application equipment. Then dispose of empty bag in a sanitary landfill or by incineration, or if allowed by state and local authorities, by burning. If burned, stay out of smoke.

If Plastic Container: Triple rinse (or equivalent). Then offer for recycling or reconditioning, or puncture and dispose of in a sanitary landfill, or by incineration, or, if allowed by state and local authorities, by burning. If burned, stay out of smoke.

STORAGE AND DISPOSAL

Do not contaminate water, food or feed by storage or disposal.

STORAGE: Store in original container and place in a locked storage area.

PESTICIDE DISPOSAL: Call your local solid waste agency (or 1-800-CLEANUP or equivalent organization) for disposal instructions. Unless otherwise instructed, place in the trash. Never pour unused product down the drain or on the ground.

CONTAINER DISPOSAL: Do not reuse this container. Do not rinse unless required for recycling. Place in trash.

DIRECTIONS FOR USE

It is a violation of Federal Law to use this product in a manner inconsistent with its labeling.

Do not apply this product in a way that will contact workers or other persons, either directly or through drift. Only protected handlers may be in the area during application. For requirements specific to your State or Tribe, consult the agency responsible for pesticide regulations.

AGRICULTURAL USE REQUIREMENTS

Use this product only in accordance with its labeling and with the Worker Protection Standard, 40 CFR part 170. This standard contains requirements for the protection of agricultural workers on farms, forests, nurseries, and greenhouses, and handlers of agricultural pesticides. It contains requirements for training, decontamination, notification, and emergency assistance. It also contains specific instructions and exceptions pertaining to the statements on this label about personal protective equipment (PPE), and restricted-entry interval. The requirements in this box only apply to uses of this product that are covered by the Worker Protection Standard.

Do not enter or allow worker entry into treated areas during the restricted entry interval (REI) of 24 hours.

PPE required for early entry to treated areas that is permitted under the Worker Protection Standard and that involves contact with anything that has been treated, such as plants, soil, or water, is: Coveralls, chemical-resistant gloves made of any waterproof material (such as polyvinyl chloride, nitrile rubber, or butyl rubber), shoes plus socks, and protective eyewear.

NON-AGRICULTURAL USE REQUIREMENTS

The requirements in this box apply to uses of this product that are NOT within the scope of the Worker Protection Standard for agricultural pesticides (40 CFR Part 170). The WPS applies when this product is used to produce agricultural plants on farms, forests, nurseries, or greenhouses.

Applicators and other handlers who handle this pesticide for any use NOT covered by the Worker Protection Standard (40 CFR Part 170) must wear: long-sleeved shirt, chemical-resistant gloves made of any waterproof material (such as polyvinyl chloride, nitrile rubber, or butyl rubber), shoes plus socks, and protective eyewear.

GENERAL INSTRUCTIONS FOR USE

Water hardness, temperature of the water, the type and amount of vegetation to be controlled, and the amount of water flow are to be considered in using Copper Sulfate to control algae. Begin treatment soon after plant growth has started. If treatment is delayed until a large amount of algae is present, larger quantities of Copper Sulfate will be required. Algal growth is difficult to control with Copper Sulfate when water temperatures are low or when the water conditions are hard water. Larger quantities of Copper Sulfate will be required to kill and control algae in water which is flowing than in a body of stagnant water. If possible, curtail the flow of water before treatment and hold dormant for approximately three days after treatment or until the algae have begun to die. When preparing a Copper Sulfate solution in water, the mixing container should be made of plastic or glass: or, a painted, enameled, or copper lined metal container. It is usually best to treat algae on a sunny day when the heavy mats of filamentous algae are most likely to be floating on the surface where it can be sprayed directly. If there is some doubt about the concentration to apply, it is generally best to start with a lower concentration and to increase this concentration until the algae are killed.

Treatment of algae can result in oxygen loss from decomposition of dead algae. This loss can cause fish suffocation. Therefore, to minimize this hazard, treat one-third to one-half of the water area in a single operation and wait 10 to 14 days in between treatments. Begin treatments along the shore and proceed outward in bands to allow fish to move into untreated water. NOTE: If treated water is to be used as a source of potable water, the metallic copper residual must not exceed 1 ppm (4 ppm copper sulfate pentahydrate).

CALCULATIONS FOR THE AMOUNT OF WATER IMPOUNDED AND FOR THE AMOUNT OF COPPER SULFATE TO BE USED: Calculate water volume as follows: (1) Obtain surface area by measuring of regular shaped ponds or mapping of irregular ponds or by reference to previously recorded engineering data or maps. (2) Calculate average depth by sounding in a regular pattern and taking the mean of these readings or by reference to previously obtained data. (3) Multiply surface area in feet by average depth in feet to obtain cubic feet of water volume. (4) Multiply surface area in acres by average depth in feet to obtain total acre-feet of water volume.

CALCULATE WEIGHT OF WATER TO BE TREATED AS FOLLOWS: (1) Multiply volume in cubic feet by 62.44 to obtain total pounds of water, or (2) Multiply volume in acre feet by 2,720,000 to obtain pounds of water.

CALCULATIONS OF ACTIVE INGREDIENT TO BE ADDED: To calculate the amount of Copper Sulfate Pentahydrate needed to achieve the recommended concentration, multiply the weight of water by the recommended concentration of Copper Sulfate. Since recommended concentrations are normally given in parts per million (ppm), it will first be necessary to convert the value in parts per million to a decimal equivalent. For example, 2 ppm is the same as 0.000002 when used in this calculation. Therefore, to calculate the amount of Copper Sulfate Pentahydrate to treat 1 acre-foot of water with 2 ppm Copper Sulfate, the calculation would be as follows:

0.000002 X 2,720,000 = 5.44 lbs. Copper Sulfate Pentahydrate

CALCULATION OF WATER FLOW IN DITCHES, STREAMS, AND IRRIGATION SYSTEMS: The amount of water flow in cubic feet per second is found by means of a weir or other measuring device.

SPECIFIC INSTRUCTIONS

SEWER TREATMENT – ROOT DESTROYER*

ROOT CONTROL GENERAL INFORMATION: Plant roots can penetrate through small cracks and poorly sealed joints of sewer lines. If not controlled, these small roots will continue to grow larger in number causing breakage, reduced flow, and eventually, flow stoppage. Copper sulfate has been known to be an effective means to control roots in residential and commercial sewers.

COMMERCIAL, INSTITUTIONAL, AND MUNICIPAL SEWERS:

ROOT CONTROL IN SEWERS: As a preventive measure, apply into each junction or terminal manhole 2 pounds of Copper Sulfate Crystals every 6 to 12 months. At time of reduced flow (some water flow is essential), add copper sulfate. If flow has not completely stopped, but has a reduced flow due to root masses, add Copper Sulfate Crystals in the next manhole above the reduced flow area. For complete stoppage, penetrate the mass with a rod to enable some flow before treatment.

ROOT CONTROL IN STORM DRAINS: Apply when water flow is light. If no water flow, as in dry weather, use a hose to produce a flow. Apply 2 pounds Copper Sulfate Crystals per drain per year. It may be necessary to repeat treatments 3 to 4 times, at 2 week intervals, if drains become nearly plugged.

SEWER PUMPS AND FORCE MAINS: At the storage well inlet, place a cloth bag containing 2 pounds of Copper Sulfate Crystals. Repeat as necessary.

RESIDENTIAL OR HOUSEHOLD SEWER SYSTEMS:

When a reduced water flow is first noticed, and root growth is thought to be the cause, treat with Copper Sulfate Crystals. It is important not to wait until a stoppage occurs because some water flow is necessary to move the Copper Sulfate Crystals to the area of root growth. Usually, within 3 to 4 weeks, after roots have accumulated sufficient copper sulfate, the roots will die and begin to decay and water flow should increase. As the roots regrow, follow-up treatments with copper sulfate will be required. Applications may be made each year in the spring after plant growth begins, during late summer or early fall, or any time a reduced water flow, thought to be caused by root growth, occurs.

Apply 2-6 pounds Copper Sulfate Crystals two times a year to household sewers. Add Copper Sulfate Crystals to sewer line by pouring about ½ pound increments into the toilet bowl nearest the sewer line and flush, repeat this process until recommended dose has been added, or remove cleanout plug and pour entire recommended quantity directly into the sewer line. Replace the plug and flush the toilet several times.

ROOT CONTROL IN SEPTIC TANK AND LEACH LINES AND LEACH LINE PIPES:

SEPTIC TANKS – The majority of the copper sulfate will settle in the septic tank itself and little will pass into the leach lines. To treat leach line pipes, add 2 to 6 pounds of Copper Sulfate Crystals to the distribution box located between the septic tank and the leach lines. To achieve effective root control in the leach lines it is necessary to transfer Copper Sulfate Crystals from the septic tank to the leach lines. A cleanout plug opening may need to be installed if the distribution box does not have an opening leading to the leach lines.

***NOTE:** Do not apply Copper Sulfate Crystals through sink or tub drains as it will corrode the metal drains.

***NOTE:** Copper sulfate added to an active 300 gallon septic tank at 2, 4 and 6 pounds per treatment will temporarily reduce bacterial action, but it will return to normal approximately 15 days after treatment. Trees and shrubbery growing near a treated line normally are not affected due to only a small portion of their roots being in contact with the copper sulfate. The copper sulfate kills only those roots inside the leach line.

***NOTE:** Do not use as a sewer additive where prohibited by State law. State law prohibits the use of this product in sewage systems in the State of Connecticut. Not for sale or use in the California counties of Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma for root control in sewers. Not for sale or use in septic systems in the State of Florida.

TO CONTROL ALGAE AND THE POTOMOGETON POND WEEDS, LEAFY AND SAGO, IN IRRIGATION SYSTEMS: Once the amount of Copper Sulfate required for treating ditches or streams has been calculated, use a continuous application method, selecting proper equipment to supply Copper Sulfate granular crystals as follows:

FOR ALGAE CONTROL – Begin continuous addition application of granular Copper Sulfate when water is first turned into the system and continue throughout the irrigation system, applying 0.1 to 0.2 lbs per cubic ft per second per day.

FOR LEAFY AND SAGO POND WEED CONTROL – Use the same continuous feeder, applying 1.6 to 2.4 pounds Copper Sulfate Pentahydrate per cubic foot per second per day. NOTE: For best control of leafy and sago pond weed, it is essential to begin Copper Sulfate additions when water is first turned into the system or ditch to be treated and to continue throughout the irrigation system. Copper Sulfate becomes less effective as the alkalinity increases. Its effectiveness is significantly reduced when the bicarbonate alkalinity exceeds 150 ppm. Should Copper Sulfate fail to control pond weeds satisfactorily, it may be necessary to treat the ditch with either a suitable approved herbicide or use a mechanical means to remove excess growth. In either case, resume Copper Sulfate addition as soon as possible.

TO CONTROL ALGAE IN IMPOUNDED WATERS, LAKES, PONDS AND RESERVOIRS: There are several methods by which to apply Copper Sulfate to impounded water. Probably the most satisfactory and simplest method is to dissolve the Copper Sulfate crystals in water and to spray this water over the body of water from a boat. A small pump mounted in the boat can easily be used for this purpose. Fine crystals may be broadcast directly on the water surface from a properly equipped boat. A specially equipped air blower can be used to discharge fine crystals at a specific rate over the surface of the water. When using this method, the direction of the wind is an important factor. Do not use this method unless completely familiar with this type of application. Where the situation permits, Copper Sulfate may be applied under the water by dragging burlap bags containing Copper Sulfate. The crystals are placed in burlap bags and dragged through the water by means of a boat. Begin treatment along the shoreline and proceed outward until one-third to one-half of the total area has been treated. Care should be taken that the course of the boat is such as to cause even distribution of the chemical. In large lakes, it is customary for the boat to travel in parallel lines about 20 to 100 feet apart. Continue dragging the burlap bags over the treated area until the minimum dosage is achieved and all crystals have been dissolved. Large or medium size crystals that dissolve slowly should be used with this method.

Copper Sulfate can be applied to impounded waters by injecting a copper sulfate solution in water via a piping system.

CONTROL OF ALGAE AND BACTERIAL ODOR IN SEWAGE LAGOONS AND PITS (Except California):

Application rates may vary depending on amounts of organic matter in effluent stream or retention ponds. Use 2 lbs. of Copper Sulfate Crystals in 60,000 gals. (8,000 cu. ft.) of effluent to yield 1 ppm of dissolved copper. Dosage levels may vary depending upon organic load. Other Organic Sludges: Copper Sulfate Crystal solution must be thoroughly mixed with sludge. Dissolve 2 lbs. in 1-2 gals. of water and apply to each 30,000 gals. of sludge.

Useful formulas for calculating water volume flow rates: Multiply the water volume in cu. ft. times 7.5 to obtain gallons. Note: 1 C.F.S./Hr. = 27,000 Gals. 1 Acre Foot = 326,000 Gals.

TO CONTROL ALGAE IN IRRIGATION CONVEYANCE SYSTEMS USING THE SLUG APPLICATION METHOD: Make an addition (dump) of Copper Sulfate into the irrigation ditch or lateral at 0.25 to 2.0 lbs. per cubic foot per second of water per treatment. Repeat on approximate 2-week intervals as required. Depending on water hardness, alkalinity and algae concentration, a dump is usually required every 5 to 30 miles. Effectiveness of Copper Sulfate decreases as the bicarbonate alkalinity increases and is significantly reduced when the alkalinity exceeds approximately 150 ppm as $CaCO_3$.

TO CONTROL ALGAE IN RICE (Domestic and Wild) FIELDS: Application should be made when algae have formed on the soil surface in the flooded field. Applications are most effective when made prior to the algae's leaving the soil surface and rising to the water surface. Apply 10-15 pounds Copper Sulfate Crystals per acre to the water surface as either crystals or dissolve in water and make a surface spray. Apply higher rate in deeper water (6 inches or greater).

TO CONTROL TADPOLE SHRIMP IN RICE FIELDS: Application should be made to the flooded fields any time the pest appears from planting time until the seedlings are well rooted and have emerged through the water. Apply 5-10 pounds Copper Sulfate Crystals per acre. The use rate per acre should be determined by the water depth and flow. Use the lower rate at minimum flow and water depth and the higher rate when water depth and flow are maximum.

STATE SPECIES BULLETIN NO. COUNTY
CALIFORNIA Solano grass EPA/ES-85-13 Solano
TENNESSEE Slackwater EPA/ES-85-04 Lawrence
Darter Wayne
Hancock
Freshwater EPA/ES-85-07 Claiborne
Mussels Hawkins
Sullivan
ALABAMA Slackwater EPA/ES-85-05 Lauderdale
Darter Limestone
Madison
VIRGINIA Freshwater EPA/ES-85-06 Grayson
Mussels Smyth
Scott
Washington
Lee

ENDANGERED SPECIES RESTRICTIONS: It is a violation of Federal Law to use any pesticide in a manner that results in the death of an endangered species or adverse modification of their habitat. The use of this product may pose a hazard to certain Federally designated endangered species known to occur in specific areas within the above counties. ***PLEASE NOTE*** Before using this product in the above counties you must obtain the EPA Bulletin specific to your area. This Bulletin identifies areas within these counties where the use of this pesticide is prohibited, unless specified otherwise. The EPA Bulletin is available from either your County Agricultural Extension Agent, the Endangered Species Specialist in your State Wildlife Agency Headquarters, or the appropriate Regional Office of the U.S. Fish and Wildlife Service. THIS BULLETIN MUST BE REVIEWED PRIOR TO PESTICIDE USE.

COPPER SULFATE REQUIRED FOR TREATMENT OF DIFFERENT GENERA OF ALGAE

The genera of algae listed below are commonly found in waters of the United States. Use the lower recommended rate in soft waters (less than 50 ppm methyl orange alkalinity) and the higher concentration in hard waters (above 50 ppm alkalinity). Always consult State Fish and Game Agency before applying this product to municipal waters.

ORGANISM ¼ to ½ ppm* ½ to 1 ppm* 1 to 1½ ppm* 1½ to 2 ppm*
Cyanophyceae Anabaena Cylindrospermum Nostoc Calothrix
(Blue-green) Anacystis Oscillatoria Phormidium Symploca
Aphanizomenon Plectonema
Gloeotrichia
Gomphosphaeria
Polycystis
Rivularia
Chlorophyceae Closterium Botryococcus Chlorella Ankistrodesmus
(Green) Hydrodictyon Cladophora Crucigenia Chara
Spirogyra Coelastrum Desmidium Nitella
Ulothrix Draparnaldia Golenkinia Scenedesmus
Enteromorpha Oocystis
Gloeocystis Palmella
Microspora Pithophora
Tribonema Staurastrum
Zygnema Tetraedron
Diatomaceae Asterionella Gomphonema Achnanthes
(Diatoms) Fragilaria Nitzschia Cymbella
Melosira Stephanodiscus Neidium
Navicula Synedra
Tabellaria
Protozoa Dinobryon Ceratium Chlamydomonas Eudorina
(Flagellates) Synura Cryptomonas Hawmatococcus Pandorina
Uroglena Euglena Peridinium
Volvox Glenodinium
Mallomonas
* ¼ - ½ ppm = .67 – 1.3 lbs/acre ft. * 1 – 1½ ppm = 2.6-3.9 lbs/acre ft.
* ½ - 1 ppm = 1.3 – 2.6 lbs/acre ft. * 1½ - 2 ppm = 3.9 – 5.32 lbs/acre ft.

SCHISTOSOME-INFECTED FRESH WATER SNAILS

For recreational lakes, reservoirs, and ponds, 5.32 -13.3 lbs/acre-ft Copper Sulfate Crystals (i.e., 2-5 ppm copper sulfate), is usually sufficient for treatment of Schistosome-infected fresh water snails. Use surface area in acres multiplied by average depth in feet to determine water volume and application rate. Apply only along shoreline swimming areas and/or to infected snail beds on a calm sunny day when water temp is at least 60°F. Not allowing swimming for at least 12 hrs following treatment is recommended. If this lower dosage is not sufficient, up to 32 ppm copper sulfate, i.e., 87 lbs/acre (= 2 lbs/1000 sq ft) bottom surface area can be applied. Not allowing swimming for 48 hrs is recommended. Using either dosage, a second application may be made if necessary, 10 to 14 days later. DO NOT make more than two applications a season. Broadcast application using boat, aircraft, or hand equipped with power or hand seeder or underwater dispenser. Do not exceed 1 ppm copper (4 ppm Copper Sulfate) in potable water systems. This labeling must be in the possession of the user at the time of pesticide application. **NOTE** : **In the State of New York** –For use in recreational lakes, reservoirs and ponds ONLY in areas where infected snail beds have been identified. Apply medium grade crystals by hand broadcast method of application only. This product is a restricted use pesticide in New York State. Pesticide applicator certification or a special use permit is required for sale, possession, or use. Each individual treatment must be approved by the Department of Environmental Conservation. Therefore, you must contact the Pesticide Control Specialist at the appropriate regional office of the Department 30 days in advance of the proposed treatment.

FOOT BATHS FOR CATTLE

Foot baths of Copper Sulfate Crystals can be used as an aid in the treatment of hoof rot in cattle. Prior to treatment, a veterinarian should be consulted to confirm presence of hoof rot. Animals may be walked through a foot bath of 2% (add 2 lbs copper sulfate to 11.8 gals water) to 5% (add 5 lbs copper sulfate to 11.4 gals water) aqueous solution with an immersion time of 5 to 20 min twice daily for a period of time as prescribed by a veterinarian. Keep foot baths clean during treatment period. Do not allow cattle to drink from foot baths as copper sulfate is highly toxic. Follow instructions under Storage and Disposal when solutions are discarded at end of treatment period.

Wisconsin State Copper fertilizer recommendations[a] Washington, Oregon, and
California Fertilizer Use
Pounds per Acre
Sands Loams,silts,clays Organic
Crop Bdct[b] Band Bdct[b] Band Bdct[b] Band
Lettuce, onion, 10 2 12 3 13 4
Spinach
Carrot, cauliflower, 4 1 8 2 12 3
celery, alfalfa, clover,
corn, oat, radish, sudan
grass, wheat

Asparagus, barley, 0 0 0 0 0 2
beans, beet, broccoli,
mint, pea, potato, rye,
soybean

[a]Recommendations are for inorganic sources of copper. Copper chelates can also be used at 1/6 of the rates recommended above. Do not apply copper unless a deficiency has been verified by plant analysis. [b]Bdct = broadcast

BORDEAUX SPRAY MIXTURE

Understanding Bordeaux Formulations: If the Bordeaux mixture instructions read 10-10-100, the first figure indicates the number of lbs of Copper Sulfate Crystals. The second figure is the lbs of hydrated spray lime and the third figure is the gallons of water to be used. Use as a full coverage spray to point of runoff.

Preparation of Bordeaux Spray Mixture: Fill a tank 1/4 full with water. Then, with agitator running, mix in Copper Sulfate Crystals through a copper, bronze, stainless steel or plastic screen. Add water so the tank is 3/4 full. Mix in the hydrated spray lime through the screen and finish filling the tank with water.

CROP USE RECOMMENDATIONS

Almond, Apricot, Peach, Nectarine: Shot Hole Fungus – Prepare a 10-10-100 Bordeaux and apply as a dormant spray in late fall or early spring.

Almond, Apricot, Cherry, Peach, Nectarine, Plum, Prune: Brown Rot Blossom Blight – Prepare a 10-10-100 Bordeaux and apply when buds begin to swell.

Apple: Fireblight – Mix 5 lbs of Copper Sulfate Crystals in 100 gals of water and spray uniformly to the point of runoff. Apply in dormant only at silver tip stage. After silver tip, severe burn will occur on any exposed green tissue. Do not mix lime to make a Bordeaux spray for this treatment.

Blueberries: Bacterial Canker – Prepare and apply an 8-8-100 Bordeaux mixture in the fall before heavy rains begin and again 4 weeks later.

Bulbs (Easter Lily, Tulip, Gladiolus): Botrytis Blight – Prepare a 10-10-100 Bordeaux mixture and apply as a foliar spray to 1 acre. Apply for thorough coverage beginning at the first sign of disease and repeat as needed to control disease at 3 to 10 day intervals. Use the shorter intervals during periods of frequent rains or when severe disease conditions persist. Avoid spray just before flower cutting season if residues are a problem.

Caneberries: For leaf and cane spot and Pseudomonas blight, prepare and apply an 8-8-100 Bordeaux mixture in the fall before heavy rains begin and again 4 weeks later.

Cherry (Sweet): Dead Bud, Bacterial Canker (Pseudomonas Syringae) – Prepare a 12-12-100 Bordeaux. Apply at leaf fall and again in late winter before buds begin to swell. In wet cool Northwest U.S. winters, a third spray may be needed between above sprays.

Cherry (Sour): Leaf Spot – Prepare a 10-10-100 Bordeaux. Apply as a full coverage spray after petal fall or as recommended by the State Extension Service.

CITRUS

(NOTE: Adding foliar nutritionals to spray mixtures containing Copper Sulfate Crystals or other products and applying to citrus during the post-bloom period when young fruit is present may result in spray burn.)

Bacterial Blast – Prepare a 10-10-100 Bordeaux spray and apply a spray in late October to early November or before fall rains begin. Make a complete coverage spray using 10 to 25 gals per mature tree.

Lemon, Orange, Grapefruit: Phytophthora Brown Rot - Prepare a 3-4.5-100 Bordeaux mixture only where there is no history of copper injury or use a 3-2-6-100 (Zinc Sulfate-Copper Sulfate Crystals-Hydrated Lime-Gallons of water) Bordeaux mixture. Spray 6 gals on skirt of tree 3 to 4 ft high and 2 to 4 gals on trunk and ground under tree. If P. hibernalis is present, use 10 to 25 gals to completely cover each tree. Apply in November or December just before or after first rain. In severe brown rot season, apply second application in January or February.

Information received by the Washington State Dept. of Agriculture regarding the components in this product is available on the internet at http://agr.wa.gov Information regarding the contents and levels of metals in this product is available at the Oregon Dept of Agriculture internet site: http://oda.state.or.us/fertilizer

Lemon, Orange, Grapefruit: Septoria Fruit, Leaf Spot;**Central California – Brown Rot, Zinc, Copper Deficiencies** – Prepare a 3-2-6-100 Bordeaux mixture (Zinc Sulfate-Copper Sulfate Crystals-Hydrated Lime Gallons of water) and use 10 to 25 gals to completely cover each tree. Apply in October, November or December before or just after first rain.

Grape: **Downy Mildew** – Prepare and apply a 2-6-100 Bordeaux spray beginning when downy mildew is detected. Repeat as needed to achieve and maintain control. This mixture and its use will exhibit some phytotoxicity on most varieties.

Grape (Dormant): Powdery Mildew – Apply in spring before bud-swell and before any green tissue is present. Use 4 to 8 lbs of Copper Sulfate Crystals per 100 gals of water. Apply in a high volume spray of 300 gals water per acre. Direct spray to thoroughly wet the dormant vine, especially the bark of the trunk, head or cordons.

Olive: Olive Leaf Spot (Peacock spot), Olive Knot – Prepare a 10-10-100 Bordeaux and apply up to MD 500 gals per acre.

Apply in autumn before heavy winter rains to prevent peacock spot. In wet winters, a repeat spray may be needed in midwinter. In areas with less than 10 inches of annual rainfall, a 5-5-100 Bordeaux applied in up to MD 500 gals per acre may be used. To help protect against olive knot, apply a 10-10-100 Bordeaux before heavy rains and again in the spring. Injury may occur in areas of less than 10 inches of rainfall.

Peach: Leaf Curl – Prepare a 10-10-100 Bordeaux and apply at leaf fall or as a dormant spray in late fall or early spring before buds begin to swell.

Potatoes: **To enhance vine-kill and suppress late blight**, apply 10 lbs. per acre in 10 to 100 gals of water (ground equipment) or in 5 to 10 gals (aerial equipment) with Diquat at vine-kill to enhance vine desiccation and suppress late blight. Additional applications can be made with Diquat if needed to within 7 days of harvest. Copper Sulfate Crystals may be applied alone until harvest to suppress late blight. NOTE: This product can be mixed with Diquat for use on potatoes in accordance with the most restrictive of label limitations and precautions. No label dosage rates should be exceeded.

Walnuts: Walnut Blight – Apply 15 lbs with 10 lbs of lime in 100 gals of water. Make application in early pre-bloom before catkin blooms are showing (10-20% pistilate) before or after rain. Use only if Bordeaux mixture has been shown to be non-phytotoxic in your area. If desired, add one-half gal summer oil emulsion per 100 gals of water. **NOTE**: Addition of summer oil emulsion to pre-bloom and early bloom sprays may result in plant injury.

GENERAL CHEMIGATION INSTRUCTIONS

Apply this product only through one or more of the following types of systems: sprinkler including center pivot, lateral move, end tow, side (wheel) roll, traveler, big gun, solid set, or hand move irrigation system(s). Do not apply this product through any other type of irrigation system. Crop injury, lack of effectiveness, or illegal pesticide residues in the crop can result from nonuniform distribution of treated water. If you have questions about calibration, you should contact State Extension Service specialists, equipment manufacturers or other experts. Do not connect an irrigation system (including greenhouse systems) used for pesticide application to a public water system unless the pesticide label-prescribed safety devices for public water systems are in place. A person knowledgeable of the chemigation system and responsible for its operation or under the supervision of the responsible person, shall shut the system down and make necessary adjustments should the need arise.

Posting of areas to be chemigated is required when 1) any part of a treated area is within 300 feet of sensitive areas such as residential area, labor camps, businesses, day care centers, hospitals, in-patient clinics, nursing homes or any public areas such as schools, parks, playgrounds, or other public facilities not including public roads, or 2) when the chemigated area is open to the public such as golf courses or retail greenhouses. Posting must conform to the following requirements. Treated areas shall be posted with signs at all usual points of entry and along likely routes of approach from the listed sensitive areas. When there are no usual points of entry, signs must be posted in the corners of the treated areas and in any other location affording maximum visibility to sensitive areas. The printed side of the sign should face away from the treated area towards the sensitive area. The signs shall be printed in English. Signs must be posted prior to application and must remain posted until foliage has dried and soil surface water has disappeared. Signs may remain in place indefinitely as long as they are composed of materials to prevent deterioration and maintain legibility for the duration of the posting period. At the top of the sign shall be the words "KEEP OUT", followed by an octagonal stop sign symbol at least 8 inches in diameter containing the word "STOP". Below the symbol shall be the words "PESTICIDES IN IRRIGATION WATER". All words shall consist of letters at least 2 ½ inches tall, and all letters and the symbol shall be a color that sharply contrasts with their immediate background. This sign is in addition to any sign posted to comply with the Worker Protection Standard.

CHEMIGATION SYSTEMS CONNECTED TO PUBLIC WATER SYSTEMS:

Public water system means a system for the provision to the public of piped water for human consumption if such system has at least 15 service connections or regularly serves an average of at least 25 individuals daily at least 60 days out of the year. Chemigation systems connected to public water systems must contain a functional, reduced-pressure zone, backflow preventer (RPZ) or the functional equivalent in the water supply line upstream from the point of pesticide introduction. As an option to the RPZ, the water from the public water system should be discharged into the reservoir tank prior to pesticide introduction. There shall be a complete physical break (air gap) between the flow outlet end of the fill pipe and the top or overflow rim of the reservoir tank of at least twice the inside diameter of the fill pipe. The pesticide injection pipeline must contain a functional, automatic, quick-closing check valve to prevent the flow of fluid back toward the injection pump. The pesticide injection pipeline must contain a functional, normally closed, solenoid-operated valve located on the intake side of the injection pump and connected to the system interlock to prevent fluid from being withdrawn from the supply tank when the irrigation system is either automatically or manually shut down.

See Treatment Instructions, below.

SPRINKLER CHEMIGATION:

The system must contain functional interlocking controls to automatically shut off the pesticide injection pump when the water pump motor stops, or in cases where there is no water pump, when the water pressure decreases to the point where pesticide distribution is adversely affected. Systems must use a metering pump, such as a positive displacement injection pump (e.g., diaphragm pump) effectively designed and constructed of materials that are compatible with pesticides and capable of being fitted with a system interlock. The system must contain a functional check valve, vacuum relief valve, and low pressure drain approximately located on the irrigation pipeline to prevent water source contamination from backflow. The pesticide injection pipeline must contain a functional, automatic, quick-closing check valve to prevent the flow of fluid back toward the injection pump. This pipeline must also contain a functional, normally closed, solenoidoperated valve located on the intake side of the injection pump and connected to the system interlock to prevent fluid from being withdrawn from the supply tank when the irrigation system is either automatically or manually shut down. The system must contain functional interlocking controls to automatically shut off the pesticide injection pump when the water pump motor stops. The irrigation line or water pump must include a functional pressure switch which will stop the water pump motor when the water pressure decreases to the point where pesticide distribution is adversely affected. Systems must use a metering pump, such as a positive displacement injection pump (e.g., diaphragm pump) effectively designed and constructed of materials that are compatible with pesticides and capable of being fitted with a system interlock.

TREATMENT INSTRUCTIONS:
Do not apply when wind speed favors drift beyond the area intended for treatment. When mixing, fill nurse tank half full with water. Add Copper Sulfate Crystals slowly to tank while hydraulic or mechanical agitation is operating and continue filling with water. Stickers, spreaders, insecticides, nutrients, etc. should be added last. If compatibility is in question, use the compatibility jar test before mixing a whole tank. Because of the wide variety of possible combinations which can be encountered, observe all cautions and limitations on the label of all products used in mixtures. Copper Sulfate Crystals should be added through a traveling irrigation system continuously or at the last 30 minutes of solid set or hand moved irrigation systems. Agitation is recommended.
NOTICE: CHEM ONE LTD. warrants that this product in its unopened package conforms to the chemical description on the label. THERE ARE NO OTHER WARRANTIES EXPRESS OR IMPLIED, INCLUDING A WARRANTY OF FITNESS FOR A PARTICULAR PURPOSE. This warranty does not extend to the handling or use of this product contrary to label instructions or under abnormal conditions or under conditions not reasonably foreseeable to seller and buyer assumes all risk of any such use.
CHEM ONE LTD.
8017 Pinemont Drive, Suite 100 ENVIRONMENTALLY HAZARDOUS SUBSTANCES
HOUSTON, TEXAS 77040-6519 SOLID, N.O.S. (CUPRIC SULFATE) UN3077, RQ
TEL: (713) 896-9966

Material Safety Data Sheet
Material Name: Copper Sulfate Pentahydrate ID: C1-121A

Issue Date: 09/09/98 13:25:58 CLW Page 1 of 11 Revision Date: 09/16/03 3:45 PM HDF

* * * Section 1 - Chemical Product and Company Identification * * *

Chemical Name: Copper Sulfate Pentahydrate
Product Use: For Commercial Use
Synonyms: Copper Sulfate Crystals, Blue Copper, Blue Stone, Blue Vitriol, Copper (II) sulfate, Cupric Sulfate, Copper Sulfate Fine 200,
Fine 100, Fine 30, 20, Small, Medium, Large, FCC IV, and Very High Purity
Supplier Information
Chem One Ltd. (Importer of record) Phone: (713) 896-9966
8017 Pinemont Drive, Suite 100 Fax: (713) 896-7540
Houston, Texas 77040-6519 Emergency # (800) 424-9300 or (703) 527-3887
General Comments
NOTE: Emergency telephone numbers are to be used only in the event of chemical emergencies involving a spill, leak, fire, exposure,
or accident involving chemicals. All non-emergency questions should be directed to customer service.

* * * Section 2 - Composition / Information on Ingredients * * *

CAS # Component Percent
7758-99-8 Copper (II) Sulfate Pentahydrate > 99
Component Related Regulatory Information
This product may be regulated, have exposure limits or other information identified as the following: Copper (7440-50-8) and
inorganic compounds, as Cu, Copper (7440-50-8) dusts and mists, as Cu and Copper fume, Cu.
Component Information/Information on Non-Hazardous Components
This product is considered hazardous under 29 CFR 1910.1200 (Hazard Communication).

* * * Section 3 - Hazards Identification * * *

Emergency Overview
Copper Sulfate Pentahydrate is a blue crystalline or powdered, odorless solid. Potentially fatal if swallowed. May cause irritation to
the eyes, respiratory system and skin. Fire may produce irritating, corrosive and/or toxic fumes. Firefighters should use full
protective equipment and clothing.
Hazard Statements
HARMFUL OR FATAL IF SWALLOWED. Can cause irritation of eyes, skin, respiratory tract and, in extreme cases, burns.

Avoid contact with eyes and skin. Avoid breathing dusts. Wash thoroughly after handling. Keep container closed. Use with
adequate ventilation. Keep from contact with clothing and other combustible materials.

Potential Health Effects: Eyes

Exposure to particulates or solution of this product may cause redness and pain. Prolonged contact may cause conjunctivitis,
ulceration and corneal abnormalities.

Potential Health Effects: Skin

This product can cause irritation of the skin with pain, itching and redness. Severe overexposure can cause skin burns. Prolonged
exposure may cause dermatitis and eczema.

Potential Health Effects: Ingestion

Harmful or fatal if swallowed. May cause gastrointestinal irritation with symptoms such as nausea, vomiting, and diarrhea.
Ingestion may cause degeneration of liver, kidney, or renal failure. Persons who survive ingestion may develop granulomatous
lesions of the kidney. Ingestion of large amounts may lead to convulsions, coma or death.

Potential Health Effects: Inhalation

May irritate the nose, throat and respiratory tract. Symptoms can include sore throat, coughing and shortness of breath. In severe
cases, ulceration and perforation of the nasal septum can occur. If this material is heated, inhalation of fumes may lead to
development of metal fume fever. This is a flu-like illness with symptoms of metallic taste, fever and chills,
aches, chest tightness and cough. Repeated inhalation exposure can cause shrinking of the lining of the inner nose.

HMIS Ratings: Health Hazard: 2* **Fire Hazard:** 0 **Physical Hazard:** 1

Hazard Scale: 0 = Minimal 1 = Slight 2 = Moderate 3 = Serious 4 = Severe * = Chronic hazard

* * * Section 4 - First Aid Measures * * *

First Aid: Eyes

Immediately flush eyes with large amounts of room temperature water, occasionally lifting the lower and upper lids, for at least 15
minutes. If symptoms persist after 15 minutes of irrigation, seek medical attention.

* * * Section 4 - First Aid Measures (Continued) * * *

First Aid: Skin

Remove all contaminated clothing. For skin contact, wash thoroughly with soap and water for at least 20 minutes. Seek immediate
medical attention if irritation develops or persists.

First Aid: Ingestion

DO NOT INDUCE VOMITING. Have victim rinse mouth thoroughly with water, if conscious. Never give anything by mouth to a
victim who is unconscious or having convulsions. Contact a physician or poison control center immediately.

First Aid: Inhalation

Remove source of contamination or move victim to fresh air. Apply artificial respiration if victim is not breathing. Do not use
mouth-to-mouth method if victim ingested or inhaled the substance; induce artificial respiration with the aid of a pocket mask
equipped with a one-way valve or other proper respiratory medical device. Administer oxygen if breathing is difficult. Get
immediate medical attention.

First Aid: Notes to Physician

Provide general supportive measures and treat symptomatically. Basic Treatment: Establish a patent airway. Suction if necessary.

Watch for signs of respiratory insufficiency and assist ventilations if necessary. Administer oxygen by non-rebreather mask at 10 to
15 L/minutes. Monitor for shock and treat if necessary. For eye contamination, flush eyes immediately with water. Irrigate each eye
continuously with normal saline during transport. Do not use emetics. For ingestion, rinse mouth and administer 5 mL/kg up to 200
mL of water for dilution if the patient can swallow, has a strong gag reflex, and does not drool. Administer activated charcoal.
Advanced Treatment: Consider orotracheal or nasotracheal intubation for airway control in the patient who is unconscious. Start an
IV with lactated Ringer's SRP: "To keep open", minimal flow rate. Watch for signs of fluid overload. For hypotension with signs of
hypovolemia, administer fluid cautiously. Consider vasopressors if hypotensive with a normal fluid volume. Watch for signs of
fluid overload. Use proparacaine, hydrochloride to assist eye irrigation.

* * * Section 5 - Fire Fighting Measures * * *

Flash Point: Not flammable **Method Used:** Not applicable
Upper Flammable Limit (UEL): Not applicable **Lower Flammable Limit (LEL):** Not applicable
Auto Ignition: Not applicable **Flammability Classification:** Not applicable
Rate of Burning: Not applicable

General Fire Hazards

Copper Sulfate Pentahydrate is not combustible, but may decompose in the heat of a fire to produce corrosive and/or toxic fumes.

Hazardous Combustion Products

Sulfur oxides and copper fumes.

Extinguishing Media

Use methods for surrounding fire.

Fire Fighting Equipment/Instructions

Firefighters should wear full protective clothing including self-contained breathing apparatus. Runoff from fire control or dilution
water may be corrosive and/or toxic and cause pollution.

NFPA Ratings: Health: 2 **Fire:** 0 **Reactivity:** 1 **Other:**
Hazard Scale: 0 = Minimal 1 = Slight 2 = Moderate 3 = Serious 4 = Severe

* * * Section 6 - Accidental Release Measures * * *

Containment Procedures

Stop the flow of material, if this can be done without risk. Contain the discharged material. If sweeping of a contaminated area is
necessary use a dust suppressant agent, which does not react with product (see Section 10 for incompatibility information).

Clean-Up Procedures

Wear appropriate protective equipment and clothing during clean-up. Shovel the material into waste container. Thoroughly wash the
area after a spill or leak clean-up. Prevent spill rinsate from contamination of storm drains, sewers, soil or groundwater.

Evacuation Procedures

Evacuate the area promptly and keep upwind of the spilled material. Isolate the spill area to prevent people from entering. Keep
materials which can burn away from spilled material. In case of large spills, follow all facility emergency response procedures.

Special Procedures

Remove soiled clothing and launder before reuse. Avoid all skin contact with the spilled material. Have emergency equipment readily
available.

* * * Section 7 - Handling and Storage * * *

Handling Procedures

It is a violation of Federal Law to use this product in a manner inconsistent with its labeling, when used as a pesticide. Do not breathe
dust. Avoid all contact with skin and eyes. Use this product only with adequate ventilation. Wash thoroughly after handling.

Storage Procedures

Keep in original container in locked storage area. Keep container tightly closed when not in use. Store containers in a cool, dry location,
away from direct sunlight, sources of intense heat, or where freezing is possible. Material should be stored in secondary containers or in a
diked area, as appropriate. Store containers away from incompatible chemicals (see Section 10, Stability and Reactivity). Storage areas
should be made of fire-resistant materials. Post warning and “NO SMOKING” signs in storage and use areas, as appropriate. Use
corrosion-resistant structural materials, lighting, and ventilation systems in the storage area. Floors should be sealed to prevent absorption
of this material. Have appropriate extinguishing equipment in the storage area (i.e., sprinkler system, portable fire extinguishers).
Empty containers may contain residual particulates; therefore, empty containers should be handled with care. Do not cut, grind, weld, or
drill near this container. Never store food, feed, or drinking water in containers that held this product. Keep this material away from
food, drink and animal feed. Inspect all incoming containers before storage, to ensure containers are properly labeled and not damaged.
Do not store this material in open or unlabeled containers. Limit quantity of material stored. Store in suitable containers that are
corrosion-resistant.

* * * Section 8 - Exposure Controls / Personal Protection * * *

Exposure Guidelines

A: General Product Information

Follow the applicable exposure limits.

B: Component Exposure Limits

**The exposure limits given are for Copper & Inorganic Compounds, as Cu (7440-50-8), Copper fume as Cu or Copper dusts
and mists, as Cu.**

ACGIH: 1 mg/m^3 TWA (dusts & mists)
0.2 mg/m^3 TWA (fume)
OSHA: 1 mg/m^3 TWA (dusts & mists)
0.1 mg/m^3 TWA (fume)
NIOSH: 1 mg/m^3 TWA (dusts & mists)
0.1 mg/m^3 TWA (fume)
DFG MAKs 1 mg/m^3 TWA Peak, 2•MAK 15 minutes, average value, 1-hr interval (copper and inorganic copper compounds)
0.1 mg/m^3 TWA Peak, 2•MAK15 minutes, average value, 1-hr interval (fume)

Engineering Controls

Use mechanical ventilation such as dilution and local exhaust. Use a corrosion-resistant ventilation system and exhaust directly to the
outside. Supply ample air replacement. Provide dust collectors with explosion vents.

*The following information on appropriate Personal Protective Equipment is provided to assist employers in complying with OSHA
regulations found in 29 CFR Subpart I (beginning at 1910.132). Please reference applicable regulations and standards for relevant*

details.
PERSONAL PROTECTIVE EQUIPMENT
Personal Protective Equipment: Eyes/Face
Wear safety glasses with side shields (or goggles) and a face shield, if this material is made into solution. If necessary, refer to U.S.
OSHA 29 CFR 1910.133.
Personal Protective Equipment: Skin
Wear chemically-impervious gloves, made of any waterproof material, boots and coveralls to avoid skin contact. If necessary, refer
to U.S. OSHA 29 CFR 1910.138.

* * * Section 8 - Exposure Controls / Personal Protection (Continued) * * *

Personal Protective Equipment: Respiratory
If airborne concentrations are above the applicable exposure limits, use NIOSH-approved respiratory protection. If respiratory
protection is needed, use only protection authorized in the U.S. Federal OSHA Standard (29 CFR 1910.134), applicable U.S. State
regulations. Oxygen levels below 19.5% are considered IDLH by OSHA. In such atmospheres, use of a full-facepiece pressure/demand
SCBA or a full facepiece, supplied air respirator with auxiliary self-contained air supply is required under OSHA's Respiratory Protection
Standard (1910.134-1998). The following NIOSH Guidelines for Copper dust and mists (as Cu) are presented for further information.
Up to 5 mg/m3: Dust and mist respirator.
Up to 10 mg/m3: Any dust and mist respirator except single-use and quarter mask respirators or any SAR.
Up to 25 mg/m3: SAR operated in a continuous-flow mode or powered air-purifying respirator with a dust and mist filter(s).
Up to 50 mg/m3: Air purifying, full-facepiece respirator with high-efficiency particulate filter(s), any powered air-purifying respirator
with tight-fitting facepiece and high-efficiency particulate filter(s) or full-facepiece SCBA, or full-facepiece SAR.
Up to 100 mg/ m3: Positive pressure, full-facepiece SAR.
Emergency or Planned Entry into Unknown Concentrations or IDLH Conditions: Positive pressure, full-facepiece SCBA, or positive
pressure, full-facepiece SAR with an auxiliary positive pressure SCBA.
Escape: Full-facepiece respirator with high-efficiency particulate filter(s), or escape-type SCBA.
NOTE: The IDLH concentration for Copper dusts and mists (as Cu) is 100 mg/m3.
Personal Protective Equipment: General
Wash hands thoroughly after handling material. Do not eat, drink or smoke in work areas. Have a safety shower or eye-wash fountain
available. Use good hygiene practices when handling this material including changing and laundering work clothing after use. Discard
contaminated shoes and leather goods.

* * * Section 9 - Physical & Chemical Properties * * *

Physical Properties: Additional Information
The data provided in this section are to be used for product safety handling purposes. Please refer to Product Data Sheets, Certificates of
Conformity or Certificates of Analysis for chemical and physical data for determinations of quality and for formulation purposes.
Appearance: Blue crystals or powder **Odor:** Odorless
Physical State: Solid **pH:** 3.7-4.2 (10% soln.)
Vapor Pressure: 20 torr at 22.5 deg C **Vapor Density:** 8.6
Boiling Point: 560 deg C (1040 deg F) [decomposes] **Freezing/Melting Point:** 150 deg C (302 deg F)

Solubility (H2O): 31.6 g/100 cc (@ 0 deg C) **Specific Gravity:** 2.28 @ 15.6 deg C (H2O = 1)
Softening Point: Not available **Particle Size:** Various
Molecular Weight: 249.68 **Bulk Density:** Not available
Chemical Formula: CuSO4*5H2O

* * * Section 10 - Chemical Stability & Reactivity Information * * *

Chemical Stability

Copper Sulfate Pentahydrate is hygroscopic, but stable when kept dry, under normal temperature and pressures.

Chemical Stability: Conditions to Avoid

Avoid high temperatures, exposure to air and incompatible materials.

Incompatibility

Copper Sulfate causes hydroxylamine to ignite and the hydrated salt is vigorously reduced. Solutions of sodium hypobromite are
decomposed by powerful catalytic action of cupric ions, even as impurities. . Copper salts, including Copper Sulfate may react to
form explosive acetylides when in contact with acetylene or nitromethane. Contact with reducing agents, can cause a vigorous
reaction, especially in solution. This product can corrode aluminum, steel and iron. Copper Sulfate Pentahydrate is incompatible with
magnesium, strong bases, alkalines, phosphates, acetylene, hydrazine, and zirconium.

Hazardous Decomposition

Sulfur oxides and Copper oxides.

Hazardous Polymerization

Will not occur.

* * * Section 11 - Toxicological Information * * *

Acute and Chronic Toxicity

A: General Product Information

Acute toxicity is largely due to the caustic (alkaline) properties of this material. Harmful or fatal if swallowed. Product is an eye and
skin irritant, and may cause burns. Product is a respiratory tract irritant, and inhalation may cause nose irritation, sore throat,
coughing, and chest tightness and possibly, ulceration and perforation of the nasal septum.
Chronic: Long term skin overexposure to this product may lead to dermatitis and eczema. Prolonged or repeated eye contact may
cause conjunctivitis and possibly corneal abnormalities. Chronic overexposure to this product may cause liver and kidney damage,
anemia and other blood cell abnormalities.

B: Component Analysis - LD_{50}/LC_{50}

Copper Sulfate Pentahydrate (7758-99-8)

Oral-rat LD_{50}: = 300 mg/kg; Intraperitoneal-Rat LD_{50}: 18,700 mg/kg; Intraperitoneal-rat LD_{50}: 20 mg/kg; Subcutaneous-rat LD_{50}: 43
mg/kg; Intravenous-rat LD_{50}: 48900 µg/kg; Unreported-rat LD_{50}: 520 mg/kg; Oral-mouse LD_{50}: 369 mg/kg; Intraperitoneal-Mouse LD_{50}: 33
mg/kg; Intraperitoneal-mouse LD_{50}: 7182 µg/kg; Intravenous-mouse LD_{50}: 23300 µg/kg

B: Component Analysis - TDLo/LDLo

Copper Sulfate Pentahydrate (7758-99-8)

Oral-man LDLo: 857 mg/kg; Oral-Human LDLo: 50 mg/kg: Behavioral: somnolence (general depressed activity); Kidney, Urethra,
Bladder: changes in tubules (including acute renal failure, acute tubular necrosis); Blood: hemorrhage; Oral-Human TDLo: 11 mg/kg:
Gastrointestinal: gastritis; Gastrointestinal: hypermotility, diarrhea, nausea or vomiting; Oral-Human TDLo: 272 mg/kg: liver, kidney,

Blood effects; Oral-Human LDLo: 1088 mg/kg; Oral-child : 150 mg/kg: Kidney, Urethra, Bladder: changes in tubules (including acute
renal failure, acute tubular ; necrosis); Blood: other hemolysis with or without anemia; unknown-Man LDLo: 221 mg/kg; Oral-Woman
TDLo: 2400 mg/kg/day: Gastrointestinal tract effects; DNA Inhibition-Human: lymphocyte 76 mmol/L; Oral-woman LDLo: 100 mg/kg:
Vascular: Blood pressure lowering not characterized in autonomic section; Liver: hepatitis (hepatocellular necrosis), diffuse; Kidney,
Urethra, Bladder: changes in tubules (including acute renal failure, acute tubular necrosis); Oral-Human LDLo: 143 mg/kg: Pulmonary
system effects, Gastrointestinal tract effects ;Oral-rat TDLo: 915 mg/kg/1 year-intermittent: Cardiac: changes in coronary arteries; Blood:
changes in serum composition (e.g. TP, bilirubin, cholesterol; Oral-rat TDLo: 157 mg/kg/6 weeks-intermittent: Endocrine: changes in
adrenal weight; Nutritional and Gross Metabolic: weight loss or decreased weight gain; Biochemical: Enzyme inhibition, induction, or
change in blood or tissue levels: dehydrogenases; Oral-rat TDLo: 7530 mg/kg/30 days-intermittent: Blood: changes in serum composition
(e.g. TP, bilirubin, cholesterol); Blood: changes in erythrocyte (RBC) count; Biochemical: Enzyme inhibition, induction, or change in blood
or tissue levels:- multiple enzyme effect; Oral-rat TDLo: 2 gm/kg/20 days-intermittent: Liver: other changes; Biochemical: Enzyme
inhibition, induction, or change in blood or tissue levels: phosphatases, Enzyme inhibition, induction, or change in blood or tissue levels;
Intraperitoneal-rat TDLo: 791 mg/kg/18 weeks-intermittent: Nutritional and Gross Metabolic: weight loss or decreased weight gain;
Intraperitoneal-rat TDLo: 7MD 500 µg/kg: female 3 day(s) after conception: Reproductive: Fertility: other measures of fertility; Subcutaneousrat
TDLo: 12768 µg/kg: male 1 day(s) pre-mating: Reproductive: Paternal Effects: testes, epididymis, sperm duct; Intratesticular-rat TDLo:
3192 µg/kg: male 1 day(s) pre-mating: Reproductive: Paternal Effects: spermatogenesis (incl. genetic material, sperm morphology, motility,
and count), testes, epididymis, sperm duct; Oral-mouse TDLo: 3 gm/kg/8 weeks-continuous: Blood: changes in spleen; Immunological
Including Allergic: decrease in cellular immune response, decrease in humoral immune response; Oral-mouse TDLo: 2 gm/kg/3 weekscontinuous:
Blood: changes in spleen; Immunological Including Allergic: decrease in cellular immune response, decrease in humoral
immune response; Subcutaneous-mouse LDLo: MD 500 µg/kg; Subcutaneous-mouse TDLo: 12768 µg/kg: male 30 day(s) pre-mating:
Reproductive: Paternal Effects: testes, epididymis, sperm duct; Intravenous-mouse TDLo: 3200 µg/kg: female 8 day(s) after conception:
Reproductive: Effects on Embryo or Fetus: fetotoxicity (except death, e.g., stunted fetus), Specific Developmental Abnormalities: Central
Nervous System, cardiovascular (circulatory) system; Intravenous-mouse TDLo: 3200 µg/kg: female 7 day(s) after conception:
Reproductive: Fertility: post-implantation mortality (e.g. dead and/or resorbed implants per total number of implants); Oral-Dog, adult
LDLo: 60 mg/kg; Intravenous-guinea pig TDLo: 2 mg/kg; Subcutaneous-Guinea Pig, adult LDLo: 62 mg/kg; Oral-Pigeon LDLo: 1000
mg/kg; Oral-Domestic animals (Goat, Sheep) LDLo: 5 mg/kg; Oral-Bird-wild species LDLo: 300 mg/kg; Intravenous-frog LDLo: 25
mg/kg; Parenteral-chicken TDLo: 10 mg/kg: Tumorigenic: equivocal tumorigenic agent by RTECS criteria; Endocrine: tumors; Oral-pig
TDLo: 140 mg/kg: female 1-15 week(s) after conception, lactating female 4 week(s) post-birth: Reproductive: Effects on Newborn:

biochemical and metabolic; Intravenous-hamster TDLo: 2130 µg/kg: female 8 day(s) after conception:
Reproductive: Fertility: postimplantation
mortality (e.g. dead and/or resorbed implants per total number of implants), Specific Developmental Abnormalities: Central
Nervous System, body wall

Material Safety Data Sheet

Material Name: Copper Sulfate Pentahydrate ID: C1-121A

Issue Date: 09/09/98 13:25:58 CLW Page 6 of 11 Revision Date: 09/16/03 3:45 PM HDF

* * * Section 11 - Toxicological Information (Continued) * * *

Carcinogenicity

A: General Product Information

Copper Sulfate Pentahydrate (7758-99-8)

Cytogenetic Analysis-Rat/ast 300 mg/kg

B: Component Carcinogenicity

Copper dusts and mists, as Cu (7440-50-8)

EPA: EPA-D (Not Classifiable as to Human Carcinogenicity - inadequate human and animal evidence of carcinogenicity or no data available)

Epidemiology

No information available.

Neurotoxicity

Has not been identified.

Mutagenicity

Human and animal mutation data are available for Copper Sulfate Pentahydrate; these data were obtained during clinical studies on
specific human and animal tissues exposed to high doses of this compound.

Teratogenicity

There are no reports of teratogenicity in humans. Animal studies indicate that a deficiency or excess of copper in the body can cause
significant harm to developing embryos. The net absorption of copper is limited and toxic levels are unlikely from industrial
exposure. **Other Toxicological Information**

Individuals with Wilson's disease are unable to metabolize copper. Thus, persons with pre-existing Wilson's disease may be more
susceptible to the effects of overexposure to this product.

* * * Section 12 - Ecological Information * * *

Ecotoxicity

A: General Product Information

Harmful to aquatic life in very low concentrations. Copper Sulfate Pentahydrate is toxic to fish and marine organisms when applied
to streams, rivers, ponds or lakes.

B: Ecotoxicity

Copper Sulfate Pentahydrate (7758-99-8)

LC_{50} (*Lepomis machochirus* bluegill) wt 1.5 g = 884 mg/L at 18°C, static bioassay (95% confidence limit 707-1,100 mg/L)
(technical material, 100% (about 25% elemental copper); LC_{50} (*Leopmis cyanellus*, Green Sunfish) = 1.1 g, 3,510 µg/L at °C; LC_{50}
(*Pimephales promelas*, Fat-head minnow) = 1.2 g, 838 µg/L at 18°C; LC_{50} (*Crassius auratus*, Goldfish) = 0.9 g, 1380 µg/L at 18°C;
LC_{50} (*Crassius auratus*, Goldfish) = 0.1-2.5 mg/L; LC_{50} (*EEL*) = 0.1-2.5 mg/L; LC_{50} (*Salmo gairdneri*, Rainbow trout) = 1.6 g, 135
µg/L at 18°C; LC_{50} (*Salmo gairdneri*, Rainbow trout) 48 hours =0.14 ppm; LC_{50} (*Daphnia magna*) no time specified = 0.182 mg/L;
LC_{50} (*Salmo gairdneri*, Rainbow trout) no time specified = 0.17 mg/L; LC_{50} (*Lepomis machochirus*, Blue gill) no time specified =

1.5 g, 884 µg/L at 18°C; LC_{50} (Stripped Bass) 96 hours = 1 ppm or lower; LC_{50} (Prawn) 48 hours = 0.14; LC_{50} (Shrimp) 96 hours =
17.0 ppm copper; LC_{50} (Blue Crab) 96 hours = 28 ppm copper; LC_{50} (Oyster) 96 hours = 5.8 ppm copper; LC_{50} (*Viviparus*
bengalensis snail) 96 hours = 0.060 ppm copper (at 32.5°C; 0.066 ppm copper static bioassay); LC_{50} (*Viviparus bengalensis* snail)
96 hours = 0.09 ppm copper (at 27.3°C; 0.066 ppm copper static bioassay); LC_{50} (*Viviparus bengalensis* snail) 96 hours = 0.39 ppm
copper (at 20.3°C; 0.066 ppm copper static bioassay)

Environmental Fate

If released to soil, copper sulfate may leach to groundwater, be partly oxidized or bind to humic materials, clay or hydrous oxides of
iron and manganese. In water, it will bind to carbonates as well as humic materials, clay and hydrous oxides of iron and manganese.
Copper is accumulated by plants and animals, but it does not appear to biomagnify from plants to animals. In air, copper aerosols
have a residence time of 2 to 10 days in an unpolluted atmosphere and 0.1 to greater than 4 days in polluted, urban areas.

* * * Section 13 - Disposal Considerations * * *

US EPA Waste Number & Descriptions

A: General Product Information

This product is a registered pesticide.

B: Component Waste Numbers

No EPA Waste Numbers are applicable for this product's components.

Disposal Instructions

All wastes must be handled in accordance with local, state and federal regulations or with regulations of Canada and its Provinces.
This material can be converted to a less hazardous material by weak reducing agents followed by neutralization. Do not reuse empty
containers. Do not rinse unless required for recycling. If partly filled, call local solid waste agency or (1-800-CLEANUP or
equivalent organization) for disposal instructions. Never pour unused product down drains or on the ground.

Pesticide Disposal

Pesticide wastes are acutely hazardous. Improper disposal of excess pesticides, spray mixtures, or rinsate is a violation of U.S.
Federal and Canadian Law. If these wastes cannot be disposed of by use, according to product label instruction, contact your U.S.
State, or Canadian Province Pesticide or Environmental Control Agency, or the hazardous waste representative at the nearest U.S.
EPA Regional Office, or the offices of Environment Canada for guidance.

* * * Section 14 - Transportation Information * * *

NOTE: The shipping classification information in this section (Section 14) is meant as a guide to the overall classification of the product.
However, transportation classifications may be subject to change with changes in package size. Consult shipper requirements under
I.M.O., I.C.A.O. (I.A.T.A.) and 49 CFR to assure regulatory compliance.

US DOT Information

Shipping Name: Environmentally Hazardous Substance, solid, n.o.s. (cupric sulfate)
Hazard Class: 9 (Miscellaneous Hazardous Material)
UN/NA #: UN 3077
Packing Group: III

Required Label(s): Class 9 (Miscellaneous Hazardous Materials)
RQ Quantity: 10 lbs (4.54 kg)[Cupric Sulfate]
Additional Shipping Information: Cupric Sulfate is a Severe Marine Pollutant (49 CFR 172.322) and requires the marine
pollutant mark for vessel transportation. Because Copper Sulfate is listed as a Severe Marine Pollutant as found in Appendix B to
172.101and when shipped by vessel, each inner package which exceeds MD 500 g (17.6 oz) will need a marine pollutant marking, UNcertified
package, marked with the Proper Shipping Name, UN Number will be required when shipped by vessel, when each inner
package exceeds MD 500 g (17.6 oz).
Limited Quantity Shipments: Inner packagings less than MD 500 g (17.6 oz) will not need to be in a UN-approved box and will not
need a Marine Pollutant marking. Such shipments need not be marked with the Proper Shipping Name of the contents, but shall be
marked with the UN Number (3077) of the contents, preceded by the letters "UN", placed within a diamond. The width of the line
forming the diamond shall be at least 2 mm; the number shall be at least 6 mm high. The total weight of each outer packaging
cannot exceed 30 kg (66 lb). For a shipment by air the Class 9 label will be required.
Domestic Transportation Exception:
49 CFR 172.504(f)(9) Domestic transportation, a Class 9 placard is not required. A bulk packaging containing a Class 9 material
must be marked with the appropriate identification number displayed on a Class 9 placard, an orange panel or a white-square-onpoint
display configuration as required by subpart D of this part. 49 CFR 172(d)(3) allows the use of the Class 9 placard to replace
the marine pollutant marking for domestic shipments.

* * * Section 14 - Transportation Information (Continued)* * *

International Air Transport Association (IATA)
For Shipments by Air transport: We classify this product as hazardous (Class 9) when shipped by air because 49 CFR 173.140 (a).
"For the purposes of this subchapter, miscellaneous hazardous material (Class 9) means a material which presents a hazard during
transportation, but which does not meet the definition of any other hazard class. This class includes: (a) Any material which has an
anesthetic, noxious, or other similar property which could cause extreme annoyance or discomfort to a flight crew member so as to
prevent the correct performance of assigned duties."
Proper Shipping Name: Environmentally hazardous substance, solid, n.o.s. (cupric sulphate)
Hazard Class: 9
UN: UN 3077
Packing Group: III
Passenger & Cargo Aircraft Packing Instruction: 911
Passenger & Cargo Aircraft Maximum Net Quantity: No Limit
Limited Quantity Packing Instruction (Passenger & Cargo Aircraft): Y911
Limited Quantity Maximum Net Quantity (Passenger & Cargo Aircraft): 30 kg
Special Provisions: A97
ERG Code: 9L
Limited Quantity Shipments: Such shipments must be marked with the proper shipping name, UN number, and must be

additionally marked with the words LIMITED QUANTITIES or LTD. QTY. The total weight of each outer packaging cannot
exceed 30 kg (66 lb.) . For a shipment by air the class 9 label will be required

International Maritime Organization (I.M.O.) Classification

For shipments via marine vessel transport, the following classification information applies.

Proper Shipping Name: ENVIRONMENTALLY HAZARDOUS SUBSTANCE, SOLID, N.O.S. (Cupric sulfate)
Hazard Class: class 9
UN #: UN3077
Packing Group: III
Special Provisions: 274, 909, 944
Limited Quantities: MD 500g.
Packing Instructions: P002, LP02
Packing Provisions PP12
EmS: Fire F-A Spill S-F
Stowage and Segregation: Category A
Marine Pollutant: This material is considered a severe marine pollutant by the IMO and shipments of the material must carry the
marine pollutant mark label. Refer to IMO Amendment 31-02 Chapter 2.10.
Limited Quantity Shipments: Inner packaging less than MD 500 g (17.6 oz) will not need to be in a UN-approved box and will not
need a Marine Pollutant marking. Such shipments need not be marked with the Proper Shipping Name of the contents, but shall be
marked with the UN Number (3077) of the contents, preceded by the letters "UN", placed within a diamond. The width of the line
forming the diamond shall be at least 2 mm; the number shall be at least 6 mm high. The total weight of each outer packaging
cannot exceed 30 kg (66l) .

* * * Section 15 - Regulatory Information * * *

US Federal Regulations

A: General Product Information

Copper Sulfate Pentahydrate (CAS # 7758-99-8) is listed as a Priority and Toxic Pollutant under the Clean Water Act.

* * * Section 15 - Regulatory Information (Continued)* * *

US Federal Regulations (continued)

B: Component Analysis

This material contains one or more of the following chemicals required to be identified under SARA Section 302 (40 CFR 355
Appendix A), SARA Section 313 (40 CFR 372.65) and/or CERCLA (40 CFR 302.4):

Copper Compounds (7440-50-8)

SARA 313: final RQ = MD 5000 pounds (2270 kg) Note: No reporting of releases of this substance is required if the diameter of
the pieces of the solid metal released is equal to or greater than 0.004 inches.

Cupric Sulfate (7758-98-7)

CERCLA: final RQ = 10 pounds (4.54 kg)

C: Sara 311/312 Tier II Hazard Ratings:

Component CAS # Fire
Hazard
Reactivity
Hazard
Pressure
Hazard

Immediate
Health Hazard
Chronic
Health Hazard
Copper Sulfate Pentahydrate 7758-99-8 No No No Yes Yes
State Regulations
A: General Product Information
California Proposition 65
Copper Sulfate Pentahydrate is not on the California Proposition 65 chemical lists. **B: Component Analysis - State**
The following components appear on one or more of the following state hazardous substance lists:
Component CAS # CA FL MA MN NJ PA
Copper 7440-50-8 Yes No Yes No Yes Yes
Copper, fume, dust and mists N/A No Yes No Yes No Yes
Copper Sulfate Pentahydrate 7758-99-8 No No No No Yes Yes
Other Regulations
A: General Product Information
When used as a pesticide, the requirements of the U.S. Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), or requirements
under the Canadian Pest Control Act, are applicable.
B: Component Analysis - Inventory
Component CAS # TSCA DSL EINECS
Copper Sulfate Pentahydrate 7758-99-8 Excepted No Yes
Although this compound is not on the TSCA Inventory, it is excepted as a hydrate of a listed compound, Copper Sulfate (CAS #
7758-98-7), per 40 CFR 710.4 (d)(3) and 40 CFR 720.30 (h)(3). Under this section of TSCA, any chemical substance which is a
hydrate of a listed compound is excepted.
C: Component Analysis - WHMIS IDL
The following components are identified under the Canadian Hazardous Products Act Ingredient Disclosure List:
Component CAS # Minimum Concentration
Copper Sulfate Pentahydrate 7758-99-8 1 percent
ANSI Labeling (Z129.1):
DANGER! MAY BE FATAL IF SWALLOWED. CAUSES SKIN AND EYE IRRITATION. HARMFUL IF INHALED. Keep from
contact with clothing. Do not taste or swallow. Do not get on skin or in eyes. Avoid breathing dusts or particulates. Keep container
closed. Use only with adequate ventilation. Wash thoroughly after handling. Wear gloves, goggles, faceshields, suitable body protection,
and NIOSH-approved respiratory protection, as appropriate. **FIRST-AID:** In Case of Contamination of Skin or Clothing: Take off
contaminated clothing. Rinse skin immediately with plenty of water for 15-20 minutes. In Case of Contamination of Eyes: Hold eye
open and rinse slowly and gently with water for 15-20 minutes. Remove contact lenses, if present, after the first 5 minutes, then
continue to rinse eye. If Inhaled: Move person to fresh air. If person is not breathing, call 911 or an ambulance, then give artificial
respiration, preferably by mouth to mouth, if possible. If Ingested: Call poison control center or doctor immediately for treatment
advice. Have person sip a glass of water if able to swallow. Do not induce vomiting unless told to do so by the poison control center or
doctor. Do not give anything by mouth to an unconscious person. Call a poison control center or doctor for treatment advice. Have the
product container or label with you when calling a poison control center or doctor, or going for treatment. In the event of a medical
emergency, you may also contact

Material Safety Data Sheet

* * * Section 15 - Regulatory Information (Continued) * * *

The National Pesticide Information Center at 1-800-858-7378. **IN CASE OF FIRE:** Use water fog, dry chemical, CO_2, or "alcohol"
foam. **IN CASE OF SPILL:** Absorb spill with inert material. Place residue in suitable container. Consult Material Safety Data Sheet
for additional information.

Labeling Information for Pesticide Use of Product:

DANGER! HAZARD TO HUMANS AND DOMESTIC ANIMALS.

DANGER: CORROSIVE: Causes eye damage and irritation to the skin and mucous membrane. Harmful or fatal if swallowed. Do
not get in eyes, on skin or on clothing. Do not breathe dust or spray mist. May cause skin sensitization reactions to certain
individuals.

PERSONAL PROTECTIVE EQUIPMENT: Applicators and other handlers must wear long-sleeved shirt and long pants, chemicalresistant
gloves, made of any water-proof material, shoes, plus socks and protective eyewear. Discard clothing and other absorbent
materials that have been drenched or heavily contaminated with this solutions of this product. Do not reuse such contaminated items.
Follow manufacturer's instructions for cleaning and maintaining PPE. If no such instructions for reusable items exist, wash using
detergent and hot water. Keep and wash PPE separately for other laundry.

USER SAFETY RECOMMENDATIONS: Persons using this product should wash hands before eating, drinking, chewing gum, using
tobacco or using the toilet. Remove clothing immediately if contaminated by the pesticide. Wash contaminated clothing thoroughly and
put on clean clothing. Remove PPE immediately after use with this product. Wash outside of gloves and other equipment before
removing. After removal of PPE, wash thoroughly and change into clean clothing.

ENVIRONMENTAL HAZARDS: This product is toxic to fish. Direct application of Copper Sulfate to water may cause a significant
reduction in populations of aquatic invertebrates, plants and fish. Do not treat more than one-half of lake or pond at one time in order to
avoid depletion of oxygen from decaying vegetation. Allow 1 to 2 weeks between treatments for oxygen levels to recover. Trout and
other species of fish may be killed at application rates recommended on this label, especially in soft or acid waters. However, fish toxicity
generally decreases when the hardness of the water increases. Do not contaminate water by cleaning of equipment of disposal of wastes.
Consult local State Fish and Game Agency before applying this product to public waters. Permits may be required before treating such
waters.

STORAGE AND DISPOSAL: PROHIBITIONS: Do not contaminate water, food or feed by storage or disposal. Open burning and
dumping is prohibited. Do not re-use empty containers. Keep pesticide in original container. Do not put concentrate or dilutions of
concentrate in food r drink containers. Pesticide wastes are acutely hazardous. Improper disposal of excess pesticide, spray mixture or
rinsate is a violation of Federal law. If these wastes cannot be disposed of by use, according to label instructions, contact your State
Pesticide or Environmental Control Agency, or the Hazardous Waste Representative at the nearest EPA Regional Office for guidance.

Completely empty bag of product into application equipment. Dispose of empty bag in a sanitary landfill or by incineration, or if allowed
by State and local authorities, by burning. If burned, avoid smoke.
DIRECTIONS FOR USE: It is a violation of Federal Law to use this product inconsistent with its labeling. Do not apply this product
in a way that will contaminate workers or other persons, either directly or through drift. Only protected handlers may be in the area
during application. For requirements specific to your State, consult the agency responsible for your pesticide regulations.
AGRICULTURAL USE REQUIREMENTS: Use this product only in accordance with its labeling and with the Worker Protection
Standard, CFR Part 170. This standard contains requirements for the protection of agricultural workers on farms, forests, nurseries and
greenhouses, and handlers of agricultural pesticides. The Standard contains requirements for the training, decontamination, notification,
and emergency assistance. It also contains specific instructions and exceptions pertaining to the statements on this label about personal
protective equipment (PPE), and restricted-entry interval. These requirements only apply to uses of this product that are covered under
the Worker Protection Standard. Do not apply this product in a way that will contaminate workers or other persons, either directly or
through drift. Only protected handlers may be in the area during application. Do not allow worker entry into treated areas during the
restricted interval (REI) of 24 hours. PPE required for early entry to treated areas that is permitted under the Worker Protection Standard
and that involves contact with anything that has been treated, such as plants, soil or water, is" Coveralls, waterproof gloves, shoes, plus
socks and protective eyewear.

* * * Section 15 - Regulatory Information (Continued) * * *

Labeling Information for Pesticide Use of Product (continued):

GENERAL USE INSTRUCTIONS: Water hardness, temperature of the water, the type and amount of vegetation to be controlled and
the amount of water flow, are to be considered in using Copper Sulfate to control algae. Begin treatment soon after plant growth has
started. If treatment is delayed until a large amount of algae is present, larger quantities of Copper Sulfate will required. Algal growth is
difficult to control with Copper Sulfate when water temperatures are low or when water is hard. Larger quantities of Copper Sulfate will
be required to kill and control algae in water which is flowing than in a body of stagnant water. If possible, curtail the flow of water
before treatment and hold dormant until approximately three days after treatment or until the algae have begun to die. When preparing a
Copper Sulfate solution in water, the mixing container should be made of plastic or glass, or a painted, enameled, or copper-lined metal
container. It is usually best to treat algae on a sunny day when the heavy mats of filamentous algae are most likely to be floating on the
surface, allowing the solution to be sprayed directly on the algae. If there is some doubt about the concentration to apply, it is generally
best to start with a lower concentration and to increase this concentration until the algae are killed. **ENDANGERED SPECIES RESTRICTION:** It is a violation of Federal Law to use any pesticide in a manner that results in the death

of an endangered species or adverse modification to their habitat. The use of this product may pose a hazard to certain Federally
Designated species known to occur in specific areas. Contact the EPA for information on these areas. Obtain a copy of the EPA Bulletin
specific to your area. This bulletin identifies areas within specific State counties where the use of this pesticide is prohibited, unless
specified otherwise. The EPA Bulletin is available from either your County Agricultural Extension Agent, the Endangered Species
Specialist in your State Wildlife Agency Headquarters, or the appropriate Regional Office of the U.S. Fish and Wildlife Service. THIS
BULLETIN MUST BE REVIEWED PRIOR TO PESTICIDE USE.
EPA REG. NO. 56576- EPA EST. NO. 52117-MX-001

* * * Section 16 - Other Information * * *

Other Information

Chem One Ltd. ("Chem One") shall not be responsible for the use of any information, product, method, or apparatus herein presented
("Information"), and you must make your own determination as to its suitability and completeness for your own use, for the protection
of the environment, and for health and safety purposes. You assume the entire risk of relying on this Information. In no event shall
Chem One be responsible for damages of any nature whatsoever resulting from the use of this product or products, or reliance upon
this Information. By providing this Information, Chem One neither can nor intends to control the method or manner by which you
use, handle, store, or transport Chem One products. If any materials are mentioned that are not Chem One products, appropriate
industrial hygiene and other safety precautions recommended by their manufacturers should be observed. Chem One makes no
representations or warranties, either express or implied of merchantability, fitness for a particular purpose or of any other nature
regarding this information, and nothing herein waives any of Chem One's conditions of sale. This information could include technical
inaccuracies or typographical errors. Chem One may make improvements and/or changes in the product (s) and/or the program (s)
described in this information at any time. If you have any questions, please contact us at Tel. 713-896-9966 or E-mail us at
Safety@chemone.com. Revision date: 05/31/01 **Key/Legend**
EPA = Environmental Protection Agency; TSCA = Toxic Substance Control Act; ACGIH = American Conference of Governmental
Industrial Hygienists; IARC = International Agency for Research on Cancer; NIOSH = National Institute for Occupational Safety and
Health; NTP = National Toxicology Program; OSHA = Occupational Safety and Health Administration
Contact: Sue Palmer-Koleman, PhD **Contact Phone:** (713) 896-9966

Revision log

07/24/00 4:24 PM SEP Changed company name, Sect 1 and 16, from Corporation to Ltd.
07/27/00 2:49 PM SEP Added “Fine 200, FCC IV, Very High Purity” to synonyms, Section 1
08/23/00 3:15 PM SEP Added “Copper Sulfate Crystals” to synonyms, Section 1
05/31/01 9:31 AM HDF Checked exposure limits; made changes to Sect 9; overall review, add SARA 311/312 Haz Ratings.
06/01/01 7:28 AM HDF Added text to label information from EPA Approved Label
07/24/01 4:31 AM CLJ Add Shipments by Air information to Section 14, Changed contact to Sue, non-800 Chemtrec Num.
09/18/01 11:34 AM SEP Added Domestic Transportation Exception, Sect 14
10/05/01 3:30 PM SEP Deleted Alternate Shipping Name, Sect 14
02/15/02 11:01 AM: HDF Revision of SARA Chronic Hazard Rating to “Yes”.
2/21/02 4:21 PM HDF Added more information on Marine Pollutant Markings and Limited Quantity Shipments
9/16/03: 3:45 PM HDF Addition of chronic health hazard information. Addition of inhalation hazard information, Section 3.

Section 4. expansion of information on Information for Physicians. Up-graded Section 10 Reactivity Information. Up-dated DFG
MAK exposure limits. Up-Dated entire Section 14 Transportation Information to include IATA, IMO and current Canadian transport
information.
This is the end of MSDS # C1-121A

DEPARTMENT OF THE ARMY
US ARMY INSTALLATION MANAGEMENT COMMAND, PACIFIC REGION
HEADQUARTERS, UNITED STATES ARMY GARRISON, HAWAII
851 WRIGHT AVENUE, WHEELER ARMY AIRFIELD
SCHOFIELD BARRACKS, HAWAII 96857-5000

REPLY TO
ATTENTION OF:

JUN 10 2014

Office of the Garrison Commander

Mr. Loyal Merhoff
Field Supervisor
US Fish and Wildlife Service
300 Ala Moana Blvd., Room 3-122
Honolulu, Hawaii 96850

Dear Mr. Merhoff:

This letter is to inform you of a fire that ignited outside of the firebreak at Schofield Barracks West Range on 28 May 2014. The fire was the result of an unexploded ordinance (UXO) detonation conducted by the Army's Explosive Ordinance Disposal Company (EOD) within the firebreak road in support of the prescribed burn.

On 27 May 2014, EOD identified two UXO rounds, one high explosive and one illumination projectile, within the firebreak road that posed a human health hazard to the firefighters (enclosure 1). On 28 May 2014, the items were disposed of on site by detonation. Effort was made during the preparation of demolitions to ensure that the illumination candle, if ejected, would eject down slope into the impact area. Upon detonation, the illumination candle ejected to the north, separated into three pieces, and landed on the upslope side of firebreak. Three small, slow moving spot fires were ignited by the candle, two of which burned out on their own within five minutes. Aircraft were launched immediately to extinguish the third spot fire, and were successful in extinguishing it within 15 minutes of ignition. There were no endangered species or their habitat impacted by this fire (enclosure 1).

To ensure future UXO disposal actions have a lower potential of starting fires outside the firebreak road, EOD teams have been instructed to make every effort to move ordnance, if fuze condition safely allows, to demolition ranges for disposal. They have also been instructed to construct protective works (sandbag bunkers or other hard barriers) around any unmovable ordnance near the firebreak that is suspected of containing illumination candles or flares.

If you have any questions or would like to meet to discuss this project, please call Ms. Michelle Mansker, Chief, Natural Resource Section, DPW Environmental Division at (808) 655-9189.

Sincerely,

Richard A. Fromm
Colonel, US Army
Commanding

Enclosure

Map removed to
protect rare resources

DEPARTMENT OF THE ARMY
US ARMY INSTALLATION MANAGEMENT COMMAND, PACIFIC REGION
HEADQUARTERS, UNITED STATES ARMY GARRISON, HAWAII
851 WRIGHT AVENUE, WHEELER ARMY AIRFIELD
SCHOFIELD BARRACKS, HAWAII 96857-5000

REPLY TO
ATTENTION OF:

AUG 06 2014

Office of the Garrison Commander

Mr. Loyal Merhoff
Field Supervisor
US Fish and Wildlife Service
300 Ala Moana Blvd., Room 3-122
Honolulu, Hawaii 96850

Dear Mr. Merhoff:

This letter is to inform you of a fire that occurred above the firebreak road at Schofield Barracks on July 24, 2014 at 12:00 pm. The fire burned a total of 2.48 acres, 0.45 of which are designated as critical habitat for the O'ahu 'Elepaio (map enclosed). The fire started via a field artillery round that landed beyond the designated firing box and just above the firebreak road. The round was fired from firing point 211 and was intended to impact in the residual impact area. The number of acres burned does not exceed the 3.7 acres that the Army is allowed to adversely modify per the 2003 Oahu Training Areas Biological Opinion.

The fire was considered contained by 6:30 pm on July 24, 2014 using both aerial and ground resources and declared out on July 28, 2014. The Army detailed the Evergreen Bell 412 model helicopter immediately to conduct water drops, Army helicopters were on standby for assistance if needed and one Hughes 500 helicopter assisted with water drops for approximately one hour in the late afternoon. Ground crews used a brush truck to put out hot spots and conducted mop up where accessible and safe from the firebreak road.

An internal investigation is underway to determine how the artillery was misfired in order to prevent reoccurrence. If you have any questions, please call Ms. Kapua Kawelo, Acting Chief, Natural Resource Section, DPW Environmental Division at (808) 655-9191.

Sincerely,

Richard A. Fromm
Colonel, US Army
Commanding

Enclosures

Map removed to
protect rare resources

WILDLAND FIRE INCIDENT REPORT 25TH ID (L) & USARHAW	1. INSTALLATION Schofield Barracks	2. INCIDENT NUMBER (YY-000)

3. DATE (YYMMDD) 140724	FIRE LOCATION (Grid Coordinates 6 digit) FP Grid. EJ 91607845	5. RANGE OCCUPIED BY UNIT 2/35 INF

6. TIME FIRE REPORTED 1150hrs	7. TIME FIRE OUT	8. TIME RANGE OPS RESPONDED 1200hrs	9. TIME FIRST SFO AT SCENE 1205hrs

10. AGENCY NOTIFICATION (*If applicable*)	PHONE	TIME CALLED	AT SCENE	REMARKS
❑ Army Fire	653-0209	1200	1205	
❑ FEDERAL FIRE DEPARTMENT ❑ IF APPLICABLE	471-7117			
❑ INSTALLATION OPS CENTER (IOC)	655-8763	1240	[redacted]	
❑ RANGE OPERATIONS SUPERV ISOR	6551434			
❑ RANGE TRG MGR	655-1990	1155		
❑ DPW NATURAL RESOURCE MGR	656-2878			
❑ INSTALLATION SAFETY OFFICE	655-6749	1220	1224	
❑ (Other ERICKSON MEDEVAC		1220	1240	

11. FIRE DANGER RATING	12. BURN INDEX (BI)	15. FIRE ESCAPE ANALYSIS	CHECK ONE YES	NO
Green	33 yellow			
x Yellow 33	13. EST. ACRES BUR Est. 1/4 ACRAS	15a. FIRE STARTED OUTSIDE FIREBREAK ROAD? 30-40 METERS NORTH	X	
Red	14. (AAR	15b. FIRE ESCAPED FIREBREAK ROAD?	X	

16. HELICOPTER SUPPORT	16b. Aircraft Call Sign	Tail No.	16c. Arrived On Scene:
ERRICKSON MEDEVAC	ERICKSON	N/A	1240
16a. BUCKET SIZE (*BAMBI*)			

17. FIRE CAUSE (*Narrative*	18. AMMUNITION TYPE	19. WEAPON SYSTEM
2/35 INF MORTAR PLT STARTED THE FIRE IN THE IMPACT AREA. THE UNIT SHOT LEFT LIMIT OF THE RESIDUAL IMPACT AREA DURING LIVE FIRE TRAININGTHAT CAUSE THE FIRE. 60MM B643	Tracer X Mortar FRTR (120MM) ❑ Artillery ❑ HE / WP ❑ Pyrotechnics Grenade Demo / Mines UNKNOWN	❑ AT-4 ❑ TOW SAW / M-16 ❑ SMAW ❑ LAW ❑ Rocket / Missile ❑ M240/M60 120MM Mortar

20. TRAINING UNIT 2/35 INF	21. UNIT OIC LT PERALTA	22. TELEPHONE 808 655-5090	23. AAR REQUIRED?

24. REMARKS

25. FIRE REPORT COMPLETED BY: KAOHU ROBERT	DATE:	26. FIRE REPORT REVIEWED BY:	DATE

DEPARTMENT OF THE ARMY
US ARMY INSTALLATION MANAGEMENT COMMAND, PACIFIC REGION
HEADQUARTERS, UNITED STATES ARMY GARRISON, HAWAII
851 WRIGHT AVENUE, WHEELER ARMY AIRFIELD
SCHOFIELD BARRACKS, HAWAII 96857-5000

REPLY TO
ATTENTION OF:

Office of the Garrison Commander

OCT 10 2014

Mr. Douglas Krofta
Field Supervisor
US Fish and Wildlife Service
300 Ala Moana Blvd., Room 3-122
Honolulu, Hawaii 96850

Dear Mr. Krofta:

This letter is to inform you of a fire that occurred above the firebreak road at Schofield Barracks on September 16, 2014 at 10:15 pm. The fire burned a total of .62 acres, 0.17 of which are designated as critical habitat for the O'ahu 'Elepaio (map enclosed). The fire started via a field artillery round that landed beyond the designated firing box and just above the firebreak road. The round was fired from firing point 308 and was intended to impact in the residual impact area. The number of acres burned does not exceed the 3.7 acres that the Army is allowed to adversely modify per the 2003 Oahu Training Areas Biological Opinion. The Army has adversely impacted a total of .62 acres of critical habitat so far in 2014.

The Directorate of Emergency Services activated an Erickson Bell 412 and requested UH-60 support from the Aviation Brigaide. All 3 aircraft worked the fire, delivering 66,000 gallons of water to the fire area. Ground crews used a brush truck to put out hot spots and conducted mop up where accessible and safe from the firebreak road. The fire was declared out on September 20, 2014.

An internal investigation is underway to determine how the artillery was misfired in order to prevent reoccurrence. If you have any questions, please contact Ms. Michelle Mansker, Chief, Natural Resource Section, DPW Environmental Division at (808) 655-9191 or by email, michelle.l.mansker.civ@mail.mil.

Sincerely,

Richard A. Fromm
Colonel, US Army
Commanding

Enclosures

WILDLAND FIRE INCIDENT REPORT
25TH ID (L) & USARHAW

1. INSTALLATION: **Schofield Barracks**

2. INCIDENT NUMBER (YY-000): 14-091

3. DATE (YYMMDD): 140916

FIRE LOCATION: Impact Area in a wooded area near the Fire Brake Road

5. RANGE OCCUPIED BY UNIT: FP-308/ ¾ CAV

6. TIME FIRE REPORTED: 2215

7. TIME FIRE OUT:

8. TIME RANGE OPS RESPONDED: 2217 hrs

9. TIME FIRST SFO AT SCENE: 1219

10. AGENCY NOTIFICATION (*If applicable*)	PHONE	TIME CALLED	AT SCENE
☐ FEDERAL FIRE DEPARTMENT	471-7117		
☐ IFSO WILDLAND PROGRAM MGR	656-1331		
☐ INSTALLATION OPS CENTER (IOC)	656-3272	0704	
☐ RANGE OFFICER	655-5243	0700	
☐ RANGE OPERATIONS SUPERVISOR	655-9509	2217	2218
☐ DPW NATURAL RESOURCE MGR	656-2878		
☐ U.S. FISH & WILDLIFE SERVICE	541-3441		
Army Fire		2218	2225
☐ RANGE OPERATION MANAGER	655-1990	0700	

REMARKS

1. 2215 16 Sept 20014 Fire was reported and Army Fire is monitoring.
2. 0045 17 Sept 2014 fire was reported and Army is monitoring.
3. Army Fire reported they needed air support for the fire. @ 0655
4. Mr. Huelsmans active Erickson for Fire Support and Called Mr. Garo.
5. FDO call OIC @ 0704 reported information that was on hand.
6. FDO called EOD @0703 to Army Fire Support to access Fire Brake Road.
7. 0750 EOD on site
8. 0824 hrs Erickson on site for support.

11. FIRE DANGER RATING
X Green
Yellow
Red

12. BURN INDEX (BI): 11

13. EST. ACRES BURNED:

14. > 10 ACRES? (AAR): N/A

15. FIRE ESCAPE ANALYSIS: Yes	CHECK ONE: YES	NO
15a. FIRE STARTED OUTSIDE FIREBREAK ROAD?	X	
15b. FIRE ESCAPED FIREBREAK ROAD?		X

16. HELICOPTER SUPPORT: Erickson Army Aircraft

16a. BUCKET SIZE (*BAMBI*): gals

16b. Aircraft Call Sign: Erickson, AC- 0436, AC-0485

Tail No.: N/A

16c. Arrived On Scene: 0824 hrs

17. FIRE CAUSE (*Narrative*): Illumination round from FP-308.

18. AMMUNITION TYPE
Tracer
X Mortar FRTR (120MM)
☐ Artillery
☐ HE / WP
☐ Pyrotechnics
☐ Grenade
☐ Demo / Mines

19. WEAPON SYSTEM
☐ AT-4
☐ TOW
SAW / M-16
☐ SMAW
☐ LAW
☐ Rocket / Missile
☐ M240/M60
X 120MM Mortar

20. TRAINING UNIT: ¾ CAV

21. UNIT OIC: SFC Bearden, Michael

22. TELEPHONE: (337) 718-2070

23. AAR REQUIRED? N/A

24. REMARKS 3/4CAV was training with C625 and CA07 at FP-308. One fire was reported at 2215 hrs on 16 Sept 14 and the second fire was started at 0045 hrs 17 Sept 2014. Fire was in the impact area and Army Fire stated that they would monitor the fire. This morning they reported that they need Erickson support to put this fire out before it jumps the fire brake road. @ 1317 hrs. FDO spoke with Army Fire that is monitoring the fire downrange and they stated that it appears that the fire was started outside the Fire Brake Road. Army Fire will complete are full report once the fire is out.

25. FIRE REPORT COMPLETED BY: Mrs. Mercado, Rashaun

DATE: 17 Sept 2014

26. FIRE REPORT REVIEWED BY:

DATE:

Map removed to protect rare resources

Hawaiian Tree Snail Conservation Laboratory
PI: Brenden Holland
2014 Annual Report

TREE SNAIL PROPAGATION SUMMARY

The UH Tree Snail Conservation Lab currently houses and cares for snails in 10 endemic Hawaiian achatinelline species, all of which are listed as federally endangered. The tree snails are housed in 28 cages maintained in four environmental chambers. Conditions in chambers are intended to mimic natural conditions of mid-elevation Hawaiian rain forest. Chambers have temperature and light control, on a 12 hour cycle. Temperatures are held at 20 or 21°C for during daylight, and 16°C during the night. Sprinkler timers are set to water cages each 8 hours, 6 days per week. There has historically been a one day no water period, again to try to mimic natural conditions.

Tasks for lab staff include weekly scheduled cage changes, removal of old leaves and branches and replacing with fresh leaves of native tree and plant species. We also count births, measure newborn snails and remove, measure and preserve any dead individuals, and note percent cultured fungus consumed.

Following removal of old leaves, cages are cleaned with hot water and detergent, sterilized with ethanol, air-dried, and snails are replaced along with fresh foliage. Members of our group hike Oahu trails weekly to collect fresh leaves, providing food for the snails in the form of surface growing arboreal fungus from leaves and tree bark.

In addition culture medium is autoclaved weekly, and 60 plates are poured and inoculated with lab fungus stock. Cultured fungus has been used as a dietary supplement in the lab for a number of years.

Pulsing (Rotation)/Release of *Achatinella*

In consultation with the Oahu Army Natural Resources Program (OANRP), the DLNR Snail Extinction Prevention Program (SEPP) and USFWS staff, we are waiting for permission for releases of *Achatinella mustelina* populations brought in to the rotation system trial in 2013. In the past the main role of this facility has been on tree snail populations that were experiencing steep declines due usually to sudden increases in predation pressure, usually due to *Euglandina rosea* and other predators moving into the area. This is still the case: we will continue to make space available for endangered tree snails on an emergency basis. However in light of the fact that recent experience has shown that over the long-term in captivity, populations of tree snails can undergo population fluctuations, the reasons for losses are difficult to understand, therefore are challenging to control. For these reasons we are more careful perhaps than in the past about bringing in a population without an exit strategy in place, for release/return to a safe, predator-controlled field locality.

Since 2012 we have begun to identify lab populations that can be released into their natural habitat on a case-by-case basis, and only where targeted, successful predator control has been conducted, or predatory activity is low has ongoing monitoring. These cases also have only been conducted after careful discussion and consensus of appropriate parties (OANRP, SEPP, USFWS), and always under USFWS permit. There are two main avenues for this scenario, one being release of snails into predator exclosure structures, and the other is release at sites where rat control has been successful and *Euglandina* and Jackson's chameleon activity has not been observed. Examples include the success at Puu Hapapa, where sudden drastic declines were observed, and *A. mustelina* were brought in to captivity at the HTSCL, numbers increased, meanwhile funding was obtained, barriers were tested, the site was prepared via native plant restoration and weed and predator removal. A state of the art predator exclusion structure was completed and 341 captive endangered snails were released into this protective structure in early 2012, and this stands as one of the most remarkable accomplishments in the history of Hawaiian tree snail conservation. One of the main strengths of this effort is the long-term safety of not only the rare achatinelline tree snails that were initially placed inside, but ongoing additions of this species as well as more than a half dozen others, some extremely rare, as well as the opportunity to preserve and protect a small ecosystem including rare plants, insects, spiders and even birds.

Another recent example of a laboratory release of endangered tree snails occurred during summer of 2013 when SEPP staff observed devastating impacts of rats on an *A. concavospira* population. Tree snails were collected and brought into the HTSCL, kept for 19 days, and then they were released inside of the Palikea snail enclosure, with one additional snail included in the release due to a birth in captivity.

Table 1. Current population status summary for *Achatinella mustelina*.

Population	**Number**
Ekahanui	**17: 17 juvenile**
Makaha	**2: 1 juvenile / 1 adult**
East Makaleha	**8: 6 juvenile / 2 adult**
Schofield West	**8: 6 juvenile / 2 adult**
Peacock Flats	**4: 1 juvenile / 3 adults**
Bornhorst	**2: 1 juvenile / 1 adult**
Palikea	**3: 3 adult**

Publications

Since the previous Annual Report my staff, students, colleagues and I have published the following three manuscripts based on OANRP funded research accepted for publication in peer-reviewed scientific journals:

- Chiaverano, L.M. & **B.S. Holland**. 2014. Impact and threat assessment of a predatory invasive lizard on the endangered Hawaiian snail *Achatinella mustelina*. *Endangered Species Research*. 24:115-123 (Impact factor 2.26)
- Chiaverano, L.M., M. Wright, & **B.S. Holland**. 2014. Movement behavior of invasive Jackson's chameleons in Hawaii. *Journal of Herpetology*. 48(3) In press. (Impact factor 0.89).
- O'Rorke R., G.M. Cobian, **B.S. Holland**, M.R. Price, & A.S. Amends. 2014. Dining local: the diet of a snail that grazes microbial communities is geographically structured, *Environmental Microbiology. doi: 10.1111/1462-2920.12630.* [Epub ahead of print]. (Impact factor 6.24)

TREE SNAIL PREDATOR STUDIES

Bird dissection results:

Aside from care and maintenance of tree snails OANRP staff has provided a number of invasive birds for dissection and gut content analysis. Observations of field biologists including relatively low counts of juvenile and subadult size classes of *Achatinella mustelina* within the predator exclosure structure, in conjunction with observed bird activity in the host trees for this endangered tree snail, motivated this investigation. To date, OANRP staff had delivered 41 invasive birds for dissection and gut content analysis, from Army managed land at Puu Hapapa.

Birds			***Snails***
Species	***n***	***Birds with snails***	
Red-Vented Bulbul	9	0	
Japanese White eye	12	0	
Shama	1	0	
Red-Whiskered Bulbul	13	0	
Red-billed Leiothrix	6	1	2
House Finch	1	0	
Francolin	1	0	
Totals	41	1	2

Table 2. Summary of invasive bird dissections from Puu Hapapa to date. The two snails found in one Leothrix were both very small (< 2 mm) nonnative species, no *Achatinella* shells have been found in a bird to date.

No additional snails have been found in the bird dissections. We dissected a large Francolin collected by OANRP personnel at Puu Hapapa during this reporting period, and found only plant material, plus one earwig (insect) in the stomach and gastrointestinal tract. We also caught and preserved an Indian Mongoose, on the trail just below the summit of Hawaii Loa Ridge while collecting HTSCL leaves for snail cages. Dissection of this specimen yielded only unidentifiable plant material, no evidence of bird or snail prey was found.

<u>Jacksons chameleon dissection results</u>:

We have examined gut contents of 74 chameleons during the reporting period. Details of snails are shown below, while arthropod composition of guts are still being analyzed, and will be made available upon completion.

Locality	***Predator***	***Number and species ID of snails***	***Identifiable non-snail gut contents***
Puu Hapapa	2 birds (1 White eye, 1 Francolin)	0	Various seeds, spiders and other arthropods
Puu Hapapa	27 chameleons	11 *Achatinella mustelina*, 13 *Philonesia*, 1 *Euglandina*	spiders and other arthropods
Palikea	1 chameleon	5 *Philonesia* 1 *Succinea*	spiders and other arthropods

Table 1. Summary of invasive predator dissections collected at Puu Hapapa (73 chameleons) and Palikea (1 chameleon), Oahu. A total of 74 chameleons have been dissected for this portion of the study to date. Snail shells were found in 28 of these, and 11 *Achatinella mustelina* were found in the guts of 6 of these chameleons, all collected at Puu Hapapa. Although incidence of snails in predator guts has remained relatively low, arthropod prey items in guts were abundant, suggesting short residence time for shells in gut (3 - 4 days). We have estimated that at the chameleon density observed at Puu Hapapa, and factoring in the rate of consumption observed, for each hectare of habitat where chameleons and tree snails are present, up to 4,870 tree snails will be eaten per year (Chiaverano & Holland, 2014. *Endangered Species Research*. 24:115-123). To date *A. mustelina* is the only achatinelline tree snail species that has been found in the guts or feces of Jackson's chameleons.

Euglandina Angle Trap Trials

We are currently testing the first attempt to target and trap *E. rosea* in Hawaii without bait or poison, by deploying double-sided angle traps that we designed and built in the lab. These consist of rigid, lightweight linear sheets of smooth material with a dual 45-degree angle affixed to the upper edge (see Figure 1), via bolts and wing nuts.

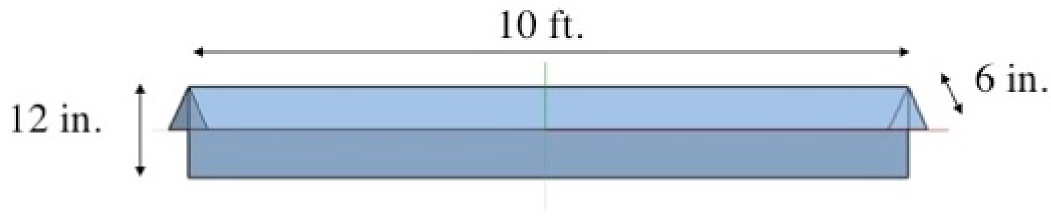


Figure 1. Schematic design for *Euglandina rosea* Angle Trap. Materials being tested are rigid plastic. Vertical element may be folded for transport, and angle is affixed in the field. Also rigid stakes are used along the bottom edge to secure trap to the ground.

The idea for the basic design is based on the angle barriers incorporated on the lower portions of the Puu Hapapa and Palikea exclosure structures. Predatory snails in native forest locations appear to randomly move through space while foraging, when they encounter the angle barriers at Puu Hapapa and Palikea, crawl up as far as the are able, until they encounter the angle barrier, where they simply stop moving and accumulate. This is a potentially inexpensive, non-toxic, noninvasive approach. We conducted preliminary laboratory testing, and demonstrated that the concept works on a small scale in the laboratory, and traps all sizes of *E. rosea* for multiple days. We are planning to optimize design, material, and scale via field-testing. If successful, initial field trials will lead to the deployment of larger scale and numbers of the angle traps in priority areas of greatest conservation concern (Fig. 2).

The total area covered by the multiple traps at these locations would depend on the unique site terrain. As a starting point, we propose to build 6 traps at dimensions shown in Figure 1. Dimensions will be adjusted to maximize effectiveness. In order to mimic conditions at the exclosure fences, and ensure that foraging predators encounter the smooth edge of the trap without passing underneath, clear ground areas are selected, and where possible/necessary, deployment sites are cleared such that traps are placed flush with the ground surface. The gap below the angle is searched with a mirror at regular intervals, ideally until no additional *Euglandina* are trapped. At that point the traps can be either be moved to an adjacent area at the same site or a new location, based on the number of invasive snails collected, etc.

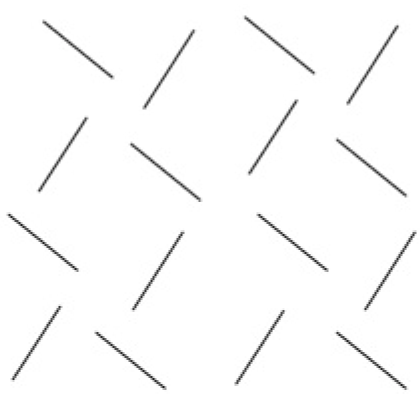


Figure 2. Example of grid deployment of Angle Traps. Along with design of traps themselves we will also optimize placement orientation to maximize encounters of foraging *Euglandina rosea*.

If effective, deployment of double sided angle traps have the potential to dramatically change the outlook for native island snail fauna. We have built 8 prototypes and deployed them at Puu Hapapa for testing, with consultation and help from the OANRP staff biologists.

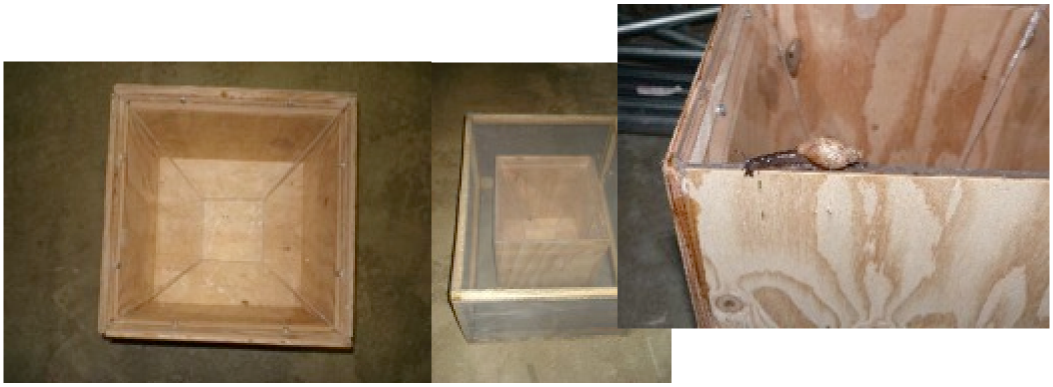


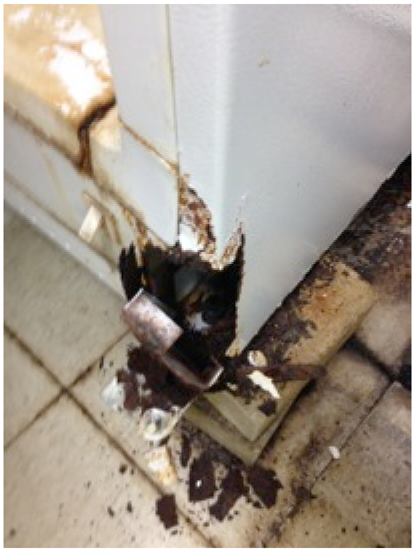
Figure 3. Angle box box lab tests were largely successful, set-up, showing screen (c) and one escaped snail (r).

Also we moved all live *Euglandina rosea* as well as Jackson chameleon research out of the HTSCL during the reporting period.

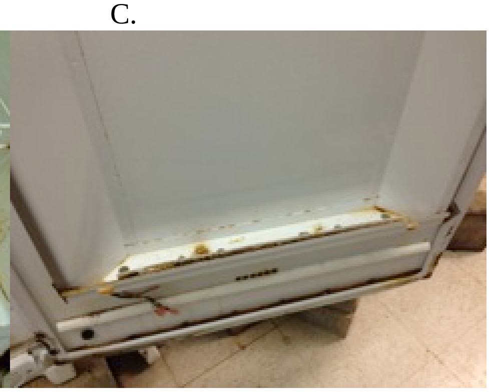
Environmental Chamber Maintenance

Although environmental chambers last for up to 10 – 12 years in the HTSCL, since we need to provide the tree snails with water three times per day, the main factor leading to chamber demise is typically rust. During the summer of 2014, for example, our oldest chamber failed when the door hinges broke free of the frame due the rust penetrating through the supporting structure. I had a chamber repair specialist here from Technical Services Hawaii, who examined the chamber and determined it is not repairable. Therefore in order to maximize the durability and life of the chambers, I have begun refurbishing and rust–proofing the portions of chambers that tend to suffer rust damage, namely the chamber floors, doors and light fixtures. This should extend the functional life of the chambers.

A.



B. C.



D. E.

Figure 1. Chamber refurbishing and maintenance. Photo labeled A shows rust penetrating the frame of the chamber, where door hinge failed. Photos B and C depict a typical rusted chamber floor and door with light fixture. We moved the chamber outdoors, treated for rust, scraped with

wire brush and steel wool, primed the surface, then repainted the interior. We waited 72 hours for the paint to dry and fumes to dissipate, then moved the chamber back inside the HTSCL.

Molecular assessment of wild *Achatinella mustelina* diet

Final Report

Richard O'Rorke and Anthony Amend
Department of Botany
University of Hawaii at Manoa,
amend@hawaii.edu

October, 2014

Introduction

Achatinella mustelina is a federally endangered tree snail endemic to the Waianae mountain range of Oahu. Efforts to exclude predators from native habitats combined with captive breeding programs have been reasonably successful at stabilizing small population sizes. Reproduction in captivity is inversely proportional with time in captivity, however, leading researchers to question diet adequacy. For this reason, we investigate the diet of wild snails. Because *Achatinella* snails are presumed to eat biofilms of fungi and bacteria off of leaf surfaces, we use molecular DNA barcoding methods to infer diet from deposited feces, since digested microbes are difficult to identify visually.

The first study of the project is now in press (Manuscript attached):

O'Rorke, Richard, Gerald M Cobian, Brenden S Holland, Melissa R Price, Vincent Costello, and Anthony S Amend (2014) Dining Local: the Microbial Diet of a Snail That Grazes Microbial Communities Is Geographically Structured. *Environmental Microbiology*

In this paper we investigate:

1) The diet of wild *Achatinella mustelina* in Oahu's Waianae mountain range
2) Whether snail diet differs from leaf microbial composition (i.e. whether snails are "picky eaters").
3) What environmental factors shape snail diet.

In addition to the project outlined above, we conducted a comparable analysis of how the diet of *A sowerbyana* differs over distance, precipitation and temperature in the Ko'olau range. The findings of this research were recently presented at the Island Biology 2014 meeting and a manuscript will be sent out to peer review by the time this report is submitted.

We have also cultured microbes that are significant in the diet of *A. mustelina.* These will be used in feeding trials to determine if the snails preferentially consume particular food items.

Samples

One hundred forty two field samples of *A. mustelina* feces, and the leaves from which they were obtained have been collected from field sites in the Waianae range: 36 from Puu Hapapa, 42 from Palikea, 18 from Kahanahaiki and 6 from Pahole. An additional 12 samples (leaves and feces) have been collected from Dr. Brendan Holland's *A. mustelina* captive populations on UH campus. Two *Auriculella ambusta* (a non-endangered endemic tree snail) were also collected from Pu'u Hapapa and dissected in order to compare gut contents with leaf surface and fecal microbial diversity.

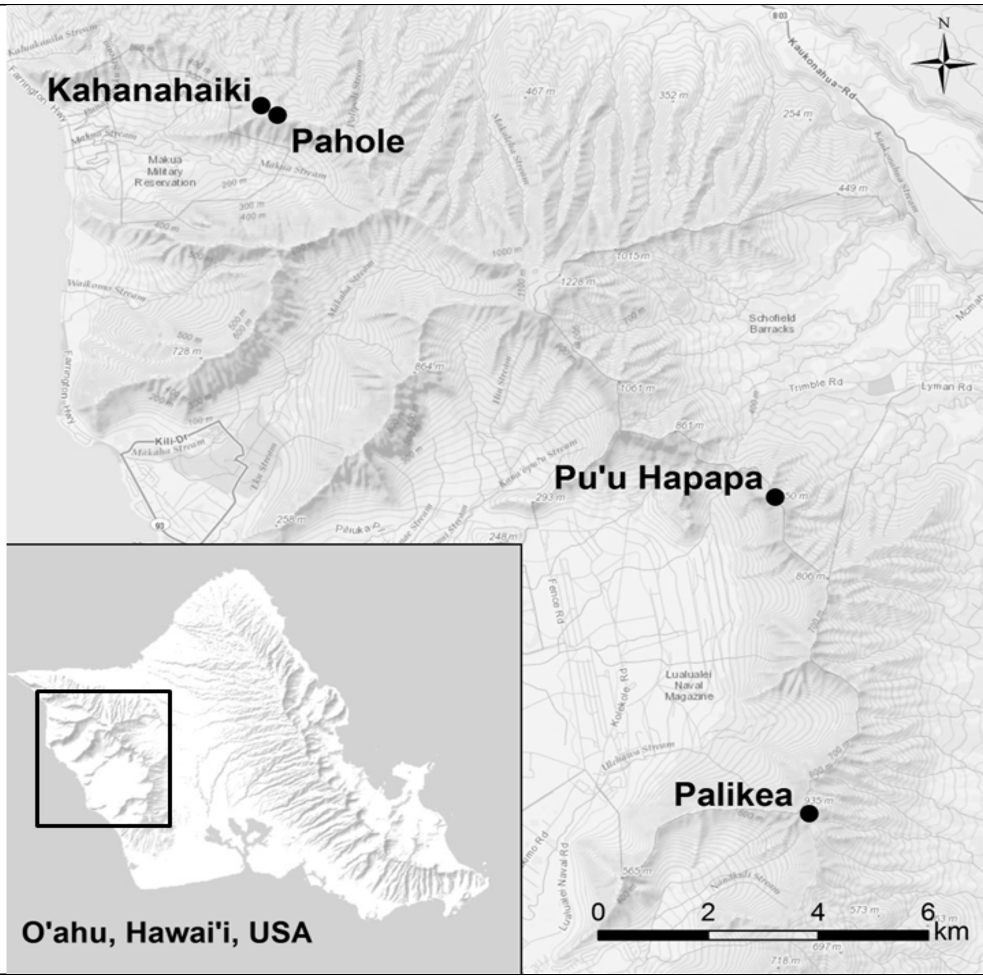


Figure 1. Sampling locations on Oahu, Hawaii.

In general, multiple samples from each host plant species were sampled in each location in order to measure variance within and among host plants. A total of twenty-nine host plants were sampled including both native and non-native species.

DNA Extraction and PCR Amplification

Genomic DNA from both feces and leaves were extracted using a commercially available kit (MO-BIO PowerSoil). Feces were added to maceration tubes directly, whereas microbial biofilms from the leaf surface were sampled using sterile swabs. Both feces and leaf samples were PCR-amplified using DNA primers specific for Fungal (ITS1f and ITS4) and Bacterial (515f and 907r) barcode regions. Each sample was PCR-amplified using a short, unique “tag” sequence of nucleotides in order that sample identity is maintained throughout the analysis. These primers amplify neither plant nor animal DNA, so a positive result indicates successful amplification of target molecules. Negative control PCR/extraction reactions were run with sterile swabs that had not come into contact with the leaf surface. Absence of a positive PCR product from these “samples” indicates that target molecules derive from leaf surface/feces rather than lab contamination.

Table 1. Plant hosts sampled by location. Each sampling was a paired sample consisting of snail feces and a leaf surface swab.

LOCATION	**Elevation [m]**	*Alyxia oliveformis*	*Antidesma sp.*	*Brousaissia arguta*	*Clioxylon sp.*	*Coprosma longiflora*	*Dianella sandwicensis*	*Diasporos sandwicensis*	*Hediodus terminalis*	*Freycinetia arborea*	*Ilex anomala*	*Melicope oahuensis*	*Metrosideros polymorpha*	*Myrsine lesertiana*	*Myrsine sp.*	*Nestegis sandwicensis*	*Perrottetia sp.*	*Perrottetia sandwicensis*	*Pipturus albidus*	*Pisonia brunoniana*	*Pisonia umbelifera*	*Pisonia sandwicensis*	*Pittosporum glabra*	*Pouteria sandwicensis*	*Psychotria sp.*	*Schinus terebinthifolius*	*Smilax sp.*	*Psidium cattleianum*	*Urera glabra*	*Urera kaali*
Puu Hapapa	848				4					3	3			4	3		1		1	2	2			3	2	3	1		2	2
Palikea	897		3	3		2	5		2	4		2	4	3				2	1						2	2		4		
Kahanahaiki	671	3	1					1	2				1	4		3							1					3		
Pahole	701					1										1						3								

Results of Illumina Miseq Sequencing

Sequencing on the Illumina MiSEQ platform resulted in 13.8 million raw amplicon sequence reads in each sequencing direction. Overall read quality was excellent. Forward reads had mean phred scores >30 (that is >99.9% accuracy) for up to 270 of the 300 bp read length. Reverse reads were of poorer quality, having considerable variability in read quality after the 100^{th} bp and mean quality dropped below a phred score of 30 by the 200^{th} bp.

The long 300bp read length enabled by the new Miseq chemistry, means that there is a substantial amount of overlap between the forward and reverse reads. This enabled the construction of a consensus read with increased fidelity, and the present study yielded 12.8 million high quality consensus reads after pairing. Reads were finally assigned to their respective samples using golay error correcting barcodes. A total of 10.2 million high quality reads were successfully assigned to samples.

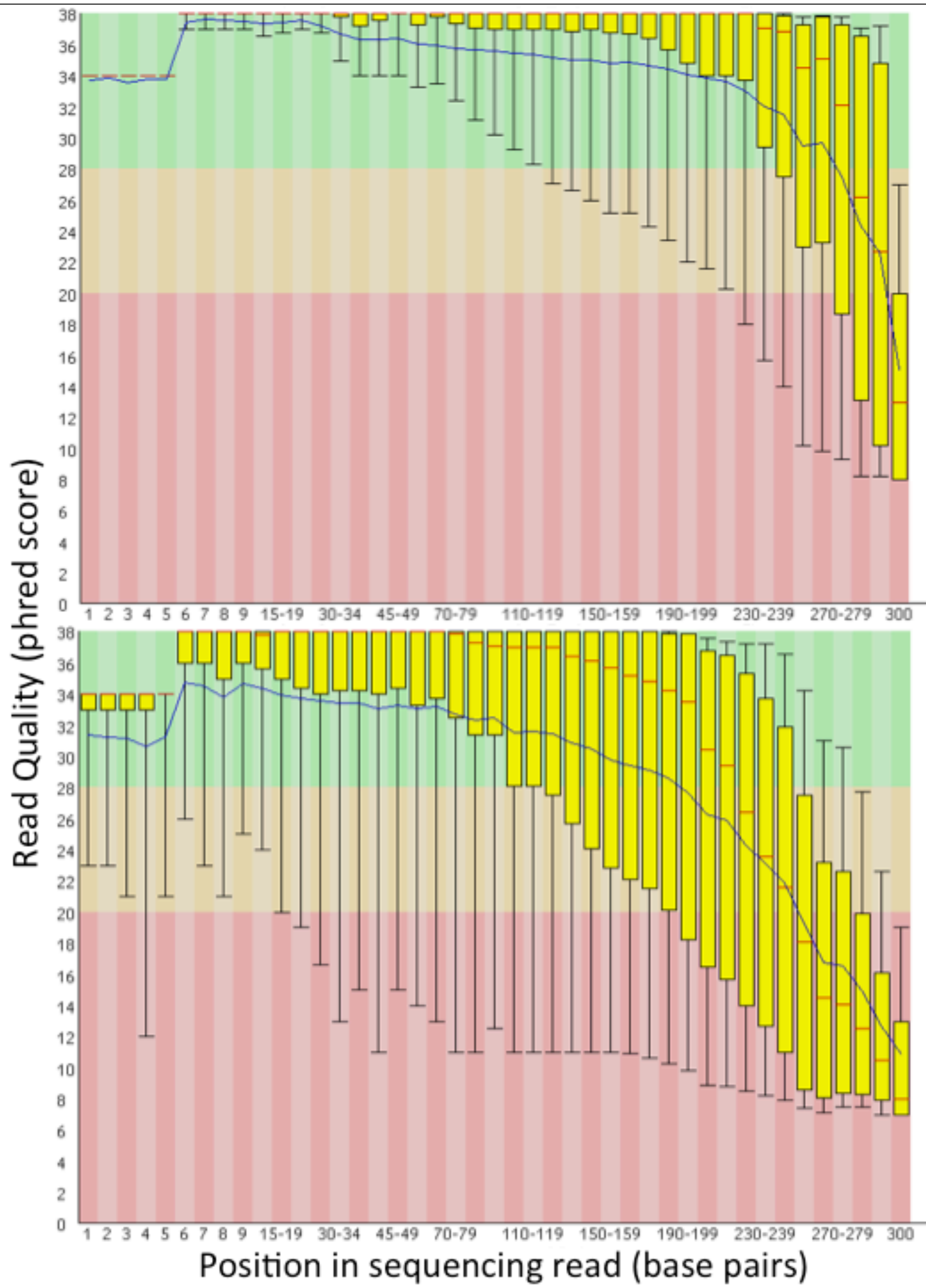


Figure 2. Mean Read Quality of Forward and Reverse Sequenced Amplicons from the Illuimna Miseq run. Forward reads were consistently high quality through to the 280th base (phred>30). The mean quality of the reverse reads is still fairly high, although it drops off after the 200th base and has considerably more variability.

Analyses: what are snails eating and what factors structure their diet?

Are snails picky eaters? No.

Feces and leaf samples have equally species-rich microbial community assemblages and most fungal and bacterial reads that were sourced from leaves were also detected in fecal samples. However, the proportional abundance of these species differs between leaf and feces samples. This is indicated by analysis of a Bray Curtis transformation of the data, which shows that the dissimilarity between feces and leaf microbe diversity is a major component structuring the dataset (Figure 4).

To determine whether fecal composition does reflect gut composition – and is not the result of environmental contamination of feces, two *Auriculella ambusta* were dissected and their gut content compared to the leaf and feces samples. The result of this study was that 64% of reads were shared between the gut, leaf and feces, confirming that the phyllosphere is being passaged through the gut and detected in feces (Figure 6).

Figure 3. Achatinella mustelina snail (center) adjacent to fresh feces (right). Photo was taken inside Puu Hapapa snail exclosure.

What factors structure snail diet and phyllosphere diversity?

The location of sampling and the taxonomic identity of the tree host are factors that structure the community composition of both fungus and bacteria. Samples from Pahole and Kahanahaiki are not dissimilar, but assort into a single

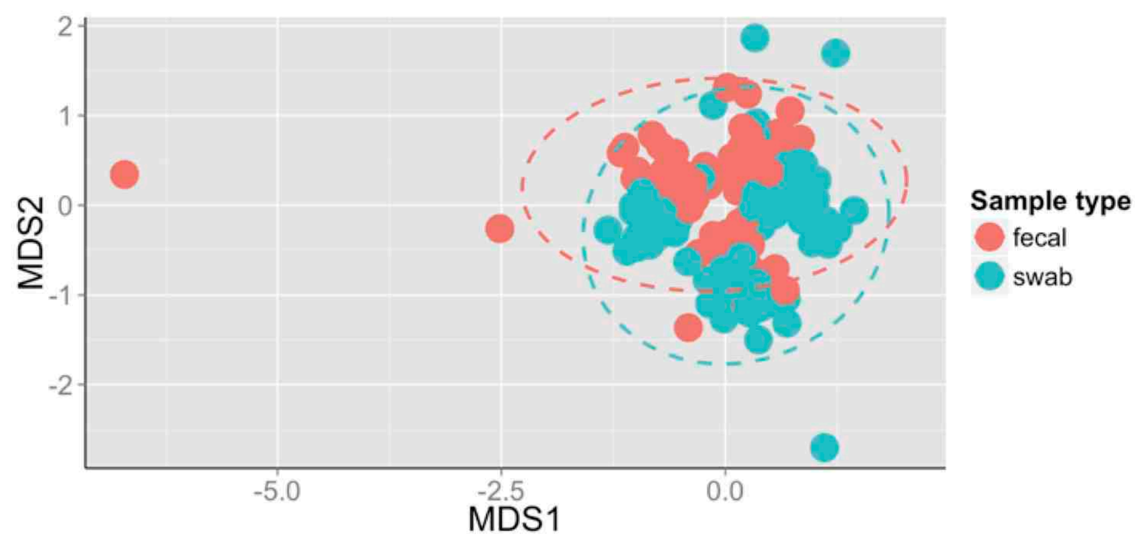


Figure 4. Multi-dimensional scaling (MDS) plot of Fungal samples. Fungal community data was transformed into a Bray Curtis Dissimilarity matrix and visualized by MDS, which is an ordination approach to visualize dissimilarity. Points that are ranked most dissimilar are graphed furthest apart. Here there is a clear separation between the feces (fecal) and phyllosphere (leaf).

group that contrasts with samples from Palikea and Pu'u Hapapa (Figure 5). However, location structures a greater component of variation for the fungal dataset than it does in the bacterial dataset.

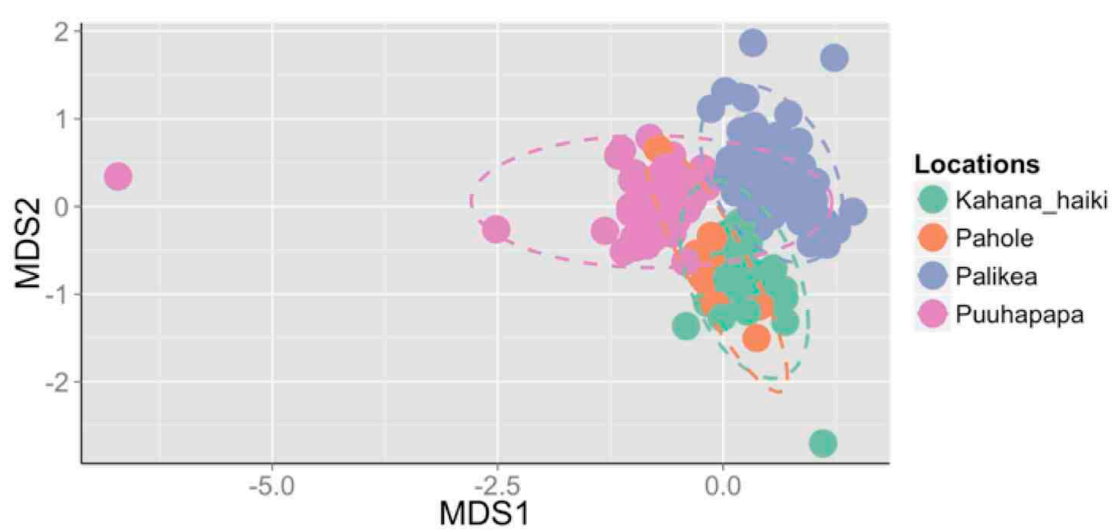


Figure 5. MDS plot with location highlighted as a factor. There is a clear gradient of dissimilarity indicating that location structures the microbial communities that constitute the diet of *A. mustelina*.

Other factors, such as whether the plant host is native or exotic don't have a significant effect on variance. However, it must be observed that the only plants sampled in the present study were those that hosted snails. It cannot be ruled out that snails are either engineering the microbial community on which they feed, nor that snails select trees with certain microbial assemblages. Therefore, little can be concluded about the component of variation explained by tree identity until a follow-up study is conducted to determine if the phyllosphere community structure is different between trees with snails and those without.

What microbe are snails eating?

Assigning a taxonomic identity to Species-level was problematic, likely due to high levels of endemism in Hawaiian microbes and a poor baseline database. Consequently, 86.5% of bacteria were identifiable at the order taxonomic level and 67.7% at the family level, compared to fungus, for which 63.4% taxa could be assigned an order and 47.3% a family. At the genus level, assignments were 38.4% for fungi and 32.61% for bacteria. In total, 7,376 fungal taxa and 3,967 bacteria taxa were detected. Microbial communities were very diverse and less than 50 species of fungi or bacteria contributed more than 0.3% of total sequence reads. The taxonomy of the most abundant fungal reads revealed that they were from fungal groups commonly associated with the phyllosphere, whereas bacterial OTUs were assigned to clades that are either common members of the phyllosphere or gut bacteria.

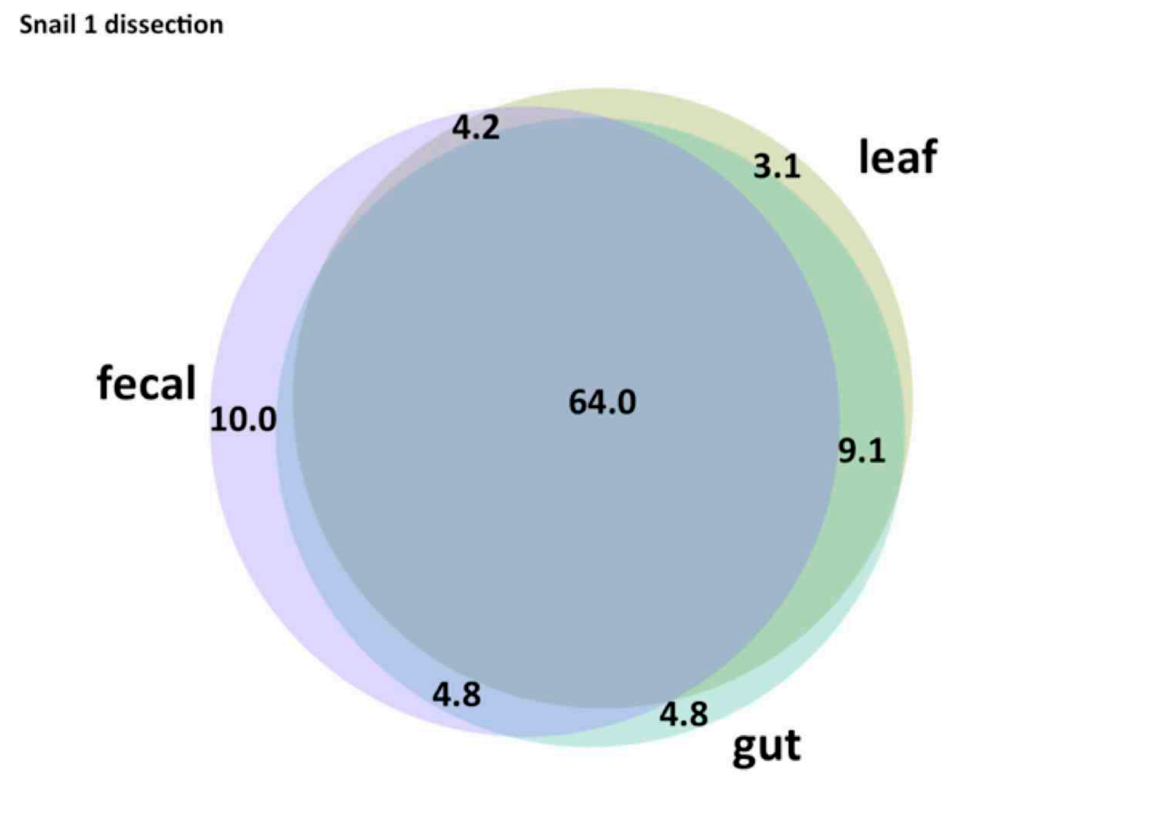


Figure 6. Comparison of fungal read abundances in snail gut, feces and the phyllosphere. Numbers represent proportions of total reads attributed to each component.

Comparisons between the *in situ* and captive snails diets.

A study was conducted to evaluate the diet of snails cultured in the *ex situ* facility (Brendan Holland's lab on UHM campus) and how this compared their diet to wild snails.

Whereas the wild diet is highly diverse the captive snail diet is dominated by a single taxon. This taxon is the *Cladosporium* species (Order: Capnodiales) that is used as a dietary supplement *ex situ* raised snails. However, this also present in the wild diet and although nowhere near as dominant as it is in the *ex situ* facility it is a major component of the wild fungal assemblage, comprising approximately 2% of wild snail diets (Figure 7).

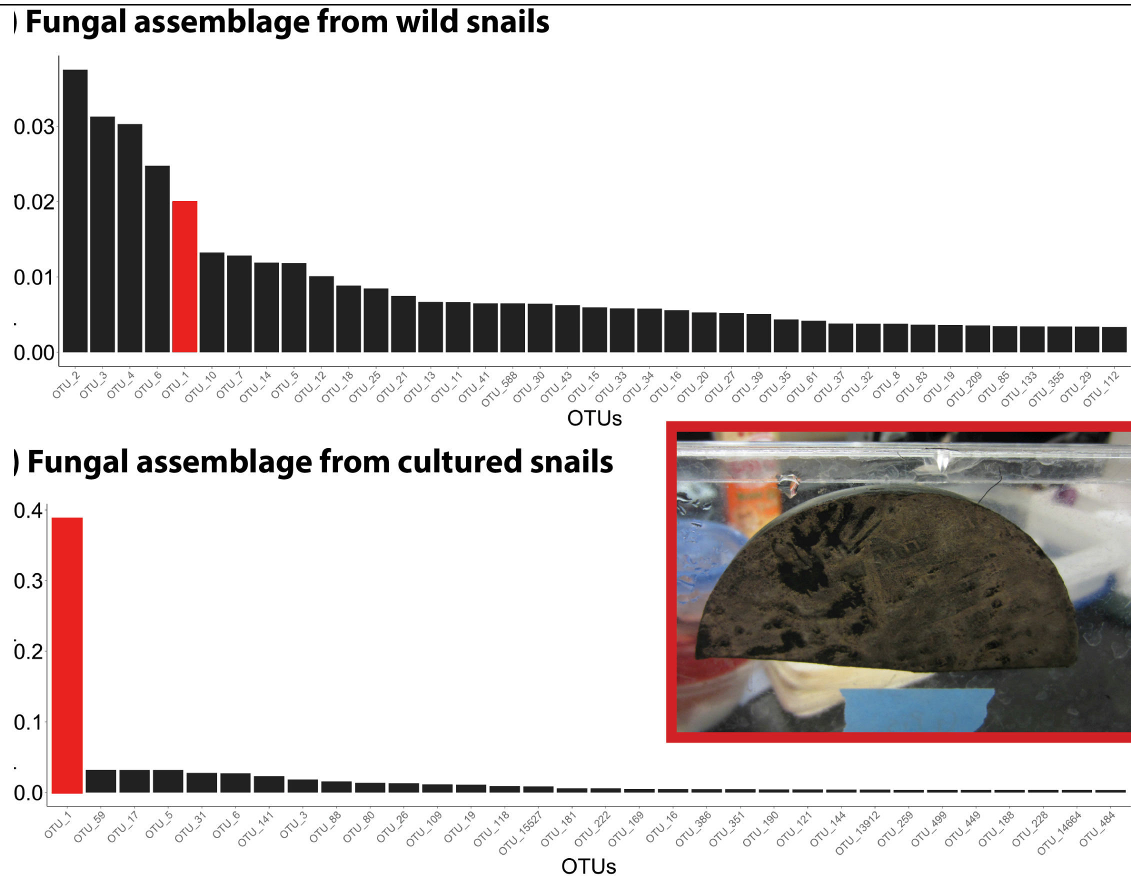


Figure 7. Rank abundance of fungal taxa from a) wild and the b) *ex situ* culture facility. While wild populations of *Achatinella* have a diverse diet with no diet items dominating their gut content, the snails in the *ex situ* facility have a diet that is dominated by a single *Cladosporium* (pictured and highlighted red), which took up almost 40% of the sequenced reads from the feces of cultured snails. This taxon also occurred in the wild (highlighted in red), but occurred in abundances slightly less than 2%. Operational Taxonomic Unit (OTU) is a technical term meaning a molecular defined "species" equivalent.

Fungus and bacteria isolation from feces and leaves

We have begun isolating the microbes that are significant in the diet of *A. mustelina*. Ninety-two fungal and bacterial strains were isolated from leaves and snail feces sampled from trees at the Pu'u Hapapa and Palikea enclosures. This work has confirmed that fungi are viable when they pass through the gut of snails and provides a set of potential food items that can be used to enhance captive culture of snails.

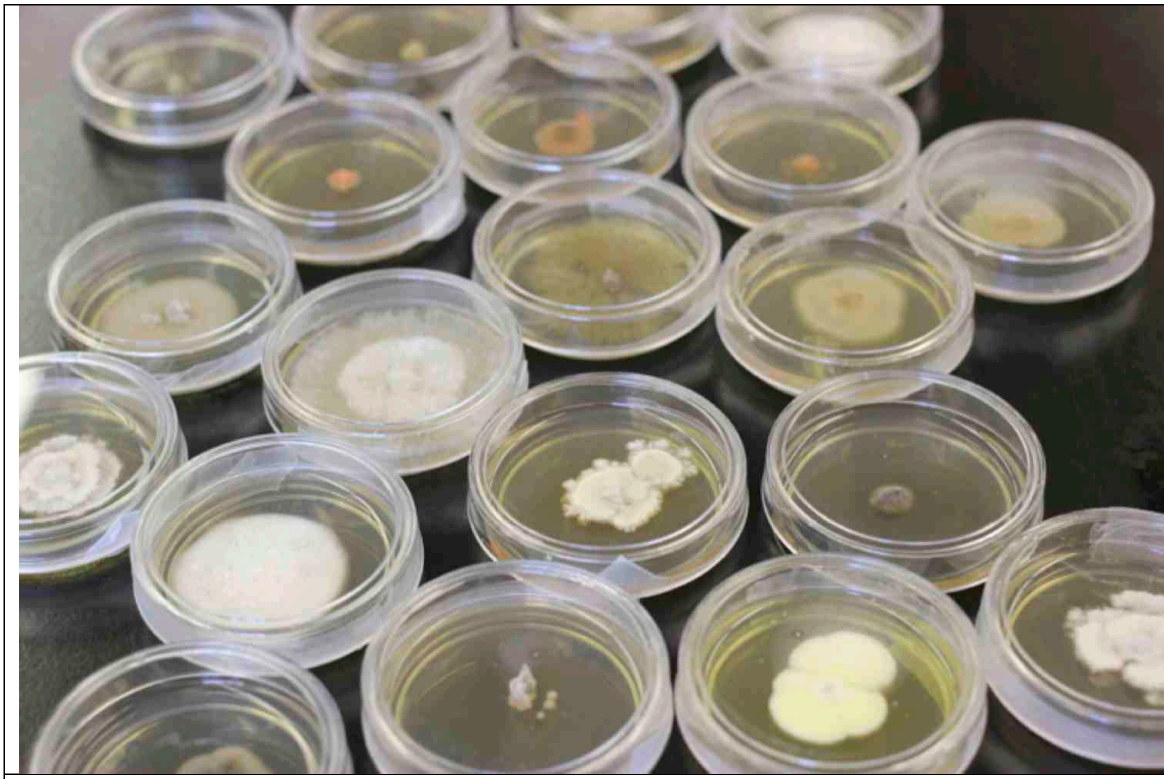


Figure 8. A selection of fungi isolated from *Achatinella mustelina* feces.

Feeding trials

The results of our study indicate that *A mustelina* indiscriminately consume microbes from whatever surface they are on. However, this does not answer whether they have particular feeding preferences. To determine if they have feeding preferences we have prepared multiple microbial lawns that will be used to trial feeding preferences of *Auriculella ambusta*, a non-listed native tree snail in the same family that will be used as a surrogate for *Achatinella.* Our amplicon sequencing dataset shows that sympatric *Auriculella* and *Achatinella* consume similar microbes, which justifies this comparison. The trial apparatus has been assembled, which consists of 10 chambers into which individual snails will be placed. Stop motion photography will capture an image every 20 seconds over 24 hours (12 dark and 12 light) to determine which of 12 food choices the snails elect to eat. The permits for this experiment have been successfully obtained and trials will begin soon. A preliminary run of the experiment can be viewed at https://www.youtube.com/channel/UCBL4mGFBZsnfQQAw-ZDT1iQ.

Comparisons with congeners *Achatinella lila* and *Achatinella sowerbiana*

A separate, related study was conducted on the diet of two species closely related *A. mustelina*: *A. lila* and *A. sowerbiana* that co-occuring in the Koolau range. This manuscript is in advance preparation: Melissa R. Price, Richard O'Rorke, Anthony S. Amend, Michael G. Hadfield (In Prep) A Buffet Strategy for Grazing Hawaiian Tree Snails, Despite Geographic Structuring of Phyllosphere Fungi.

This study found that, similar to *A mustelina*, the snail diet does not differ from the microbial community of the leaves. There was also no evidence that diet differed between the two species with overlapping ranges (Table 2).

Table 2. Results of a Permutational Multivariate Analysis of Variance test indicate that while fungal communities differed based on sample type (leaf vs. feces), there was no difference in diet amongst overlapping *Achatinella* species.

Source	SS	MS	Pseudo-F	*P*(perm)
Snail Species	3865	3865	1.06	0.293
Fecal or Leaf	11854	11854	3.25	0.0001
Residual	1.28E+05	3652		
Total	1.44E+05			

However, fungal communities found in snail feces were much more similar to each other than were communities found on leaf surfaces, supporting the hypothesis that snails may exert top-down selection on phyllosphere communities by selective digestion (Figure 9).

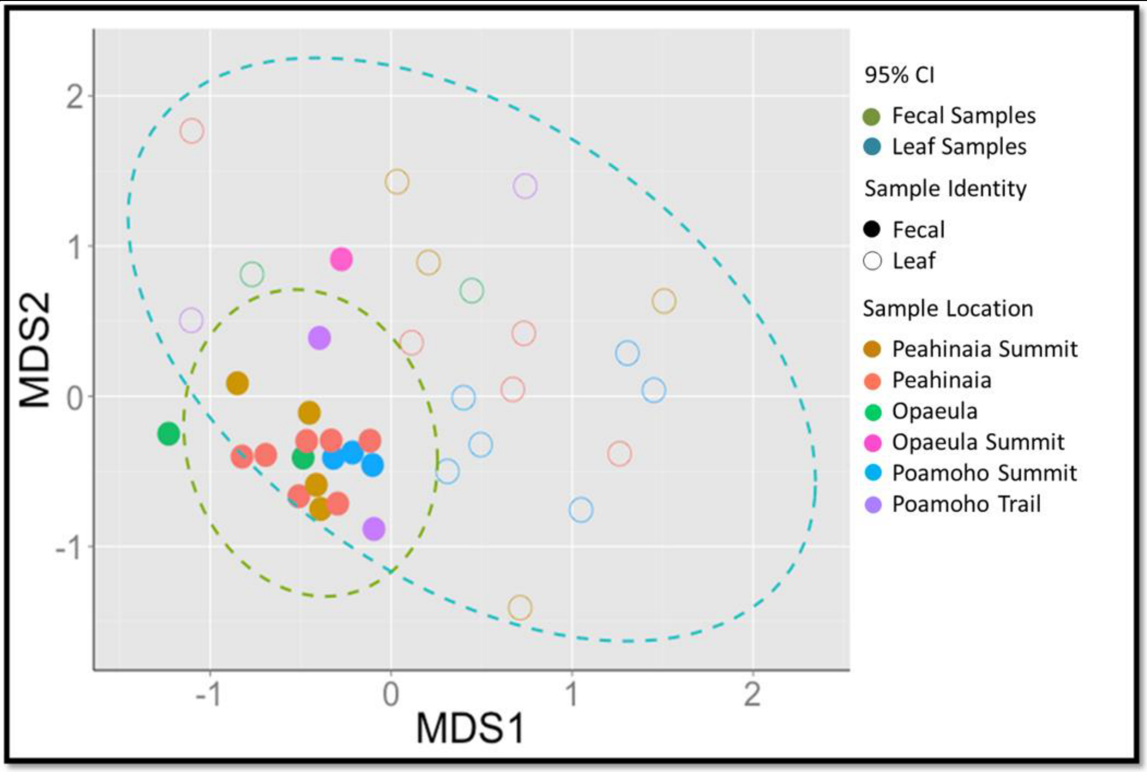


Figure 9. Multi-dimensional Scaling Plot for fecal and leaf samples identified by location. Fungal communities from fecal samples clustered more tightly than those from plant samples.

Conclusions

Although *A. mustelina* subsists entirely by grazing microbes from leaf surfaces of native trees, little was known about fundamental aspects of these microbe assemblages: not taxonomic composition, how this varies with host-plant or location, nor whether snails selectively consume microbes. To address these questions we have completed a high-throughput MiSeq sequencing study to determine how microbial community structure varies across the habitat range of the endangered tree snail *A. mustelina*. We have found that:

- Snails are not selective feeders, but are generalists at the phyllosphere scale
- The diversity of the microbial communities that snails feed on is surprisingly high, with few species dominating the assemblage
- By contrast, the diet of captive raised snails is dominated by a single taxon
- Microbes consumed by snails vary by location and host-plant identity, with fungal community composition being strongly determined by location

Future work: determining the implications for management

Snail conservation is currently dependent on the success of *in situ* field enclosures. These enclosures are situated in the natural ranges of the snails, and therefore they do not need to simulate the natural environment. However, the results of our present work raise an important question: can we simulate the microbial communities that snails live on in the laboratory or in convenient and accessible patches of land? If this were possible, then snail enclosures could be built near conservancy offices, eliminating the expense, danger and climatic unpredictability associated with building enclosures in the field and transporting the materials to these enclosures. It would also eliminate the need to collect leaves for the captive snails from the wild. This might eliminate expense, and eliminate a potential vector for disease.

We will next undertake an experiment to determine if domesticated trees can be inoculated with a 'wild' microbial assemblage. This will be complimented by a set of experiments that will determine what the minimal requirements are for maintaining this assemblage *ex situ*. The results of our present study lead us to devise a set research objectives for the coming year that will help with snail management:

- Can we simulate a wild snail diet?
- How does snail translocation affect the composition of the microbial community?
- What are the affects of sourcing leaves from multiple locations for *ex situ* propagation?
- What are the impacts of the lack of dietary diversity in captive cultures?
- The tools developed in the present study should be used to determine differences between sites colonized by snails and sites that are not.

Environmental Microbiology

Dining local: the microbial diet of a snail that grazes microbial communities is geographically structured

Richard O'Rorke[1*], Gerald M. Cobian[1], Brenden S. Holland[2], Melissa R. Price[3], Vincent Costello[4], Anthony S. Amend[1]

[1] Department of Botany, University of Hawaii at Manoa, Honolulu, HI 96822, USA
[2] Center for Conservation Research & Training, Pacific Biosciences Research Center, University of Hawaii, Honolulu HI 98822 USA
[3] Kewalo Marine Lab, Pacific Biosciences Research Center, Honolulu HI 96822, USA
[4] Research Corporation of the University of Hawaii Honolulu, HI 96822 U.S.A.

*Corresponding author.
Email: rororke@hawaii.edu,
Phone: 1 808 956 0936
Department of Botany
University of Hawaii Manoa
3190 Maile Way, Room 101
Honolulu, HI 96822 U.S.A.

Subject category: Microbe-microbe and microbe-host interactions

Running title: Diet of *A. mustelina*

In Press: Advanced copies online via http://www.ncbi.nlm.nih.gov/pubmed/25285515
And http://onlinelibrary.wiley.com/doi/10.1111/1462-2920.12630/abstract

Abstract

Achatinella mustelina is a critically endangered tree snail that subsists entirely by grazing microbes from leaf surfaces of native trees. Little is known about fundamental aspects of these microbe assemblages: not taxonomic composition, how this varies with host-plant or location, nor whether snails selectively consume microbes. To address these questions we collected 102 snail fecal samples as a proxy for diet, and 102 matched-leaf samples from four locations. We used Illumina amplicon sequencing to determine bacterial and fungal community composition. Microbial community structure was significantly distinct between snail feces and leaf-samples, but the same microbes occurred in both. We conclude snails are not 'picky' eaters at the microbial level, but graze the surface of whatever plant they are on. In a second experiment, the gut was dissected from non-endangered native tree snails in the same family as *Achatinella* to confirm that fecal samples reflect gut contents. Over 60% of fungal reads were shared between feces, gut and leaf samples. Overall, location, sample type (feces or leaf) and host-plant identity all significantly explained the community composition and variation among samples. Understanding the microbial ecology of microbes grazed by tree snails enables effective management when conservation requires captive breeding or field relocation.

Key words: Phyllosphere/Microbial community/Diet/MiSeq/Beta-diversity/tree snail

Introduction

The Hawaiian tree snail genus *Achatinella* once comprised approximately forty-one species, all restricted to narrow ranges, endemic to the island of Oahu. Although considered extremely rare today, as recently as the 19th and early 20th centuries the Hawaiian tree snails were abundant, broadly distributed and could be viewed by the thousands during a single excursion in the forest. The combined pressures of shell collection, predation by alien species (Chiaverano *et al*. 2014; Holland *et al*. 2012) and habitat alteration and loss have severely impacted achatinelline species diversity and distributions. Today, only ten species remain in the genus *Achatinella* (Holland & Cowie, 2009), all of which are listed as federally endangered (USFWS 1981) and require extensive conservation intervention to prevent the extinction of remaining species. *Achatinella mustelina* is endemic to the Waianae mountain range of western Oahu, and consists of six genetically distinct populations (Holland & Hadfield, 2002; 2007). However, the snails are patchily distributed and it is unknown if their diet is similar across the distribution. All members of the Hawaiian tree snail subfamily Achatinellinae feed on microbial communities growing on the surface of (predominantly native) leaves, but attempts to characterize their microbial diet have been limited to the isolation of a single *Cladosporium* sp. fungus, isolated from a native Ohia tree (*Metrosideros polymorpha*), for the purpose of *ex situ* tree snail culture (Kobayashi & Hadfield, 1996). The objective of the present study was to examine how geography and host-plant taxonomy determines the microbial diet of this rare endemic Hawaiian tree snail.

Recent applications of molecular methods to characterize the diet of consumers via the digesta (Pompanon *et al.*, 2012) hold potential to expedite our understanding of fundamental aspects of diet ecology and feeding behavior in the wild. DNA based approaches have been successfully applied to animals that consume fungus (Jørgensen *et al.*, 2005; Remén *et al.*, 2010; O'Rorke *et al.*, 2013; Soininen *et al.*, 2013). A cloning-based study showed that all 144 fungal DNA reads taken from the guts of several collembolans were *Aspergillus*, excluding a range of potential diet items (Jørgensen *et al.*, 2005). A pyrosequencing study found that the fungus in the guts of Norwegian lemmings derived predominantly from species with small fruiting bodies and concluded that it was unlikely that mycophagy plays a major role in the mostly herbivorous diet (Soininen *et al.*, 2013). However, these studies involved the sacrifice of the consumer in order to access their gut contents, and are therefore unsuitable models for the endangered *A. mustelina*. A non-lethal approach to DNA diet studies is to extract DNA from the feces, which has been demonstrated with large herbivores and carnivorous predators (Barnett *et al.*, 2010; Oehm *et al.*, 2011; Parsons *et al.*, 2005; Brown *et al.*, 2011; Deagle *et al.*, 2009),

Comparatively more is known about the microbes comprising the phyllosphere in general. This is due to a steady effort of research based on culture and characterization of microbial isolates (e.g. Morris *et al.*, 1998; Baker *et al.*, 1979), and molecular characterization of the phyllosphere (e.g. Knief *et al.*, 2010; Thompson *et al.*, 1993). More recently, there has been a surge in community-level information about the phyllosphere facilitated by the high yields of sequence data from high-throughput DNA sequencing technologies (Jumpponen & Jones, 2009; reviewed in Müller & Ruppel, 2013; Vorholt, 2012), suggesting that the phyllosphere is structured primarily by distance, local environment and host-plant characteristics. Importantly, these more recent studies have moved away from model systems and are using the power of high-throughput technologies to explore phyllospheres in wild plant assemblages (Kembel & Mueller, 2014; Kim *et al.*, 2012; Finkel *et al.*, 2011).

For the present study we assessed the variance in community composition of the microbes constituting the diet of *A. mustelina*, a federally endangered species. We sequenced DNA from *A. mustelina* feces occurring on multiple replicate host trees from four sites in the Waianae mountain range, to measure the extent to which location and plant host identity correlate with diet. Paired samples from leaf microbial communities were also collected, enabling us to assess whether microbial community variance in feces was correlated with that of the phyllosphere. To evaluate the extent to which microbes detected in the feces correspond with gut content, we also dissected the gastrointestinal tract from two *Auriculella ambusta* individuals, which are non-endangered snails in the same family as *A. mustelina*, and compared the microbial composition to that of their feces and the phyllosphere. Finally, we discuss how novel molecular methods within a tri-trophic ecological framework can abet basic natural history research for the conservation of an enigmatic endangered species.

Methods

Sampling

Sampling stations and dates are given in table 1. To ensure the sampled feces were recently deposited, tree foliage was searched at nighttime for snails, and the trees in which snails were present were flagged. *Achatinella* feces are distinctively large and any that were freshly deposited on leaf surfaces of the flagged trees were then collected the subsequent morning. Efforts were made to locate snail feces on a range of host-plant species at each site. Snail feces were transferred from leaves into sterile microcentrifuge tubes using sterile forceps. Leaf microbes were sampled by applying a sterile swab to both leaf surfaces. Two *Auriculella ambusta* snails were also collected from the Puu Hapapapa station (Figure 1) and transported along with host leaves in a container so that the gut could be dissected under laboratory conditions.

DNA extraction, PCR amplification, and sequencing

Genomic DNA from feces, leaf swabs and the *Auriculella ambusta* gut were extracted using a commercially available kit (MO-BIO PowerSoil) following the manufacturer's instructions. Negative control PCR/extraction reactions were run with sterile swabs that had not come into contact with the leaf surface.

PCR reactions were run in duplicate and targeted the nuclear ITS1 region of fungus as well as the V4 region of the bacterial 16S rRNA using thermal cycler programs and PCR primers as in Smith and Peay (2014). All samples were PCR amplified using fusion primers that consisted of a locus specific priming site at the 3' end, the 'a' or 'b' Illumina adapter at the 5' end and, in the case of the a-adapter primer, an error-correcting Golay barcode in between (Caporaso *et al.*, 2011). PCRs were conducted in 25 µl reactions using 1× Phusion® Hot Start Flex mix (New England Biolabs, Massachusetts), primer A (0.2 µM), primer B (0.192 µM) and gDNA (~5 ng). PCR products were visualized on 1.25% agarose gels and duplicate positive reactions were combined and made equimolar using

SequalPrep™ Normalization plates (Invitrogen, New York). All fungi and bacteria libraries were subsequently pooled, cleaned using a SPRI plate (Beckman Coulter, California) and Sera-Mag Speed-beads (FisherSci, Pittsburgh) in an amplicon:bead ratio of 1.8:1, and quantified on a Qubit fluorometer (Invitrogen) using the dsDNA HS assay. Fungi and bacteria amplicons were then combined in 3:2 ratio (as per the recommendation of; Smith & Peay, 2014) and were finally subject to quality control on a Bioanalyzer Expert 2100 High Sensitivity chip (Agilent Technologies, California) and qPCR to determine cluster density before sequencing.

Sequencing was undertaken at the University of Hawaii, Genetics Core Facility using the Illumina MiSeq platform with the MiSeq Reagent v3 chemistry (Illumina) that enables 300bp paired-end reads. Three primers were used for each amplicon sequenced, one for each sequencing direction and for the sample index ID. Raw paired end reads are available in NCBIs SRA under accessions SAMN03019997 - SAMN03020200.

Sequence processing

Full processing pipeline commands are available online in the supplementary material, but briefly: FASTQ files were quality checked (S2) and forward and reverse reads merged (PEAR; Zhang *et al.*, 2013). Paired reads were assigned to samples (Caporaso *et al.*, 2010) and then dereplicated, chimera screened (UCHIME; Edgar *et al.*, 2011) and clustered at 97% (UPARSE; Edgar, 2013). Taxonomy was assigned using the Wang method (MOTHUR; Schloss *et al.*, 2009) against either the Greengenes database (for bacteria) or a modified UNITE database for fungi augmented with non-target outgroup taxa (refer Supplemental Scripts).

Data analyses

Apart from the mixed-effects model analyses, which were conducted in PRIMER-6 (Clarke & Warwick, 2005), data were analyzed in R using the packages vegan (Dixon, 2009), MASS (Venables & Ripley, 2002), indicspecies (De Cáceres & Legendre, 2009) and were visualized with ggplot2 (Wickham, 2009). Full scripts are available in the supplementary materials. Libraries were rarefied to 2,000 reads and samples with less than 2,000 reads were discarded. Samples were square root transformed to down-weight the influence of excessively abundant reads and used to calculate a Bray-Curtis dissimilarity matrix (Bray & Curtis, 1957). Correlation between fecal and leaf matrices were assessed using a Mantel test (Mantel, 1967). The influence of different factors on variance were then visualized by NMDS ordinations and modeled using PERMANOVA (Anderson, 2005) under a reduced model. Due to the imbalance of some of the sampling levels, a type III (partial) sums of squares was used. Individual OTUs that were significantly associated with a particular factor were subsequently identified using indicspecies (De Cáceres & Legendre, 2009).

Results

Sampling results

A total of 102 snail feces/phyllosphere pairs were sampled from Puu Hapapa, Palikea, and from adjacent sites at Kahanahaiki and Pahole (Table 1). The snails were collected from a diverse range of host-plant species (Table 1) including the exotic species *Psidium cattleianum* (strawberry guava) and *Schinus terebinthifolius* (Christmas berry) sampled because they periodically serve as non-native tree snail host-plants. A fecal/phyllosphere pair was also collected from plastic flagging tape, on which snails are occasionally found.

Sequencing results

The mean number of fungal reads (± sd) was 18,777 ± 568 per sample and for bacteria reads was 9,435 ± 303. Four fungal samples and eleven bacterial samples had < 2,000 reads and were removed from subsequent analysis. Total richness was high with 7,376 fungal OTUs and 3,967 bacteria OTUs being detected after removal of singletons and rarefication of samples. Microbial communities followed a log-normal distribution with a long tail with only 10 fungal and 12 bacterial OTUs contributing more than 1% of total reads (Figures 2a and 2b). The β diversity between all samples was highly diverse (Bray-Curtis dissimilarity ± sd: fungi = 0.85 ± 0.07, bacteria = 0.73 ± 0.09).

Taxonomic assignment of OTUs

At higher taxonomic resolutions the bacteria OTUs are mostly identifiable using our methods, with 86.5% of bacteria assigned to an order and 67.7% a family, compared to fungus, for which 63.4% OTUs could be assigned an order and 47.3% a family. At taxonomic scales such as genus, assignments were at 38.4% for fungal and 32.61% for bacterial reads.

Factors that structure microbial beta diversity

The community composition of microbes was structured by sample type (feces/leaf), geographic locations from which samples were taken, and taxonomic identity of the tree host (Table 2). Samples taken from the host plant *Mersine lessertiana*, which occurs across the three major sampling locations, were also analysed and both geographic location and sample type remained significant factors ($p<<0.5$) that explained sample variance in both bacteria and fungi (Supplementary tables 1a and 1b). Furthermore, when analyses are constrained to the three plant host orders that were abundant across all sites it is the case that geographic location, sample type and plant host order remain significant factors, and geographic location remains the greatest factor that determines variance (Supplementary tables 1c and 1d). Whether leaves were from native or exotic host-plants was not significant ($p>0.05$). For fungi, location explained a greater component of variation than the other factors (Figure 4). By contrast, location, host-plant and sample type were largely equal components of variation for bacteria communities (Figure 4)..

Does fecal assemblage resemble leaf assemblage?

To determine whether snails were selective in their diet we used indicator species analysis and identified that no fungal OTUs were statistically associated with leaves and two OTUs (order Chaetothyriales) were associated with feces and not leaves (Table 3). However, there were no OTUs that occurred exclusively on either feces or leaves. The β diversity of fungal OTUs detected in feces correlates positively with that of the phyllosphere (Mantel test, $r = 0.58$, $p=0.001$) suggesting that both are likely to be structured by similar determinants. The β diversity of bacteria leaf and fecal OTU assemblages are also positively correlated, although to a lesser extent (Mantel test, r = 0.41, p=0.001) and do have OTUs that are significantly associated with either leaves (orders: Actinomycetales, Cytophagales and Saprospirales) or feces (Acidobacteriales, Enterobacteriales, Chthoniobacterales; Table 3b). Bacterial OTU_2 (Enterobacteriaceae) was the second most abundant bacterial OTU detected in the entire dataset (Figure 2), has a likelihood of 93% of occurring in feces, but only a 15% chance of occurring in the phyllosphere (Table 3).

Dissection experiment

Because snail feces are nutrient rich and moist, they likely provide an attractive substrate for environmental microbes. To determine the extent to which fecal microbial composition reflects gut composition, as opposed to exogenous colonization, two *Auriculella ambusta* were dissected and their gut contents compared to the leaf and fecal samples. Our dissection experiment showed that the majority of fungal sequencing reads (>60%) were shared between the gut, leaf and feces, supporting the hypothesis that these phyllosphere microbes are passaged through the gut and detected in feces (Figure 5).

Discussion

What determines microbial composition of Achatinella diet?

Achatinella mustelina has the largest natural distribution (~24 km; Holland & Hadfield, 2002) within the genus, and the strongest determinant of fungal and bacteria community composition was geographic location within the snail's range (Table 2). As has become the *de facto* rule for microbial biogeography in general (Hanson *et al.*, 2012), both geographic distance and environment have been shown to play a role in structuring Hawaiian phyllosphere microbes. Our results are concordant with previous studies using both culture-based techniques (Baker *et al.*, 1979; Marsh, 1966), and culture-independent techniques (Zimmerman & Vitousek, 2012), to demonstrate geographic patterning of microbial communities across spatial gradients in the Hawaiian Islands.

Whereas previous studies of the Hawaiian phyllosphere considered a maximum of three host species (Baker *et al.*, 1979; Marsh, 1966, Zimmerman & Vitousek, 2012), we include measures of among-species variance here reflecting the diverse range of *A. mustelina* host-plants. Host-plants vary in morphology and biochemistry, and are therefore a selective substrate in the composition of microbial communities (Whipps *et al.*, 2008). In other studies, host ecotypes have been shown to affect community composition more powerfully than geographic location (Cordier *et al.*, 2012), which is a pattern that extends up to a global scale (Redford *et al.*, 2010). A study of the tropical phyllosphere on Barro Colorado Island found that host-plant identity explained 56% of the variance among hosts of fungal epiphytes (Kembel & Mueller, 2014). However, although significant, host-plant identity was not the strongest explanatory factor in our study. This might be a property of the microbes that are abundant on the leaves of plants on which *A mustelina* feed. For example *Methylobacterium*, which were a dominant bacterium in this study, have been shown to be structured by location more so than host identity and form similar communities across sympatric but unrelated host-plant species (Knief *et al.*, 2010). Alternatively, the snails might have a homogenizing effect on the phyllosphere community (discussed below).

Does snail fecal composition correlate with phyllosphere composition?

One objective of the present study was to assess the extent to which the microbial composition of snail feces resembled that of the phyllosphere in which the snails occurred, in order to determine if the snails were indiscriminately feeding on microbes or were feeding selectively. Almost all OTUs detected in the phyllosphere were also detected in feces, and only a few OTUs were indicators for feces or phyllosphere communities (Table 3). Furthermore, the dissection experiment of *Auriculella ambusta* confirmed that OTUs detected in the feces and phyllosphere were also found within the gut. In contrast to patterns observed with other consumers of hyphae (Jørgensen *et al.*, 2005), here there is no evidence that *A. mustelina* specialize in consuming any particular fungal or bacterial species present on leaf surfaces, and they can instead be considered true generalists that consume a wide range of microbes.

Our results suggest that snails are not ‘picky eaters’. The indicator species analyses found no microbes that were exclusive to either feces or leaves and that there were few microbes that were more likely to be associated with either feces or leaves (Table 3). There is also considerable overlap in microbe identity found in gut contents, feces and leaves (Figure 5). However, the community frequency distributions also appear to be skewed by the digestive process (Figure 3 and Table 2). The extent to which dietary composition is preserved through digestion has been investigated with predators of large multicellular organisms, and while the diet's composition remains constant throughout digestion for some predators (Bowles *et al.*, 2011; Murray *et al.*, 2011) this is often not the case (Deagle *et al.*, 2013; 2010). Therefore, with a generalist consumer of complex microbial communities such as *A. mustelina* it is unlikely that the community frequency distribution will be maintained through the process of digestion.

Diversity and Composition of Microbes in feces and phyllosphere

The diversity of the microbial environment in which *A. mustelina* occurs is concordant with other recent studies of the tropical phyllosphere. The estimated (rarefaction) number of OTUs for fungal communities, 274 ±6, is slightly greater than that detected in non-surface sterilized leaves of *Metrosideros polymorpha* on Hawai'i Island which varied from 223 to 258 OTUs per rarefied sample (Zimmerman & Vitousek, 2012), and comparable to the Barro Colorado phyllosphere study: 279 ±6 (excluding OTUs with <10 reads; (Kembel & Mueller, 2014). The OTU distributions of both bacteria and fungi conformed to log normal distributions (Figure 2a, 2b), although bacterial distributions were characterized by greater dominance by fewer OTUs, which has been observed in a previous study of co-occurring soil fungi and bacteria (Hartmann *et al.*, 2012).

The most common fungal classes detected in the present study were the Dothidiomycetes, Eurotiomycetes and Sordariomycetes, which is consistent with other investigations of the fungal phyllosphere (Kembel & Mueller, 2014). Fungi from the order Xylariales were also ubiquitous, with three OTUs from the genus *Pestalotiopsis* totalling 6.87% of reads (OTUs 3, 5, 6). *Pestalotiopsis* species and many of the other fungi that were discovered, such as *Khuskia*, are plant specialists and are common plant endophytes in the tropics (Kembel & Mueller, 2014; Baker *et al.*, 1979), but other abundant OTUs, such as OTU_1 (2.01%), assign to highly cosmopolitan and saprobic taxa such as *Cladosporium* (Bensch *et al.*, 2010). While many of these OTUs can be identified as taxa that are commonly observed in the phyllosphere, there remain a considerable number of unidentified OTUs. This lack of taxonomic resolution points towards large geographic gaps in mycological research in Oceania and contrasts with previous inferences from culture-based studies that the Hawaiian phyllosphere consists of globally cosmopolitan species (Baker *et al.*, 1979).

Several bacterial OTUs were observed across all samples. Many of these OTUs were from the subphylum Gammaproteobacteria (OTU_1, Oceanospirillales; OTU_1050, Enterobacteriaes and OTU_4, Alteromonadales), which comprised 17% of reads. Of the Gammaproteobacteria the Enterobacteriales (e.g. OTU_2) were most abundant in fecal samples (Table 3), but these OTUs were also discovered on leaf surfaces. It is not unusual to find Enterobacteriaceae species in the phyllosphere (Hunter *et al.*, 2010; Lopez-Velasco *et al.*, 2011), which can be fairly widely distributed (Redford & Fierer, 2009) and the present study highlights the role that small invertebrates might play in occurrences of these bacteria. The Rhizobiales were ubiquitous in the present study and are frequently observed in the phyllosphere (Redford *et al.*, 2010; Delmotte *et al.*, 2009); some can fix nitrogen (e.g. *Beijerinckia*) and many can metabolise C_1 molecules (e.g. Beijerinckia and Methylobacteriaceae), which are a product of plant growth metabolism (Kutschera, 2007). The Alphaproteobacteria were also significant components of the phyllosphere and fecal samples. For example, OTUs 12 and 258 from the diverse order Sphingomonadales, known for the ability to metabolise complex polymers, were also ubiquitous (Redford *et al.*, 2010; Delmotte *et al.*, 2009). Therefore, although the present study does not corroborate Baker et al. (Baker *et al.*, 1979) in their inference the Hawaiian phyllosphere consists of cosmopolitan microbes, it does agree that the Hawaiian phyllosphere consists of functional groups of fungi and bacteria that commonly occur throughout the phyllosphere at a global scale.

Presence of tree snails: a common factor that determines microbe communities, a direction for future research

Animals, including snails, have been shown to alter the community structure of microbes on which they feed (Poulsen & Boomsma, 2005; Rollins *et al.*, 2001; Aizenberg-Gershtein *et al.*, 2013; Silliman & Newell, 2011; Sieg *et al.*, 2013). Snails rasping the surface of leaves can influence biosphere community succession and nutrient cycling, and may alter antimicrobial barriers of plants such as the wax layer and antimicrobial compounds therein (Yadav *et al.*, 2005; Lindow & Brandl, 2003). Mucus secreted during terrestrial gastropod locomotion, know as the slime trail, has been shown to have selective antimicrobial properties (Kubota *et al.*, 1985; Iguchi *et al.*, 1985; 1982). A third potentially important factor in determining arboreal microbial community structure could be that tree snail feces recycle, deposit, and fertilize fungal spores back into the phyllosphere. This process may play an as yet undocumented role in determination and maintenance of microbial community structure. The fungal phyllosphere is presumably horizontally inherited (Osono

& Mori, 2003) and tree snails could be a significant component in the transfer of fungus to recently budded leaves.

Achatinelline tree snails are frequently observed clustered on native host-plants, and only rarely observed on exotic species (Hadfield, 1986). These associations are not readily explained by plant traits *per se*, since host-plants vary widely in terms of stature, chemistry, and leaf surface characteristics, spanning multiple taxonomic classes. For this reason, it had long been hypothesized that phyllosphere microbial community composition would differ among host-plants that had evolved in Hawaii over millions of years, and those introduced within the last century. However, surface swabs and snail feces sampled from exotic host-plant taxa, and even plastic flagging tape, did not differ significantly. Plants that do not serve as snail hosts were not sampled in this study, so inferences about the role of snails in structuring their microbial environment may be a fruitful direction for future research.

Conservation implications

Although Hawaiian tree snails had been known to feed on microbes, the composition of these microbial communities had previously not been characterized. Determining the identity and distribution of the most abundant microbe lineages therefore provides the first baseline data for monitoring changes in the food-web structure of *A. mustelina* and provides information regarding candidate species of fungi and bacteria that might be isolated to complement existing efforts to safeguard snails via *ex situ* propagation (Kobayashi & Hadfield, 1996). The affects of abrupt diet changes on the immediate health and long-term fitness of *A. mustelina* is an area that warrants further research, but the present study offers an effective approach to understand the composition of their microbial diet.

Conclusions

The present study used high-throughput MiSeq sequencing determine if microbial community structure varies across the habitat range of the endangered tree snail *A. mustelina*. By comparing fecal samples to matched leaf samples we also addressed whether snails are selective feeders, and found that this species tends to be a generalist feeder, and that the microbes consumed vary with location and host-plant identity. The current method of safeguarding these snails against extinction is to relocate them to predator-proof enclosures in concert with *ex-situ* breeding. The outcomes of these conservation strategies are considerably enhanced through having determined the composition of the microbial communities the snails depend upon in their native habitat.

Acknowledgements

We are grateful to Susan Alford and the staff of the Hawaiian Tree Snail Conservation Lab for assistance in the field and laboratory, and for putting up with the crappy job of fecal sampling and preparation. We also thank Sarah Stuart, Stephanie Joe, and David Sischo for their field expertise and assistance. This project was funded through the U.S. Army cooperative agreement W9126G-11-2-0066 with Pacific Cooperative Studies Unit, University of Hawaii through the Pacific International Center for High Technology Research and NSF award #1255972 to ASA.

Supplementary data, including scripts used to demultiplex, cluster and analyze data are available online.

References

Aizenberg-Gershtein Y, Izhaki I, Halpern M. (2013). Do Honeybees Shape the Bacterial Community Composition in Floral Nectar? *PLoS ONE* 8:e67556

Anderson MJ. (2005). PERMANOVA. Permutational multivariate analysis of variance, a computer program. Department of Statistics, University of Auckland.

Baker GE, Dunn PH, Sakai WS. (1979). Fungus communities associated with leaf surfaces of endemic vascular plants in Hawaii. *Mycologia* 71:272.

Barnett A, Redd KS, Frusher SD, Stevens JD, Semmens JM. (2010). Non-lethal method to obtain stomach samples from a large marine predator and the use of DNA analysis to improve dietary information. *J Exp Mar Biol Ecol* 393:188–192

Bensch K, Groenewald JZ, Dijksterhuis J, Starink-Willemse M, Andersen B, Summerell BA, *et al.* (2010). Species and ecological diversity within the *Cladosporium cladosporioides* complex (*Davidiellaceae, Capnodiales*). *Stud Mycol* 67:1–94.

Bowles E, Schulte PM, Tollit DJ, Deagle BE, Trites A. (2011). Proportion of prey consumed can be determined from faecal DNA using real-time PCR. *Mol Ecol Res* 11:530–540.

Bray JR, Curtis JT. (1957). An ordination of the upland forest communities of southern Wisconsin. *Ecol Monogr* 27:325.

Brown DS, Jarman SN, Symondson WOC. (2011). Pyrosequencing of prey DNA in reptile faeces: analysis of earthworm consumption by slow worms. *Mol Ecol Res* 12:259–266.

Caporaso JG, Kuczynski J, Stombaugh J, Bittinger K, Bushman FD, Costello EK, *et al.* (2010). QIIME allows analysis of high-throughput community sequencing data. *Nat Methods* 7:335–336.

Caporaso JG, Lauber CL, Walters WA, Berg-Lyons D, Lozupone CA, Turnbaugh PJ, *et al.* (2011). Global patterns of 16S rRNA diversity at a depth of millions of sequences per sample. *Proc Natl Acad Sci USA* 108 Suppl 1:4516–4522.

Chiaverano, LM, Holland BS. (2014) Impact of a predatory invasive lizard on the endangered Hawaiian snail *Achatinella mustelina:* a threat assessment. *Endanger Species Res* 24:115-123

Clarke RK, Warwick MR. (2005). *Primer-6 Computer Program*. Natural Environment Research Council, Plymouth.

Cordier T, Robin C, Capdevielle X, Desprez-Loustau M-L, Vacher C. (2012). Spatial variability of phyllosphere fungal assemblages: genetic distance predominates over geographic distance in a European beech stand (Fagus sylvatica). *Fungal Ecol* 5:509–520.

De Cáceres M, Legendre P. (2009). Associations between species and groups of sites: indices and statistical inference. *Ecology* 90:3566–3574.

Deagle BE, Chiaradia A, McInnes J, Jarman SN. (2010). Pyrosequencing faecal DNA to determine diet of little penguins: is what goes in what comes out? *Conserv Genet* 11:2039–2048.

Deagle BE, Kirkwood R, Jarman SN. (2009). Analysis of Australian fur seal diet by pyrosequencing prey DNA in faeces. *Mol Ecol* 18:2022–2038.

Deagle BE, Thomas AC, Shaffer AK. (2013). Quantifying sequence proportions in a DNA-based diet study using Ion Torrent amplicon sequencing: which counts count? *Mol Ecol* 13:620–633.

Delmotte N, Knief C, Chaffron S, Innerebner G, Roschitzki B, Schlapbach R, *et al.* (2009). Community proteogenomics reveals insights into the physiology of phyllosphere bacteria. *Proc Natl Acad Sci USA* 106:16428–16433.

Dixon P. (2009). VEGAN, a package of R functions for community ecology. *J Veg Sci* 14:927–930.

Edgar RC. (2013). UPARSE: highly accurate OTU sequences from microbial amplicon reads. *Nat Methods* 10:996–998.

Edgar RC, Haas BJ, Clemente JC, Quince C, Knight R. (2011). UCHIME improves sensitivity and speed of chimera detection. *Bioinformatics* 27:2194–2200.

Finkel OM, Burch AY, Lindow SE, Post AF, Belkin S. (2011). Geographical location determines the population structure in phyllosphere microbial communities of a salt-excreting desert tree. *Appl Env Microb* 77:7647–7655.

Hadfield MG. (1986). Extinction in Hawaiian achatinelline snails. *Malacologia* 27:67–81.

Hanson CA, Fuhrman JA, Horner-Devine MC, Martiny JB. (2012). Beyond biogeographic patterns: processes shaping the microbial landscape. *Nat Rev Microbiol* 10:497–506.

Hartmann M, Howes CG, VanInsberghe D, Yu H, Bachar D, Christen R, *et al.* (2012). Significant and persistent impact of timber harvesting on soil microbial communities in Northern coniferous forests. *ISME J* 6:2199–2218.

Holland BS, Cowie RH. (2009). Land snail models in island biogeography: a tale of two snails *. *Am Malacol Bull* 27:59–68.

Holland BS, Hadfield MG. (2002). Islands within an island: phylogeography and conservation genetics of the endangered Hawaiian tree snail *Achatinella* *mustelina*. *Molecular Ecology* 11:365–375.

Holland BS, Hadfield MG. (2007). Molecular systematics of the endangered O'ahu tree snail *Achatinella mustelina*: Synonymization of the subspecies and estimation of gene flow between chiral morphs. *Pac Sci* 61:53–66.

Holland BS, Chock T, Lee A, Sugiura S. (2012).Tracking behavior in the snail, *Euglandina rosea*: First evidence of preference for endemic versus biocontrol target pest species in Hawaii. *Am Malacol Bull* 30:153-157.

Hunter PJ, Hand P, Pink D, Whipps JM, Bending GD. (2010). Both leaf properties and microbe-microbe interactions influence within-species variation in bacterial population diversity and structure in the lettuce (*Lactuca species*) phyllosphere. *Appl Env Microb* 76:8117–8125.

Iguchi SM, Aikawa T, Matsumoto JJ. (1982). Antibacterial activity of snail mucus mucin. *Comp Biochem Physiol A Comp Physiol* 72:571–574.

Iguchi SM, Momoi T, Egawa K, Matsumoto JJ. (1985). An N-acetylneuraminic acid-specific lectin from the body surface mucus of African giant snail. *Comparative Biochemistry and Physiology Part B: Comparative Biochemistry* 81:897–900.

Jumpponen A, Jones KL. (2009). Massively parallel 454 sequencing indicates hyperdiverse fungal communities in temperate *Quercus macrocarpa* phyllosphere. *New Phytol* 184:438–448.

Jørgensen HB, Johansson T, Canbäck B, Hedlund K, Tunlid A. (2005). Selective foraging of fungi by collembolans in soil. *Biol Lett* 1:243–246.

Kembel SW, Mueller RC. (2014). Plant traits and taxonomy drive host associations in tropical phyllosphere fungal communities. *Botany*. 92: 303-311

Kim M, Singh D, Lai-Hoe A, Go R, Abdul Rahim R, Ainuddin AN, *et al.* (2012). Distinctive phyllosphere bacterial communities in tropical trees. *Microb Ecol* 63:674–681.

Knief C, Ramette A, Frances L, Alonso-Blanco C, Vorholt JA. (2010). Site and plant species are important determinants of the *Methylobacterium* community composition in the plant phyllosphere. *ISME J* 4:719–728.

Kobayashi SR, Hadfield MG. (1996). An experimental study of growth and reproduction in the Hawaiian tree snails *Achatinella mustelina* and *Partulina redfieldii* (Achatinellinae). *Pac Sci* 50:339–354.

Kubota Y, Watanabe Y, Otsuka H, Tamiya T, Tsuchiya T, Matsumoto JJ. (1985). Purification and characterization of an antibacterial factor from snail mucus. *Comp Biochem Physiol C, Comp Pharmacol Toxicol* 82:345–348.

Kutschera U. (2007). Plant-associated methylobacteria as co-evolved phytosymbionts: a hypothesis. *Plant Signal Behav* 2:74–78.

Lindow SE, Brandl MT. (2003). Microbiology of the Phyllosphere. *Appl Env Microb* 69:1875–1883.

Lopez-Velasco G, Welbaum GE, Boyer RR, Mane SP, Ponder MA. (2011). Changes in spinach phylloepiphytic bacteria communities following minimal processing and refrigerated storage described using pyrosequencing of 16S rRNA amplicons. *J Appl Microbiol* 110:1203–1214.

Mantel N. (1967). The detection of disease clustering and a generalized regression approach. *Can Res* 27:209–220.

Marsh DH. (1966). Microorganisms of the Phyllosphere, with Particular Reference to Fungi , Occurring on the Dominant Plants of Biogeoclimatic Zones of the Hawaiian Islands. MSc: University of Hawaii.

Morris C, Monier J, Jacques M. (1998). A technique To quantify the population size and composition of the biofilm component in communities of bacteria in the phyllosphere. *Appl Env Microbiol* 64:4789–4795.

Murray DC, Bunce M, Cannell BL, Oliver R, Houston J, White NE, *et al.* (2011). DNA-based faecal dietary analysis: a comparison of qPCR and high throughput sequencing approaches. *PLoS ONE* 6:e25776.

Müller T, Ruppel S. (2013). Progress in cultivation-independent phyllosphere microbiology. *FEMS Microbiol Ecol* 87:2–17.

O'Rorke R, Lavery SD, Wang M, Nodder SD, Jeffs AG. (2013). Determining the diet of larvae of the red rock lobster (*Jasus edwardsii*) using high-throughput DNA sequencing techniques. *Mar Biol* 161:551–563.

Oehm J, Juen A, Nagiller K, S N, Traugott M. (2011). Molecular scatology: how to improve prey DNA detection success in avian faeces? *Mol Ecol Res* 11:620–628.

Osono T, Mori A. (2003). Colonization of Japanese beech leaves by phyllosphere fungi. *Mycoscience* 44:437–441.

Parsons KM, Piertney SB, Middlemas SJ, Hammond PS, Armstrong JD. (2005). DNA-based identification of salmonid prey species in seal faeces. *J Zool* 266:275–281.

Pompanon F, Deagle BE, Symondson WOC, Brown DS, Jarman SN, Taberlet P. (2012). Who is eating what: diet assessment using next generation sequencing. *Mol Ecol* 21:1931–1950.

Poulsen M, Boomsma JJ. (2005). Mutualistic fungi control crop diversity in fungus-growing ants. *Science* 307:741–744.

Redford AJ, Bowers RM, Knight R, Linhart Y, Fierer N. (2010). The ecology of the phyllosphere: geographic and phylogenetic variability in the distribution of bacteria on tree leaves. *Environ Microb* 12:2885–2893.

Redford AJ, Fierer N. (2009). Bacterial succession on the leaf surface: a novel system for studying successional dynamics. *Microbiol Ecol* 58:189–198.

Remén C, Krüger M, Cassel-Lundhagen A. (2010). Successful analysis of gut contents in fungal-feeding oribatid mites by combining body-surface washing and PCR. *Soil Biol and Biochem* 42:1952–1957.

Rollins F, Jones KG, Krokene P, Solheim H, Blackwell M. (2001). Phylogeny of Asexual Fungi Associated with Bark and Ambrosia Beetles. *Mycologia* 93:991–996.

Schloss PD, Westcott SL, Ryabin T, Hall JR, Hartmann M, Hollister EB, *et al.* (2009). Introducing mothur: open-source, platform-independent, community-supported software for describing and comparing microbial communities. *Appl Env Microbiol* 75:7537–7541.

Sieg RD, Wolfe K, Willey D, Ortiz-Santiago V, Kubanek J. (2013). Chemical defenses against herbivores and fungi limit establishment of fungal farms on salt marsh angiosperms. *J Exp Mar Biol Ecol* 446:122–130.

Silliman BR, Newell SY. (2011). Fungal farming in a snail. *Proc Natl Acad Sci USA* 100:15643–15648.

Smith DP, Peay KG. (2014). Sequence depth, not PCR replication, improves ecological inference from next generation DNA sequencing. *PLoS ONE* 9:e90234.

Soininen EM, Zinger L, Gielly L, Bellemain E, Bråthen KA, Brochmann C, *et al.* (2013). Shedding new light on the diet of Norwegian lemmings: DNA metabarcoding of stomach content. *Polar Biol* 36:1069–1076.

Thompson IP, Bailey MJ, Fenlon JS, Fermor TR, Lilley AK, Lynch JM, *et al.* (1993). Quantitative and qualitative seasonal changes in the microbial community from the phyllosphere of sugar beet (*Beta vulgaris*). *Plant Soil* 150:177–191.

USFWS (1981) Endangered and threatened wildlife and plants; listing the Hawaiian (Oahu) tree snails of the genus *Achatinella* as endangered species. [Prepared by the U. S. Department of the Interior, U.S. Fish and Wildlife Service]. Federal Register, 46:3178–3182.

Venables WN, Ripley BD. (2002). Modern Applied Statistics with S. Fourth. Springer: New York.

Vorholt JA. (2012). Microbial life in the phyllosphere. *Nat Rev Microbiol* 10:828–840.

Whipps JM, Hand P, Pink D, Bending GD. (2008). Phyllosphere microbiology with special reference to diversity and plant genotype. *J Appl Microbiol* 105:1744–1755.

Wickham H. (2009). ggplot2: elegant graphics for data analysis. Springer: New York.

Yadav RKP, Karamanoli K, Vokou D. (2005). Bacterial Colonization of the Phyllosphere of Mediterranean Perennial Species as Influenced by Leaf Structural and Chemical Features. *Microb Ecol* 50:185–196.

Zhang J, Kobert K, Flouri T, Stamatakis A. (2013). PEAR: a fast and accurate Illumina Paired-End reAd mergeR. *Bioinformatics*.

Zimmerman NB, Vitousek PM. (2012). Fungal endophyte communities reflect environmental structuring across a Hawaiian landscape. *Proc Natl Acad Sci USA* 109:13022–13027.

Figure 1. Sampling locations of snail feces and leaves. Samples were collected from four sites across the Waianae Mountain range on west Oahu, Hawaii.

Figure 2. Rank abundance of dominant OTUs. Figure 2a shows the 39 fungal OTUs and Figure 2b the 47 bacterial OTUs that contributed more than 0.3 % of total sequencing reads.

Figure 3. NMDS plot illustrates how sample type and location structure (A) fungal and (B) bacterial community composition.

Ellipses represent standard error of the mean (95%) for sampling locations illustrate the PERMANOVA findings that mean centroids do not overlap between the three key sites: Puu Hapapa, Palikea and (Pahole+Kahanahaiki). Pahole and Kahanahaiki which lie within 0.94 Km, are indistinguishable. Points are color-coded to indicate sample type, i.e. feces or leaf sample origin. Both fungi and bacteria samples were separated in ordination space by sample type, but location was the most important component of fungal community composition, rather than sample type or host plant identity. Stress values of the ordination are 0.21 (fungi), and 0.17 (bacteria).

Figure 4. PERMANOVA: Estimates of components of variation ($\sqrt{\ }V$).

Location, sample type (feces or leaf) and host plant identity explained over 50% of the community composition variance. Host plant order had a similar affect on community composition for both bacteria and fungi (14.0% and 14.6%). Location was the strongest determinant of fungal composition (23.5% of variance), whereas sample type and location contributed similarly to bacterial compositional structure (19.3% and 19.7%).

Figure 5. Gut dissection experiment demonstrates high overlap of microbial assemblages. Proportion of fungal DNA sequence reads detected in the gut, feces and phyllosphere associated with two *Auriculella ambusta* snails. Values in the overlapping regions refer to the percentage of reads that assign to OTUs detected in more than one sample. Most reads were detected in the union of the gut, feces and leaf samples.

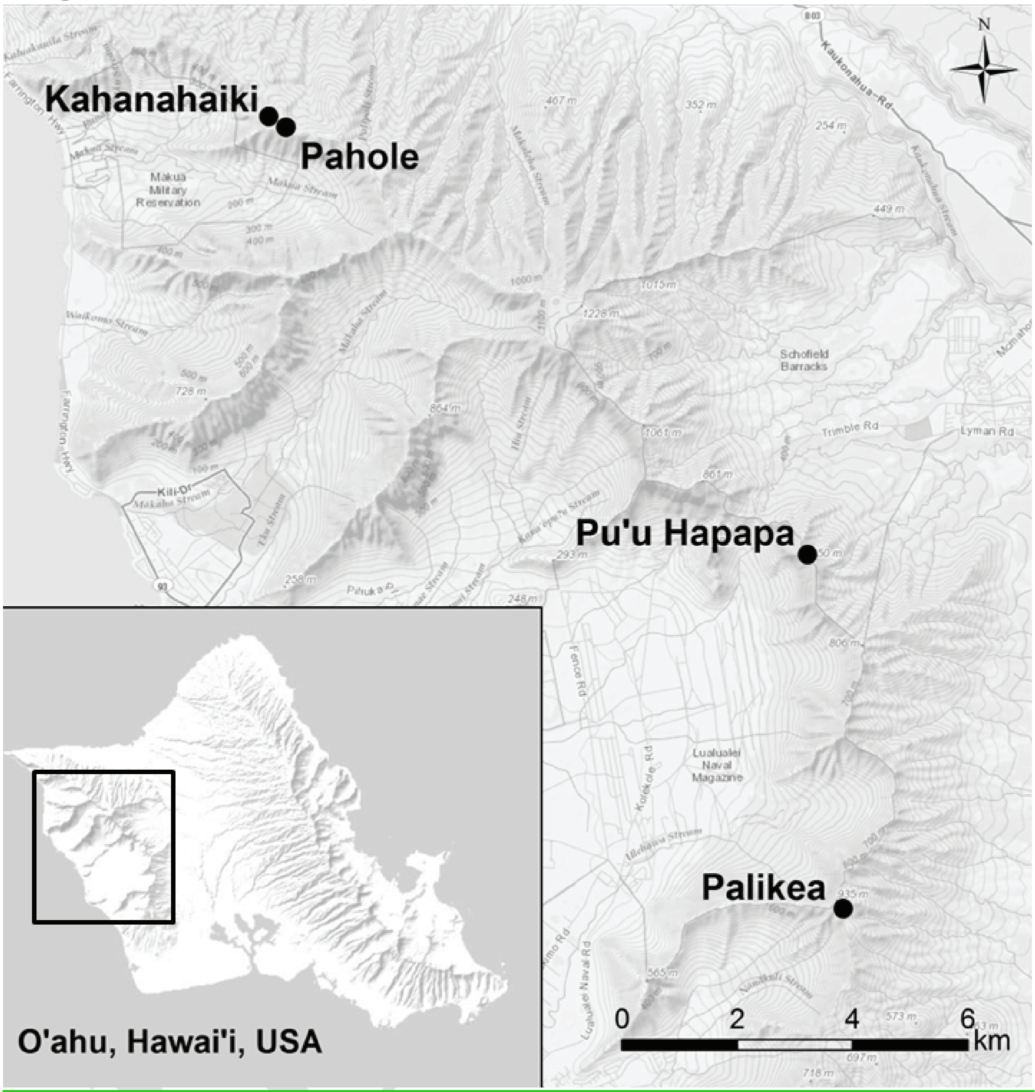
Table 1. Samples collected from locations and host plants. Number and identity of samples collected from each location (rows), organized by host plant species (columns). For each sample, data were collected for fungal and bacterial communities present in snail feces and on leaf surfaces.

Table 2. PERMANOVA for bacterial and fungal diversity (Bray Curtis) across samples. A mixed effects model was used in which sample type and location were fixed and plant host was taken as a random factor. All levels significantly explained variance.

Table 3. OTUs significantly associated with either leaves (a) or feces (b). Rows are filled in if an OTU is significantly associated with either feces or leaves. The “stat” column is the Indicspecies statistic that describes how good an indicator a particular OTU is for a particular combination of levels. “B” is the false

discovery rate, i.e., the likelihood that the OTU will occur in another level. The % column refers to abundance of the OTU in the dataset, value following each taxonomic assignment is a bootstrap statistic indicating the level of confidence in that taxonomic assignment.

Figure 1


Kahanahaiki
Pahole
Pu'u Hapapa
Palikea
O'ahu, Hawai'i, USA
0
2
4
6
km
N
Makua Military Reservation
Schofield Barracks
Lualualei Naval Magazine

Integrated Pest Management of Powdery Mildew and Additional Plant Pest of Endemic Mint in Hawaii

Gabriel Schierman M.S. UH Manoa

Introduction to Native Mint: *Phyllostegia*

Phyllostegia is a genera of flowering mints which belong to the Lamiaceae family. *Phyllostegia* is endemic to Hawaii with 27 known species, five which have become extinct, and twelve species listed on Hawaii's Endangered and Threatened Species Web Site. Native mints in Hawaii are located at upland elevations, along steep shaded slopes, cliffs, ridges and gulches, in wet forest environments. The key focus of conservation of Hawaii native mint, are to protect current populations and establish new populations. The Oahu Army Natural Resources Project, (OANRP), can successfully germinate and propagate endangered native mints in the greenhouse at Schofield Barracks. However, when transplanted into the field, plant material becomes overwhelmed with powdery mildew and other pathogens. The three species of *Phyllostegia* currently grown at Schofield Barracks consist of; *P. Hirsuta*, *P. Mollis* and *P. Kaalaensis.*

P. hirsuta (Fig. 1a), is a perennial herb with erect subshrub or vines, the stems are densely covered with coarse hairs, these mints are located along steep surfaces at elevations of (640 to 3,943 m) in mesic forest of the Wai'anae and Ko'olau Mountains of Oahu. *P. hirsuta* is currently listed as critically endangered according to the Hawaii Natural Heritage Ranking; with a 146-172 observed plants and estimated population of no more than 300 plants. *P. Mollis* (Fig. 1b), is perennial herb, with dense hairy leaves, oval in shape and range from 10 to 24 cm in length, located along various moist elevated (450 to 1830 m) mountain ranges on Oahu, Maui, and Molokai. Currently, *P. Mollis* grows in the Waianae Mountains, and Walopai Gulch in East Maui, currently these mints are listed as critically endangered with less than 50 suspected wild individuals. *P. Kaalaensis* (Fig. 1c), is a perennial herb with white flowers, oval leaves that which range between 5 to 13 cm in length, these plants are located along vertical surfaces at elevations of 374 to 796 m, in mesic forest of the Wai'anae mountain range. *P. Kaalaensis* is currently listed as critically endangered with a suspected population of no more than 45 plants on state and private lands.

Fig. 1a *P. Kaalaensis*

Fig. 1b *P. Mollis*

Fig. 1c *P. Hirsuta*

Permits, Location and Timeline

State and federal permits were required to conduct research on endangered mints in Hawaii. Research for native mint restoration is conducted at the University of Hawaii at Manoa, plants and infected material where provided by OANRP at Schofield Barracks. No wild plants where collected, and tests were conducted at the University of Hawaii at Manoa, in the St. John building room #304. Submission for state and federal began February 2013. In April the state plant permit was approved; the federal permit however was not improved until August, 2013. By October, 2013 approximately 40 plants were transported from OARNP to the University of Hawaii at Manoa, and stored in the greenhouse at Magoon Research Station. The plants were propagated and planted in potting soil, and lacked powdery mildew and other wild pathogens. At the beginning of November, powdery mildew infected leaves were collected from the field crew, unfortunately the sample size, age and lack of fungal growth was insufficient to culture on plant tissue at UH Manoa. December, 2013 powdery mildew samples were collected and inoculated onto living plant tissue. By late January, 2014, powdery mildew inoculation took and infected plants were separated by rooms in greenhouse at Magoon Research Station. Collections were additionally gathered in field surveys additional pathogens were collected from wild tissue (not entire plants), and adjacent soil.

Introduction to Pathogens and Pests of Native Mints

Wild populations of these three native mint species have struggled to reach and maintain maturity stage. Transplanted seedling and propagated plants become overwhelmed with powdery mildew and other pathogens. Unfortunately, there are few fungicides which are approved for use in natural forested areas. Furthermore, we do not want to introduce such compounds into relatively intact natural areas. Therefore, several avenues of research where used to gain a better understanding of the underlying problem.

The first avenue of research was to Identify and describe powdery mildew found on native mint. Powdery mildews are species specific and are likely to have been imported on a commercially imported species. Identification of powdery mildews is difficult to determine and is a slow process since reproduction stages of mature fungi are needed for identification, and additionally these sexual stage does not occur naturally in Hawaii's tropical climate. Identification from powdery mildew grown on native mint therefore was conducted using molecular methods.

Alternative pathogens from roots, stems and leaves of native mint have been cultured and isolated from stressed, dead or dying plants. Initial inoculations of these pathogens to healthy plants may have occurred from introduction of wild tissue and soil provided by OANRP, or naturally within the Magoon Greenhouse.

Identification of insect pests and the damage associated with their behavior, on native mints will be described. Shortly after the initial transportation of native mints from Schofield Barracks to Manoa, various insect populations began to invade and destroy healthy plant tissue.

Introduction Powdery Mildew on Endemic Mints

Powdery mildew is an obligate pathogen, which requires a living host for survival and is rarely known to kill its host. However, under heavy infestations this pathogen may overwhelm the host and cause the shedding of leaves. Powdery mildew does not need water in order to germinate, although the preferred environment for this pathogen; are wet, humid and shaded. Cultures of this pathogen exist only on living plant material and no artificial media exists for mass production and isolation. All three Phyllostegia spp. are susceptible to powdery mildew, and the OANRP crew have witnessed high infestation in the wild (Fig. 2a). High infestation of potted plants at UH Manoa, also occur and symptoms appear approximately 6 weeks post inoculation (Fig. 2b), while young propagate plants may only take a few weeks (Fig. 2c)

Fig. 2a Wild Infection

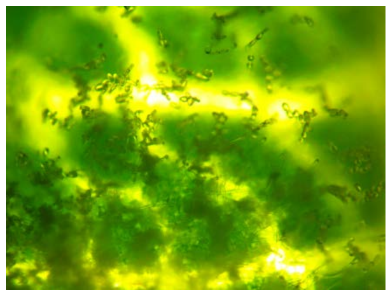


Fig. 2b Conidia on Leaf

Fig. 2b Propagated with early infection

No seeds have been germinated from the lab at UH Manoa, propagation of plants have primarily came from one *P. Kaalaensis,* due to the infrequent amount of available plants and the health of alternative plants. Propagation is at an approximate success of on <90%, when rooted in water, and then a success of approximately 50% when transplanted in potting soil, depending on the species of mint. The mint is slow growing and is prone to various pathogen and insect damage, at developing stages plants appear to be highly susceptible.

Inoculation of Powdery Mildew

Powdery mildew at Magoon Research Station was purposely applied to 20 plants of all three species, from wild leaves of *P. Mollis* using a paint brush. Inoculation of powdery mildew in the lab was first attempted in November, 2013, with a rate application of $1x10^8$, the application of these spores did not germinate onto the leaf tissue of 7 attempted plants. Since water can inhibit germination and even kill spores, dry application using infected leaves and transplanting spores via a paint brush has been the continued method of application. Powdery mildew was observed and maintained on various stages of plant development, however continuous cultivation of powdery mildew was maintained on propagate mint that was rooted in water (Fig. 3)

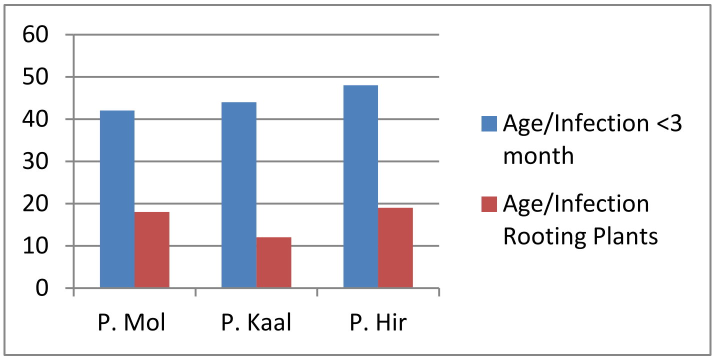


Fig .3 Approximate Infection of Powdery Mildew

After inoculation

Identification of Powdery Mildew: Materials and Methods

Powdery mildew is species specific; identification of this pathogen can limit possible alternative hosts and effect control methods. We determined that the spores were oval to fusifom in shape, and were produced in short chains, appressoria were nipple to lobed; fibrosin bodies were not present in the cytoplasm of spores. Based on characteristics that we gathered we can say that a possible genera is Erysiphe and excluded genera are; Sawadaea, Podophaera, Pleochaeta, Phyllactinia, and Leveillula. No teleomorphic stage for the identification of powdery mildew was observed, and manipulating alternative environmental conditions for growing mildew on media were ineffective.

With the lack of morphological characteristics available to separate species of mildew, the use of molecular analysis was used as a tool for identification of. PCR primers were designed to work on a wide range of powdery mildew based on the internal transcribed spacers (ITS), and sequence the obligate pathogens. The primers developed for this sequencing came from literature provided by Cunnington et al (2001), the primers are useful for nucleotide sequencing of rDNA of major clades of the Erysiphe fungi, instructions for PMITS primers came from the, “Center for Invasive Species and Ecosystem Health at the University of Georgia,” bugwood.org. Forward and reverse primers were purchased and contructed by IDT at UH Manoa in May, 2014. Powdery mildew leaves were prepped for amplification using PMITS (Single-Round PCR) in expected amplification base pair range of 700-800.

PCR for powdery mildew of native mint was conducted in July, negative control was spearmint without powdery mildew, there was no positive control and samples of infected native mint came from infected leaves of *P. Mol*. The results (Fig. 4a) a strong band indicated amplification, and the sequence was blasted against NCBI data base, strongly matching (98%) *to Neoerysiphe galeopsidis* (Fig. 4b).

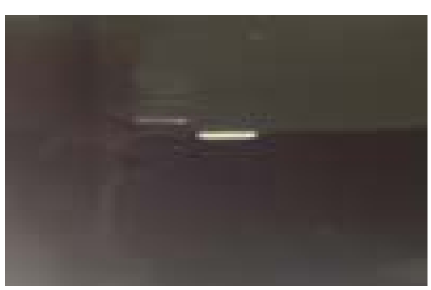


Fig. 4a Amplification Band

Neoerysiphe galeopsidis genes for 18S rRNA, ITS1, 5.8S rRNA, ITS2, 28S rRNA, partial and complete sequence, specimen_voucher: KW:58378F, MUMH 4676

Sequence ID: gi|295047726|dbj|AB498948.1|Length: 1520Number of Matches: 1

Related Information

Range 1: 1 to 610GenBankGraphicsNext MatchPrevious Match

Score	Expect	Identities	Gaps	Strand
1046 bits(566)	0.0	598/613(98%)	3/613(0%)	Plus/Plus

Fig. 4b Blast Results

Powdery Mildew: Results and Discussion

Neoerysiphe galeopsidis is recorded on 12 families of plants mainly all of which are in the *Lamiaceae* family, with 432 fungi-host combinations according to the USDA Fungus-Host Database. Of these hosts it is most likely interact with *Stachys* species in Hawaii. Phylogenetic analyses suggest that the lineages of Hawaiian mints are from the genus *Stachys*, however powdery mildew strains within a species can differ markedly as to host range so literature can be of little use when trying to deal with specific situations. This would be particularly true when dealing with and introduced powdery mildew that is now established in an environment with potential new hosts. Cross-inoculations have been conducted with alternative hosts that are marketed in nurseries and stores, with no success.

Powdery Mildew Pathogenicity: Materials and Methods

N. galeopsidis pathogenicity test have been unsuccessful, due to an un-consistent amount of plant species and inoculum, and rate of powdery mildew infection. The concept of the experiment was to count the number of leaves that shed from an inoculated plant, measure the diameter of the spot, and test thresholds of powdery mildew for each species of native mint. When sufficient inoculated plants are available the experimental design will be as follows: A complete block design, with 3 plants of each species and one of each species as a control without inoculated leaves. Inoculation can be transferred onto clean tissue of native mints at all levels of development, and pathogen development is more sudden at early stages of development or when plants are being rooted.

Excellent information can be ascertained from germinating conidia, quality spores are needed and a procedure to insure germination needs to be developed. Germ tubes from conidia occur in high populations on Bacto Water Agar, with adequate powdery mildew germination rates can be assessed and fungicides and application rates can be observed. When trying to reproduce germination for fungicide in vitro for test purposes problems arose with consistent germination and a proper method for producing germinating spores is still being developed.

Among the three species of *Phyllostegia,* it has been observed that *P. Kaalaensis* responds best to propagation, with rooting and transplanting into soil at a 70% success rate. Propagation of *P. Mollis* and *P. Kaalaensis* are difficult with soft stems, and large broad leaves, propagation final success on average is approximately 40%. Culture of powdery mildew is now being collected and established from rooting *P. Kaalaensis* in water which can be seen from (fig. 2b).

Fungicide Trial of Powdery Mildew: Materials and Methods

Powdery mildew has a delayed infection, and speculated but un-known environmental stimulates trigger heavy and sudden infestation. After heavy exposure to powdery mildew most leaves become frail and begin to shed. Using a systemic fungicide seems to be the best approach for management of powdery mildew for wild populations. Four systemic fungicides where selected for control powdery mildew all three levels of infestation. One plant at each level for each treatment, three plants total for each treatment, and the control was no treatment. The first level was inoculated plants with no previous symptoms of powdery mildew. The second levels were plants with slight infestations. The last levels were heavily infested leaves. Plants were selected in similar plant height and vigor among each treatment (Fig. 5a). Treatment was conducted at Magoon Research Station, and leaf count and a scale of powdery mildew symptoms ranged from 1-4 (Fig. 5b)

Fig. 5a Fungicide Test

Fig. 5b PM Infection

Systemic fungicides were Cleary 3336 (Thiophane Methyl), Bayleton (Triadimeton), Heritage Azoxystrobin) and Rally (Myclobutinal). Leaf count, pathogen rating, and plant height were measured pre-treatment on September 5th, 2014. Measurements rates of each treatment was calculated from the MSDS, and sprayed to cover each leaf. Each week new leaves were counted and pathogen rating were documented, new pathogen growth was noted on either new leaves or old. The fungicides used are not eradicates and should be used as a preventive measure, although some early pathogen exposure may be controlled, extensive mildew growth will not be controlled with these fungicides. Results of fungicide trial (Fig. 6), showed that Cleary 3336 and Bayleton was effective in reducing symptoms of mildew even of some heavy infected leaves, and were effective of preventing mildew on new leaves.

New leaves were counted each week (Fig. 6) and monitored for mildew; old leaves were rated for any decrease in symptoms. Within the first week 5 plants had died from unknown reasons. 1 control plant with a rating of 4, 2 Rally treated plants with a rating of 1 and 0, a Bayleton treatment with a rating of 1. Bayleton treated plants, appeared to have some preventative control of mildew on heavily infected leaves. As of October 10th, 2014, All the Rally plants have died. Of the two remaining plants treated with Cleary 3336, one plant that initially had a rating of 4, has no symptoms of powdery mildew, 20 new leaves developed and 4 of the 8 leaves that were heavily infected have no symptoms and remain on the plant, the other plant from this treatment had a rating of 0, has 12 new leaves, and 0 infection. Bayleton as a treatment also has two remaining plants, one which had an initial rating of 1, has 14 new leaves 0 infection and 3 out the 3 heavily infected leaves remain on the plant, the other plant had a rating of 0, has 6 new leaves and no infected leaves. The control plants had similar results as the treatments, with 2 surviving plants approximately 12 new leaves each, all heavily infected leaves on one plant shed, and currently there is no mildew, the other plant was originally rated as 0 and remains infection free.

Fig. 6

This fungicide test will be replicated several times and conducted at various stages of plant growth and infection, at this current junction of the project, it appears that Cleary 3336 and Bayleton may produce the best treatment, however Rally as a treatment needs to be revisited since all three plants died before any results could be produced, once again from unknown reasons. Treatment will also be conducted in water solutions for propagated plants where control of plants and the pathogens may provide greater results. Fungicide test may also be conducted on water agar, if proper germination methods is developed.

Introduction to *Fusarium* : Soil and Dead Plant tissue

At the beginning of accepting plants from OANRP Ampelomyces and Fusarium were discovered; this fungus is a parasite of powdery mildew and a potential disease control. The samples collected were too contaminated to isolate either the Fusarium or any other fungi. The observations show that it is possible that both the Ampelomyces could act as a control of powdery mildew and that Fusarium could be one of the primary pathogens. Death to some native mints were sudden (Fig. 7a) with or without mildew symptoms, each time this sudden death occurred cultures of Fusarium was present, the roots of these plants were short and rotted out (Fig. 7b). Fusarium was produced on water agar plates, single spores from these cultures were then transplanted onto 10% v-8 nutrient agar. After a week colonies of *Fusarium subglutinas*, where collected, stored in agar tubes (Fig. 8), and used for pathogenicity test.

Fig. 7a Sudden Death

Fig. 7b Root-rot

Fig. 8 *Fusarium subglutinas*

***Fusarium:* Pathogenicity Test**

Due to a lack a plants at the time pathogenicity test for Fusarium was conducted on two plants and is now being replicated with more inoculated plants and controls present. However, from one preliminary observation and the most recent pathogenicity test root-rot and death have occurred. Of the most recent test one of the two mints has died within 5 weeks (Fig. 9 a-e). During the preliminary test conducted with the first observation of Fusarium all three plants died from root-rot within three months.

Fig. 9a Week 1

Fig. 9b Week 2

Fig. 9c Week 4

Fig. 9d Week 5

Fig. 9e Week 5

Fusarium certainly seems to contribute to the death of native, with more testing conclusive expectations can help predict plant damage and management for controls of this pathogen. Control of soil of pathogens is problematic, especially when treatment is in forested areas and more research and testing will need to be made if control for this pathogen is necessary.

Introduction to Insect Damage

Whiteflies, aphids, mealy bugs, mites, and bark beetles have been treated with insecticide (Marathon). When native mint is treated with Marathon; whiteflies, aphids, broad mites, and mealy bugs are completely controlled. However, populations of spider mites take over and cause significant damage to new and old leaves. The bark beetles (Fig. 10a) have only been found burrowed in several plants, the holes they leave are obvious (Fig. 10b) and usually there are less than ten beetles on each plant. The interesting part about these beetles is they tend to farm fungi within host plants, and from each sample, Fusarium was found from cutting taken from the stem, and beetle which was cultured on water agar and then moved onto v-8 agar. The Fusarium has not yet been identified or used within a pathogenicity test, although the Fusarium does not appear to be *F. subglutinas*, this observation and test will be conducted shortly.

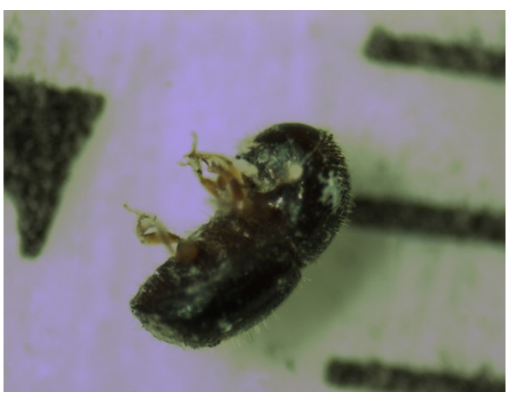


Fig. 10a Beetle from Native Mint

Fig. 10a Holes from Bark Beetle

Although insect damage is not the focus of this project, insect damage in the greenhouse is a continuous struggle and is severe threat to native mint development. The red spider mite is a difficult pest in the greenhouse, infestations occur when broad insecticides are used. Mitcides or simply soap water mix can temporarily solve infestation levels, but populations quickly reemerge. Since Marathon has not controlled spider mites; it is very possible that the broad insecticide is killing beneficial predator mites. There is a commercial available predatory mite *Phytoseiulus* persimilis which is reared sold in various states; however this biological control is not available for purchase in Hawaii. Rearing methods and the use of predatory mites is being approached with an *In vivo* cage design, described for mass rearing of predator mites by a biological control unit within the USDA (Morales-Ramos and Rojas 2014). The design for this part of the project will be discussed in the next section.

Introduction to Biological Control

For the forest environment in which native mint is being reestablished, natural predators of various pests and pathogens are void or lack population levels to manage severe outbreaks. Ideally management of plant pathogens or pests is to produce a program that continuously allows for plant damage to remain under threshold levels, at least for a large portion of the population. From what has been observed during this experiment it appears there are various pests that severely limit plant development. It is likely that all the pests that persist on native mint are exotic to the environment, and when plants are reintroduced, there is little to no protection for the transplants to thrive. The goal and concept of biological control for the forest environment, is to discover natural occurring predators that are present on the plants and found within the environment. However, do to some limitations of available resources and permit restrictions some commercial products have been included and are being evaluated at UH Manoa.

Biological Control: Powdery Mildew

Ampelomyce were first observed from the powdery mildew collected from OANRP, unfortunately, these samples were heavily infested with various microorganisms, and isolation of this mildew parasite could never be isolated. The culturing of this pathogen has the potential of being an effective management tool, and should be closely examined.

Bacillus subtilis was purchased from Ko'olau Farmers, and is commercial product produced by Serenade. *B. Subtilis* is a bacterium most commonly found in the soil and plant undergrowth, and are believed to stimulate plant growth through nutrient cycling, and some strains are believed to attack various fungi (Jacobsin, 2004). According to the label, Serenade controls a broad range of fungal pathogens and is used on ornamental crops with black spot, downy mildew, grey mold, late blight, early blight, fire blight, powdery mildew and others. Test have not yet been conducted with this product, but will be conducted with other microbes to test for pathogen control and as a soil enrichments for root stimulation.

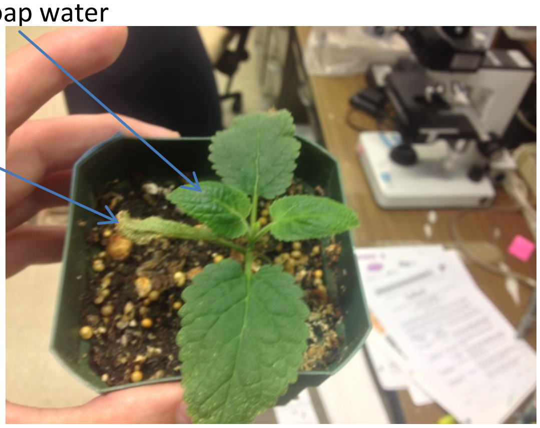
Yeast Isolated from powdery mildew samples are cultures on acidic potato dextrose agar, and yeast morphological agar. The yeast has yet to be identified but exists from many of the sampled leaves that have shed from powdery mildew. Yeast can have benefits in disease control and from the repeated isolation from powdery mildew samples there appears to be a close association between the two organisms, it is possible that yeast can reduce the production of conidia (Urquhart, Menzies et al. 1994).

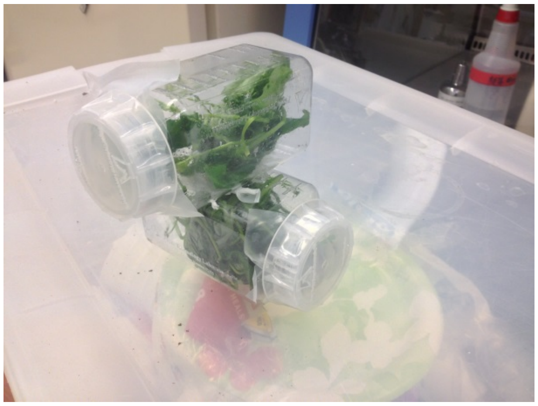
This biological control has been tested on various mint samples infected with powdery mildew, with no current results. Test of this isolated yeast will continue to be examined.

Trichoderma has been collected and cultured from all parts of the native mints. This fungus is present in all soils and is most commonly found on the roots of many plants, and is purposely mixed into many potting, for stimulated plant growth. Originally it was believed the fungi being isolated came from contamination introduced via the potting soil, however when stem samples were taken from the bark beetle *Trichoderma* was occurring on all sections of the plant tissue. Samples have since been extracted from leaf tissue, soil, roots and stems. This fungi may have benefits of foliar fungi (Chang, CHANG et al. 1986), and so far only been tested as a root stimulant. For the present test with *Trichoderma*, cultures grown on v8 agar and then introduced and stirred in potting soil, the mint plants that have already rooted are then planted in the inoculated soil. No observations indicate advanced plant growth, although a survival appears to be slightly higher with transplanted mint in inoculated potting mix than that of the control. This part of the projected needs to be repeated and root size will be measured in the next few weeks. Additional testing will be to apply *Trichoderma* to leaves and stems of mint infected with powdery mildew, as a possible foliar control of the pathogen.

Biological Control of Insects: Red Spider Mites

Red spider mites cause severe damage to native mint in the greenhouse, causing dry brittle leaves (Fig. 11). Rearing of predator is being conducted within a cage system(Chang, CHANG et al. 1986). The cage system is designed to mass rear predatory mites, within separate containment spaces (Fig. 12). Although the cage system for this experiment is small, it has primarily been constructed to observe if predatory mites and there population control of spider mites. The design connects two containers with a tunnel, one container with a plug that can be detached, so that one container traps and then later be opened for mites to move into the next compartment.   Since leaves from lima bean are adequate for spider mites to feed on for considerable time, full plants are not necessary for rearing purposes. A papaya leaf with heavy infestation of spider mites is originally placed in one compartment, along with a leaf of light infestation. When infestation of spider mites decline, the other compartment is opened and allowing for spider mites to travel to new leaves. The idea being that the compartment with the original infestation will have higher populations of predatory mites, which I can then later use for mass rearing on live tissue.





Concluding Remarks

Fig. 11 Red Spider Mite Damage

Fig. 10a Predator Mite Rearing Cage

Powdery Mildew has been identified although alternative hosts in the wild are suspected to be primary hosts of inoculums have yet to be discovered. Powdery mildew can limit plant growth although; it is strongly believed there are many limiting factors contributing to native mint death. Devices are available to monitor powdery mildew levels and may be helpful in determining proactive control on powdery mildew. Pathogen test will continue to be conducted on native mints at various stages of growth and more fungicide trials will conclude the best chemical control to powdery mildew. Insect infestations are severe in early developed at Magoon Research Station, and can be controlled with repeated treatments. Providing developmental microorganisms may increase root and plant growth, but have yet to be shown from present experiments. A synergism between fungi is going to be observed soon, along with accumulated pest inoculations, testing for early and late plant thresholds. There have been various problems with achieving enough plants to test, and from mass propagation and some recently acquired native mints, many tests can be conducted and much more conclusive treatments and cultural practices can be acquired.

Work Cited:

Chang, Y.-C., et al. (1986). "Increased growth of plants in the presence of the biological control agent Trichoderma harzianum." Plant disease **70**(2): 145-148.

Morales-Ramos, J. A. and M. G. Rojas (2014). "A Modular Cage System Design for Continuous Medium to Large Scale In Vivo Rearing of Predatory Mites (Acari: Phytoseiidae)." Psyche **2014**: 8.

Urquhart, E., et al. (1994). "Growth and biological control activity of Tilletiopsis species against powdery mildew (Sphaerotheca fuliginea) on greenhouse cucumber." Phytopathology **84**(4): 341-351.

Assessment of the short and long-term population dynamics of endangered flora native to Hawaii that are managed by the Oahu Army Natural Resources Program

U.S. Army Garrison Hawaii: 2014 Activity Report

Principal Investigator: PI: Orou Gaoue and Kasey Barton
GA: Lalasia Bialic-Murphy
University of Hawaii at Manoa
Botany Department
3190 Maile Way, Room 101
Honolulu, HI 96822
Phone: (808) 443-7484
E-mail: lalasia.murphy@gmail.com

1 - 2014 Activities

1.1 - Quarter 2: January-March

The primary activities that were conducted are:

1) A field data collection monitoring protocol was developed for *S. obovata.*
2) Gear was organized in preparation for the field season.
3) The appropriate State of Hawaii T&E permits were written and field dates were scheduled with Oahu Army Natural Resources managers.
4) An extensive literature review of all relevant studies was conducted, including - rare species population demography, matrix modeling methodologies and associated physiological mechanisms hypothesized to underpin the study species ability to withstand ecological alterations and environmental stressors.
5) R code was written for the following:
    5.1 - Project the long-term population growth rate (i.e. stage structured stochasticity analysis)
    5.2 - Assess the relative importance of key life stages on long-term population dynamics (i.e. stochastic elasticity analysis)
    5.3 - Project the number of individuals in the mature stage class in 20 years (stochastic transient analysis)
6) A protocol was developed to test the effect of drought and soil moisture availability on population dynamics for *S. obovata* (refer to the final report for details).
7) Annual life stage vital rates data were collected for the *D. waianaeensis* Kal-C site. Specifically, data on individual height to apical meristem, basal diameter, reproductive status, vigor, and rooting substrate were recorded for a sub-set of

tagged plants. In addition, the total number of individuals in each life stage was counted.

1.2 - Quarter 3: April-June

The primary activities that were conducted are:

1) Annual life stage vital rates data were collected for the *S. obovata* MMR-G and *C. dentata* MMR-A sites. Specifically, height to apical meristem, basal diameter, reproductive status, vigor, and rooting substrate were recorded for a sub-set of tagged plants. In addition, the total number of individuals in each life stage was counted at the *C. dentata* site.
2) A list of predetermined abiotic variables was monitored at the *S. obovata* study site, including: monthly precipitation, percent canopy cover, and understory species diversity and percent cover of native and exotic vegetation.
3) The June gravimetric soil water content (GSWC) data were collected at the *S. obovata* MMR-G population, which took a total of six field days. These data will be used for the control greenhouse experiment that will be conducted in the spring of 2015 to evaluate the affect of climate change projections (focusing on precipitation patterns) on population growth rate.
4) *S. obovata* propagation material was collected (300 seeds) and processed for storage. The collected seeds will be used as the source material for the greenhouse experiment in Spring 2015.
5) To monitor rodent depredation on *D. waianaeensis* fruits two motion sensing cameras were installed at the study site during the 2014 peak fruiting season. Cameras were aimed directly at two patches of mature plants (two and four plants in each patch) and were left out for a total of fifteen trap nights. The only visitation recorded was by black rats. All photographs capturing black rats were during the night. Black rats were photographed climbing *D. waianaeensis* plants and interacting with mature fruit each night of the study.
6) The 2014 field monitoring data was entered into an excel database.
7) Preliminary analysis of the population dynamics of the *C. dentata* and *D. waianaeensis* populations were conducted, including: long-term population growth rate, expected number of mature individuals in 20 years, and long-term elasticity analysis.
8) Preliminary study results of the *C. dentata* MMR-A population were presented at the Island Biology conference (a copy of the PowerPoint presentation is attached).

Island Biology: Submitted Abstract

Using a stage-structured model to evaluate the population dynamics of an island endemic shrub, *Cyrtandra dentata*

Introduced feral ungulates, invasive weeds, and rodents are primary factors that drive habitat degradation, disrupting ecosystem and population level dynamics. This is particularly true across island state ecosystems. Mitigating these threats has been widely adopted as an initial step, taken by conservation practitioners, to stabilize rare plant populations. Surprisingly, evaluation of this strategy to reverse negative trends has been primarily qualitative. Furthermore, when rare species stabilization efforts fail, the environmental parameters driving population decline are rarely identified. We studied the demography of *Cyrtandra dentata*, an endangered Oahu endemic shrub, to elucidate the primary drivers of population dynamics and predict long-term persistence. Preliminary analysis suggests that the long-term population stability has been achieved. Furthermore, we found that the dynamics of the population is the most sensitive to the survival of the mature individuals, followed by the growth of seedlings and immature plants. However, additional years of data need to be collected to assess the effect of environmental stochasticity on the population trajectory. In addition, transient analysis should be conducted to help prioritize short-term management actions and to fully evaluate the risk of ultimate extinction.

1.3 - Quarter 4: July-September

The primary activities that were conducted are:

1) The August gravimetric soil water content (GSWC) data were collected at the *S. obovata* MMR-G population, which took a total of two field days. These data will be used for the control greenhouse experiment that will be conducted in the spring of 2015 to evaluate the affect of climate change projections (focusing on precipitation patterns) on population growth rate.
2) A detailed three-year research outline was written (refer to the attached document).

2 - 2015 Field Data Collection Schedule

1) Fecundity Data Collection:
   - 1.1 - *D. waianaeensis* - Implement in February and will be monitored once a month until the end of the fruiting season
   - 1.2 - *S. obovata* - Implement in March and will be monitored once a month until the end of the fruiting season
2) *D. waianaeensis* Rodent Depredation:
   The study will be conducted in the peak fruiting season, which will most likely be in February or March
3) Demographic Data Collection:
   - 3.1 - *D. waianaeensis* - February
   - 3.2 - *S. obovata* vital rate data collection - April
   - 3.3 - *C. dentata* - June
4) *S. obovata* greenhouse climate change and drought tolerance study:
   Will be conducted in quarter 3

3 - 2015 Data Analyses and Synthesis

1) R code will be written for the following:
   - 1.1 - Project population growth rate using continuous state variables (i.e. Integral Projection Modeling) for the *S. obovata* study sites.

1.2 - Assess the relative importance of key life stages on short-term population dynamics in a changing environment (i.e. stochastic transient elasticity analysis) for the *D. waiananeensis*, *S. obovata and C. dentata* study sites.

2) *D. waianaeensis, S. obovata and C. dentata* preliminary data analysis and synthesis will be conducted in quarter 4

4 - 2015 Presentations, Conference Schedule and Exams

1) PhD research proposal will be presented in Quarter 1.
2) PhD Oral comprehensive exam will be taken in Quarter 3. The exam will cover the following topics: Quantitative Population Demography, Conservation Biology and Plant Physiology.
3) An abstract will be submitted to the 2015 International Congress for Conservation Biology (ICCB) conference. If accepted, preliminary results of the *D. waianaeensis* study will be presented at the conference in August.

ASSESSMENT OF THE POPULATION DYNAMICS OF ENDAGERED PLANTS NATIVE TO HAWAI'I

Lalasia Bialic-Murphy
Ph.D. Proposal, October 1, 2014
Department of Botany
University of Hawai'i at Manoa

Dissertation Committee
Orou Gaoue
Kasey Barton
Tom Ranker
Tamara Ticktin
Qi Chen

Table of Contents

1 - Introduction

The primary focus of population ecology is understanding species' population dynamics and the environmental parameters and physiological mechanisms underpinning survivorship, growth, and reproduction (i.e., vital rates) (Menges 1990; Morris & Doak 2002). Altered abiotic and biotic environmental stressors (i.e., threats), such as climate change and the introduction of exotic competitors, predators and pathogens, can have long-lasting effects on a species' vital rates and population persistence (Ehrlen 2013).

The influence of species interactions on population growth rate is dependent on which life stages are impacted and the magnitude of effect. Previous studies suggest that the relative importance of life stages on population growth vary systematically by life history. In general, the relative importance of seedling survival and growth on population growth rate is often proportionally greater for short-lived species. Conversely, the effect of changes in the survival of mature plants on population growth rate is often proportionally greater for long-lived species (Silvertown et al. 1996). However, these general patterns do not always hold true, particularly for declining populations that have undergone recent disturbance or active management (Menges 1990; Silvertown et al. 1996). To fully understand the effect of environmental stressors on population dynamics, it is necessary to link the effect of targeted environmental stressors on susceptible life stages to population growth rate.

To date, the primary strategies that are used by conservation practitioners to prevent the loss of biodiversity and manage endangered species are to protect and maintain critical habitat, suppress the obvious biotic threats contributing to population decline and reintroduce rare plant populations into natural areas (Maschinski & Haskins 2012; Soorae 2013). The end goal of these actions is to prevent immediate extinction, achieve and maintain self-sustaining populations and reverse negative population trends (HPPRCC 2011; Maschinski & Haskins 2012). To evaluate if the suppression of primary threats and plant reintroduction will likely result in the desired end goal (such as a targeted population size or self-sustaining population persistence) or if additional management is needed, it is necessary to project the expected future status of a population. Demographic matrix modeling is a key analytical approach that can be used for this purpose.

Demographic modeling can also be a useful tool to evaluate the strength of species interactions, such as exotic herbivores, and anthropogenic abiotic alteration, such as climate change, on population dynamics. For species that occur in extremely altered environments a comparative demographic modeling approach is a particularly useful tool to identify which environmental stressor, if managed, would have the greatest impact on population dynamics.

Understanding the impact of anthropogenic alterations on population dynamics may be especially important to efficiently and effectively manage endangered species native to oceanic island ecosystem for the following reasons: 1) Though anthropogenic alterations, such as the introduction of exotic herbivores and predators, are the dominant drivers of species endangerment globally, the impacts are thought to be more severe for island species (Wilcove et al. 1998). This is in part due to the absence of shared evolutionary history, such as the presence of herbivores and mammals (Gillespie & Clague 2009). With lack of diverse herbivore and predator communities, island plants often have lower mechanistic and physiologic tolerance to the introduction of exotic pests (Gillespie & Clague 2009; Whittaker & Fernández-Palacios 2007). 2) Local island endemics have an elevated risk of extinction due to their geographically limited and numerically small populations, making them more susceptible to habitat degradation (Gilpin & Soule 1986; Menges 1990; Shaffer 1981).

The use of demographic modeling to assess rare plant population dynamics has increased significantly over the last four decades. By 2011 over 90 published population demography studies had been conducted for endangered plants (Crone et al. 2011). The primary focus of these previous studies was to gain a better understanding of basic population dynamics of endangered species and to evaluate the effect of range management (particularly fire and grazing) on population persistence.

Surprisingly, few detailed rare plant demographic studies have been conducted that explicitly link the primary drivers of endangerment of native species on oceanic islands to population dynamics. Furthermore, only four demographic modeling studies have been conducted to evaluate when plant reintroduction can be an effective tool for establishing self-sustaining populations and what factors contribute to successful population establishment and persistence (Bell et al. 2003; Colas et al. 2008; Liu et al. 2004; Maschinski & Duquesnel 2007). Given this, it remains unclear if these commonly used conservation strategies of rare species native to oceanic islands result in the desired end goal.

Hawai‘i is an ideal location to study the ecology of localized island endemic plants and gain a deeper understanding of the effect of species interactions with environmental stressors on population dynamics. The flora of Hawai‘i is characterized as having one of the highest rates of endemism in the world, with an estimate of over 89% of the flowering plant species being endemic (Wagner et al. 1999). In the last four decades Hawai‘i has undergone massive habitat conversion and exponential increase in the introduction of exotic species, resulting in a severe decline of ecosystem function (Cuddihy & Stone 1993). Over 40% of the endemic species native to Hawaii are listed as critically endangered or threatened (USFWS 2012), 99% of which are threatened by multiple anthropogenic alterations (though assessments are primarily based on qualitative assessment and expert opinion) (Wilcove et al. 1998). This severe decline of biodiversity and high level of endangerment has led to Hawai‘i being dubbed the endangered species capital of the world.

For this study I will use demographic modeling to examine the population ecology of endangered plants endemic to Hawai‘i and investigate the effect of key species interactions and abiotic tolerance associated with the endangerment of island plants on population dynamics. I will also use demographic modeling to gain a deeper understanding of when plant reintroduction and the suppression of primary threats are effective strategies to achieve self-sustaining populations and compare conservation management options.

The species selected for this case study are three endangered taxa native to Hawaiʻi, *Cyrtandra dentata* St. John & Storey (Gesneriaceae), *Delissea waianaeensis* Lammers (Campanulaceae) and *Schiedea obovata* (Sherff) W.L. Wagner & Weller (Caryophyllaceae). *Delissea waianaeensis* and *S. obovata* are outplanted populations and *C. dentata* is a naturally occurring population. For each study system, I will project the ambient population dynamics and identify the relative importance of life stages and associated vital rates on population dynamics. Furthermore, I will use a simulation demographic modeling approach to assess the following questions:

1. How does microhabitat heterogeneity affect population persistence of critically endangered plants confined to narrow ecological niches? A case study of an island endemic shrub, *Cyrtandra dentata*.

2. How does fruit depredation by rodents and pollen limitation affect the long-term population growth rate of endangered plants native to island ecosystems? A case study of an island endemic shrub, *Delissea waianaeensis*.

3. How will climate change affect population dynamics of endangered plants native to island ecosystems? A case study of an island endemic shrub, *Schiedea obovata.*

4. For plant reintroductions, are the vital rates of outplanted individuals and the first filial generation different? If so, does the transition from an outplanted to a naturally occurring population affect short and long-term population dynamics?

2 - Overview of Demographic Modeling Techniques

There are several different demographic modeling approaches that can be used to gain insight into various aspects of plant population dynamics.

Demographic modeling can be used to project the long-term population growth rate.

There are several different modeling approaches that can be used for this purpose, unstructured (count based) and structured (stage or age based) models being the most common. An unstructured model requires the least amount of data collection and is the most simplistic. The assumption of this method is that individuals within a population are identical. For many organisms however, there are important differences in the survival, growth and reproduction of individuals. A structured modeling approach is the primary tool used to assess the population dynamics of these "structured" organisms. Structured demographic models also allow for integration of vital rates (i.e., survival, growth, and reproduction) to project long-term asymptotic growth rate (using a stochastic stage structure matrix model) and identify the relative importance of demographic processes on population dynamics (using stochastic elasticity analysis) (Caswell 1989; Morris & Doak 2002). A population growth rate (λ) > 1 indicates a growing population and a λ < 1 represents a declining population.

There are two types of structured models, deterministic and stochastic. An assumption of a deterministic model is a constant environment. To overcome the constraint of this assumption a stochastic modeling approach can be used, allowing for incorporation of environmental variability into population simulations. A detailed description of deterministic and stochastic modeling techniques can be found in Caswell (1989). A primary assumption of structured models is that the population has reached a stable stage distribution (SSD), meaning that there is a constant proportion of plants in each defined life stage over time.

Structured models require dividing the population into discrete state variables, for example seedling, immature and mature life stages. For species that do not have clear biologically significant breaking points, artificial classification is necessary. Creating too few classes, however, can lead to misrepresentation of vital rates and creating too many classes can lead to sample size issues and limited statistical power (Caswell 1989).

For species that do not have clear breaking points (age or life stages), integral projection modeling (IPM) may be a more appropriate modeling technique to use. IPM may also be a more appropriate tool to evaluate population dynamics when working with limited demographic datasets (< 300 individuals) because it reduces the bias and variance of the population projections (Ramula et al. 2009). Similar to structured matrix models, IPM incorporates survival, growth and fecundity to project population dynamics. Unlike a structured model, IPM integrates continuous state variables by incorporating vital rates based on individual plant size rather than as discrete stage or age class mean vital rates. (Easterling et al. 2000).

When evaluating population dynamics it is also important to quantify short-term trends (Fox & Gurevitch 2000; Haridas & Tuljapurkar 2007; Koons et al. 2005). Short-term population level responses to temporal variations in vital rates can deviate from long-term projections, depending on the initial population structure. This is particularly true for a population that is not at, or close to, a SSD. Evaluating short-term trends may be especially important from a management perspective for the following reasons: 1) the timeframe of conservation plans are often predefined, making it important to assess benchmark goals; 2) disturbance (such as fire) and active management (such as threat control) can cause temporal variation in vital rates. These factors can significantly alter population structure, causing it to deviate from a SSD and long-term population projections. Until the affected (or missing) life stages fill in and a SSD has been realized, short-term population growth will depend on temporal shifts in vital rates and the resulting change in population structure. In extreme cases, year-to-year fluctuations in vital rates and the resulting population structure may cause extinction prior to a SSD and asymptotic growth being achieved (Fox & Gurevitch 2000).

To evaluate short-term population dynamics transient analysis can be used to project population structure (i.e., number of individuals within each life stage at a given time) and quantify the risk of short-term extinction. Stochastic transient elasticity analysis can be used to identify which life stages and threat control management actions have the largest proportional effect on short-term population dynamics (Caswell 2007; Fox & Gurevitch 2000; Haridas & Tuljapurkar 2007).

For this research I will use a combination of stochastic stage structured matrix modeling and IPM techniques to project long-term population growth for the study species and simulate how demographic parameters and environmental parameters (i.e., microhabitat heterogeneity, pollen limitation, predation by rodents, climate change and artificial cohort transition of plant reintroduction) influence population growth rate. I will also use transient analysis to evaluate short-term population dynamics of each study system.

3 - Study Question #1: How does microhabitat heterogeneity affect population persistence of critically endangered plants confined to narrow ecological niches? A case study of an island endemic shrub, *Cyrtandra dentata*.

Background and Rationale

Fine-scale habitat heterogeneity can have significant effects on the establishment and growth of the seedling (Harper 1977). The effect of habitat heterogeneity and safe-site availability on seedling establishment is well documented (Dostálek & Münzbergová 2013; Eriksson & Ehrlen 1992; Fetcher et al. 1983). The degree of suitability between substrates can vary dramatically. Substrate with disproportionally greater seedling establishment is often referred to as a "safe-site". Important abiotic characteristics of safe-sites include high light availability (Denslow 1980), suitable substrate characteristics (Dostálek & Münzbergová 2013), low disturbance (Eriksson & Ehrlen 1992), and sufficient water availability (Fetcher et al. 1983). The presence of nurse plants can also be an important determinant of seedling establishment. For example, moss increases localized water and nutrient levels and benefits initial establishment of *Primulina tabacum* (Ren et al. 2010). However, integrative demographic studies that explicitly link fine-scale abiotic characteristics to population persistence are limited. Picó and Riba (2002) determined that a long-lived herb, *Ramonda myconi*, was geographically confined to fine-scale habitat of shady ravines in the Pyrenees and population persistence was highly dependent on temporal variation in precipitation and temperature. García (2003) found that a critically endangered plant, *Borderea chouardii*, was likely geographically restricted to shaded crevices of north-facing limestone due to its incapacity to germinate and survive on other substrates. A detailed demographic study of three isolated populations of a perennial herb, *Petrocoptis pseudoviscosa,* was conducted to evaluate population dynamics and identify the functional traits driving population persistence. For one of the populations, deeper shade and higher humidity were positively correlated with high recruitment and fast growth, relative to the other two populations. The impact of abiotic conditions on vital rates was not, however, an important determinant of long-term population persistence.

With limited knowledge of how habitat heterogeneity and the availability of substrate with relatively higher seedling establishment (i.e., safe-sites) affect population dynamics it remains unclear if these species interactions are important determinants of long-term population persistence.

I propose to conduct a detailed demographic study to gain a deeper understand of how microhabitat heterogeneity affects the persistence of a rare plant confined to a narrow ecological niche. The study system, *C. dentata*, is a critically endangered taxon endemic to Hawaiʻi, confined to the gulches of wet to mesic forest communities (Wagner et al. 1999), often located in close proximity to seasonal waterfalls. Preliminary analysis indicates that seedling establishment on elevated rocky outcroppings is significantly greater than on the soil substrate (L. Bialic-Murphy, unpublished data). The reason for this is unknown but winter rains, which cause pooling of water in the gulch bottom, may be a contributing factor. Identifying the effect of substrate type on seedling establishment and population dynamics is particularly important for effectively managing suitable habitat of *C. dentata* and for selecting appropriate outplanting sites, which will be necessary for delisting this taxon (USFWS 1998).

Material and methods
Study species

Cyrtandra dentata is a federally endangered shrub endemic to the island of Oahu in Hawaiʻi. *Cyrtandra dentata* reaches 1.5 to 5 m at maturity and produces white subumbelliform cymes, 3–9 inch long and the fruit are white ovate berries, 1–2.6 cm long (Wagner et al. 1999). The reproductive biology of *C. dentata* is poorly understood but floral characteristics suggest that it is moth pollinated and fleshy berries are indicative of frugivorous bird dispersal (OANRP 2003b). Flowers and fruit have been collected year round but peak fruiting occurs from September to October (L. Bialic-Murphy, unpublished data). The typical habitat is shady gulch bottoms of mesic to wet forest communities.

Cyrtandra dentata historically spanned the northern Waianae Mountains and the leeward side of the northern Koolau Mountains, from 300–610 m elevation (Wagner et al. 1999). In 1996 it was listed as federally endangered and by 2010, it was restricted to seven geographically isolated locations (USFWS 2012). The primary drivers of its endangerment are predation by feral ungulates, rodents, and slugs, competition by non-native plants, climate change and fires (USFWS 1998).

Study site

The study population is in the Kahanahaiki Management Unit (36 ha), referred to hereafter as Kahanahaiki, which is located in the northern Waianae Mountain Range, on the island of Oahu (21° 32' N, -158°12' W). Kahanahaiki is a tropical mesic forest; composed of a mix of native and exotic flora and fauna. The dominant native canopy species include *Acacia koa, Metrosideros polymorpha, Nestegis sandwicensis, Diospyros sandwicensis, Pouteria sandwicensis, Pisonia umbellifera* and *Antidesma platyphyllum*. The dominant native understory species include *Alyxia stellata, Bidens torta, Coprosma foliosa*, and *Microlepia strigosa*. The exotic canopy species include *Psidium cattleianum* and *Schinus terebinthifolius*. The exotic understory species include *Blechnum appendiculatum, Clidemia hirta, Melinis minutiflora* and *Cyclosorus dentatus* (OANRP 2009). The mean monthly rainfall is 53–227 mm (Giambelluca et al. 2013), and mean daily temperature range is 16–24 °C (Shiels & Drake 2011).

The Kahanahaiki *C. dentata* population is one of the two largest known populations, in both numerical size and demographic structure. The population is located in the main Kahanahaiki drainage, extending from the base of a seasonal waterfall to the north approximately 150 meters (Figure 1). The plants are concentrated in the gulch bottom and along the steep, mossy rock walls.

Map removed to protect rare resources

Figure 1: Location of a single population of *Cyrtandra dentata* in the Kahanahaiki Management Unit, in the northern Waianae Mountain Range of Oahu.

Management history

Since 1995, the Kahanahaiki MU has been actively managed by the Oahu Army Natural Resources Program (OANRP) as part of a larger mitigation effort to offset the potential impact of military training operations on 89 rare plants and animals.

In 1996, OANRP constructed the Kahanahaiki fence for the protection of *C. dentata* and eleven other managed taxa (Figure 1). By 1998, OANRP eradicated pigs from the fenced area and initiated selective weed control directly surrounding the population, targeting known ecosystem-altering vegetation. Since then, OANRP staff has conducted annual ecosystem-level weed control across the study site (OANRP 2009). The goal of fencing and weed control was to limit the direct and indirect threat that pigs and exotic vegetation pose to ecosystem function. Feral ungulates directly impact all life stages of many native and introduced species. In general, native seedlings, saplings, and mature plants increased in frequency and density following fencing and feral ungulates removal (Busby et al. 2010; Cole et al. 2012; Kellner et al. 2011; Loh & Tunison 1999). Exotic vegetation is a primary competitor, invading and displacing native vegetation (Vitousek 1996). Following suppression of top-down effects, the missing life stages (the seedling and small immature plants) started establishing (M. Kiehn, unpublished data).

Data collection
Demographic data

Detailed demographic data collection started in June of 2010. A subset of plants was permanently tagged and will be monitored annually for five consecutive years. The life cycle of *C. dentata* was divided into four discrete life stages: mature (>80cm), large immature (20cm – 80cm), small immature (<20cm) plants, and seedling (less that 2cm). Since there were less than 50 plants in the mature and large immature life stages, all plants in these life stages were permanently tagged to maintain a robust sample size. For the small immature and seedling life stages, a random sample of 50 plants was permanently tagged. Individual plants > 10 cm in height were permanently tagged using OANRP's standard metal tag and wire method. Plants < 10 cm in height were marked using pin flags and metal tags, placed two inches upslope from the plants. Plants growing on the upper gulch walls were excluded from sampling to avoid risk of damaging suitable habitat. Seedlings growing on rocky substrate were marked using florescent-colored buttons, glued to the rocks two inches above each plant.

For each tagged plant, height to apical meristem (when possible), basal diameter, reproductive status, vigor, and rooting substrate were recorded. In addition, the total number of plants in each life stage will be counted the final year of the study. Data were also recorded for a subset of abiotic and biotic environmental parameters including annual precipitation, and percent cover of native and non-native vegetation. These data will be used to investigate how the subset of environmental parameters is associated with temporal variation in vital rates and population dynamics.

Seedling establishment and microhabitat

To calculate the effect of abiotic habitat characteristics on seedling establishment necessary for matrix model simulation, I collected additional field data in 2014. First, I classified the substrate into two categories, talus rocky outcroppings and soil. Then, I installed 1m x 1m quadrats directly underneath ten randomly selected mature plants. For each plot, data were recorded for the total number of seedlings established and percent cover (based on ocular estimation) of each substrate type. These data will be used to calculate the expected and observed seedling establishment rate on each substrate type. I assumed that the ratio of seeds that fell and germinated on each substrate type would be directly proportional to the percent cover of each substrate type if there were no differences in substrate suitability.

Data Analysis

Matrix projection model

Assessing population dynamics, using a structured modeling approach, first requires using the collected demographic data to construct yearly Lefkovitch transition matrices using the following formula (Caswell 2001):

$$\mathrm{n}(t+1) = \mathbf{A}\mathrm{n}(t) \quad (1)$$

where the vector $\mathrm{n}(t)$ represents the number of plants in four discrete life stage at time t and $\mathbf{n}(t+1)$ represents the number of plants in each life stage the following year. The matrix, $\mathbf{A}$, is composed of 8 matrix elements (a_{ij}), which represent the transition probability of the *s* (seedlings), *si* (small immature), *sl* (large immature), *m* (mature) life stages from time t to t+1. The matrix, $\mathbf{A}$**,** is parameterized in terms of the probability of survival σ, the probability of growing to the next stage class γ, and the fertility term φ_m of each life stage. The fertility term is the product of fecundity, the probability of fruiting and the germination and establishment rate. For *C. dentata* the fertility term will be calculated by dividing the number of seedlings counted by the number of mature plants the previous year.

$$
\boldsymbol{A} = \begin{pmatrix} \sigma_s(1-\gamma_s) & 0 & 0 & \sigma_m\varphi_m \\ \sigma_s\gamma_s & \sigma_{si}(1-\gamma_{si}) & 0 & 0 \\ 0 & \sigma_{si}\gamma_{si} & \sigma_{li}(1-\gamma_{li}) & 0 \\ 0 & 0 & \sigma_{li}\gamma_{li} & \sigma_m \end{pmatrix}
$$

The dominant eigenvalues of each of these yearly transition matrices, **A,** represent the long-term population growth rates, λ. A population with $\lambda < 1$ indicates a declining population, a population growth rate = 0 indicates a stable population and a $\lambda > 1$ indicates a growing population.

In order to incorporate the effects of environmental stochasticity on population dynamics I will use a stochastic stage-structured modeling approach. The form of this model is as follows:

$$
\mathrm{n}(t+1) = \mathbf{A}(t)\mathrm{n}(t) \tag{2}
$$

where **A**(*t*) is a random population projection matrix selected at each year *t* from the pool of four yearly matrices with equal probability. This model is similar to the deterministic model developed in eqn (1) with the main difference that the in eqn (2), the matrix **A** is temporally variable. The stochastic growth rate, λ_s, will be calculated by simulation using 100 000 iterations following Tuljapukar *et al* (2003):

$$
\log\boldsymbol{\lambda_s} = \lim_{t\to\infty}\left(\frac{1}{t}\right)\log\left[P(t)/P(0)\right] \tag{3}
$$

where $P(t)$ is the population size, i.e., the sum of the elements of $n(t)$ at a given time t.

To identify the relative importance of life stages on the long-term population growth rate, λ, I will conduct elasticity analysis. The elasticity of λ to perturbation of matrix elements a_{ij} will be calculated following Caswell (1989), which is:

$$
e_{ij} = \frac{a_{ij}}{\lambda}\frac{\partial\lambda}{\partial(a_{ij})} = \frac{\partial(\log\lambda)}{\partial(\log a_{ij})} \tag{4}
$$

To simulate how the removal of optimal microhabitat substrate type would alter population dynamics I will construct an additional set of yearly transition matrices, $\mathbf{A_f}$, by changing values of the fertility element, F, in the ambient yearly transition matrices, **A.** The fertility element will be adjusted by the percent decrease of seedling establishment on the sub-optional substrate type. I will then use these yearly transition matrices to simulate how removal of the optimal seedling establishment "safe-site" substrate would affect population dynamics and the results will be compared to the ambient projections.

Short-term population dynamics

The yearly transition matrices of the ambient (i.e., field vital rate data) and removal of optimal microhabitat treatments will also be used to project the expected number of mature individuals in 20 years of the two treatments using eqn (1). The solution of the deterministic model eqn (1) which projects the size structure of the population at a given time *t,* with an initial size structure n(0), can be written as follows:

$$\mathrm{n}(t) = \mathbf{A}^{t}\mathrm{n}(0) \qquad (5)$$

To account for the effect of environmental variability, the expected number of individuals $\mathrm{n}(t)$ will be iteratively calculated by simulation, multiplying the number of individuals at given time (t), starting with n(0), by the matrix $\mathbf{A}(t)$. Since the objective is to project the expected number of mature individuals in 20 years, n(20), after the final year of the study I will use the observed population size during the last monitoring period as the starting condition n(0). I selected 20 years as the projection timeframe because it is a standard timeframe used to assess short-term changes in population size and growth rate (Caswell 2007).

To identify the relative importance of life stages on the short-term population growth rate stochastic transient elasticity analysis will be conducted following (Caswell 2007), which is:

$$n_i(t)\ to\ \theta_j = \frac{\theta_j}{n_i(t)} \frac{\mathrm{d}n_i(t)}{\mathrm{d}\theta_j} \tag{6}$$

4 - Study Question #2: How does fruit predation by rodents and pollen limitation affect the population dynamics of endangered plants native to island ecosystems? A case study of an island endemic shrub, *Delissea waianaeensis*.

Background and rationale

Two of the primary threats implicated in the decline of species native to oceanic islands are rodents and the loss of native pollinators (Carpenter 1976; Pender et al. 2014; Shiels & Drake 2011). Rodents are the most pervasive predators of native plants in island ecosystems (Ruffino et al. 2009; Towns et al. 2006; Traveset et al. 2009), primarily impacting reproduction (Shiels et al. 2014). Shiels and Drake (2011) found that in mesic forest communities in Hawai‘i black rats consume > 44% of the available fruits of common native and non-native species. Rodents also consume vegetative plant material, which may impact plant fitness. Pollen limitation affects plant fertility, reducing seed set and decreasing genetic diversity (Burd 1994).

While the influence of fruit and seed predation by rodents on susceptible life stages has been extensively studied, only one study has assessed the influence of exotic rodents at the population level (Pisanu et al. 2012). The results of that study indicated that rodent suppression, in some cases, can positively influence the probability of plant population persistence. Furthermore, while the impact of pollen limitation on plant fitness has been well examined only a limited number of studies have linked pollen limitation to population growth rate (Bierzychudek 1982; Ehrlén & Eriksson 1995; García & Ehrlén 2002; Parker 1997), and most of those found that pollen limitation did not impact plant population persistence.

I propose to investigate the affect of pollen limitation and fruit depredation by black rats (*Rattus rattus*) on population dynamics of a critically endangered island endemic shrub, *Delissea waianaeensis*. Investigating the population level impact of both exotic rodents and pollen limitation simultaneously will provide a deeper insight into the synergistic effects of these biotic stressors on plant population persistence.

Preliminary analysis of a study conducted at the Pahole and Kahanahaiki reintroduction sites suggest *D. waianaeensis* is pollen limited (Pender 2013b) and a study conducted at the Kaluaa reintroduction site confirms black rats consume *D. waianaeensis* fruit (L. Bialic-Murphy, unpublished data). Previous research indicates that *D. waianaeensis* seeds remain viable following digestion by black rats (Shiels 2010). However, it is unresolved if seeds following digestion are deposited in habitat suitable for germination and establishment. The foraging habits and den characteristics of black rats suggest that *D. waianaeensis* seeds following digestion are not deposited in favorable sites. Black rats primarily make dens below ground in soil and fractured rock substrate, under logs, in thick understory vegetation, and inside partially dead non-native trees. When foraging, black rats are the most active in areas with thick vegetation cover, 10–30 cm above them (Shiels 2010). Naturally occurring *D. waianaeensis* seedlings and immature plants at the study site are primarily found in open areas (Lalasia Bialic-Murphy, unpublished data), which suggest that black rats have a negative impact on *D. waianaeensis* fertility.

Material and methods

Study species

Delissea waianaeensis is a long-lived arborescent woody shrub endemic to the Waianae Mountain Range, on the island of Oahu. It grows into a single or branched erect stem, reaching 1–3 meters tall at first reproduction (Wagner et al. 1999). It produces purple, red, white, and pink berries which are indicative of frugivorous bird dispersal and floral characteristics suggest *D. waianaeensis* was historically pollinated by native birds in the honeycreeper (Drepanidinae) and Hawaiian Mohoideae (Mohoidae) groups (Lammers & Freeman 1986; Pender 2013a). Anthropogenic alterations have driven many of the bird species in these families to extinction (Banko et al. 2009). The Hawaiʻi ʻamakihi (*Hemignathus flavus*) and Oahu ʻapapane (*Himatione sanguinea*), which are still present in the Waianae Mountain Range, are ineffective pollinators and nectar robbers (Pender 2013). Manipulative pollination treatments suggest *D. waianaeensis* is pollen limited, having significantly less seed set per fruit for control and self-pollination treatments, relative to a pollen-addition treatment (Pender 2013). Production of viable seeds from isolated plants indicates that *D. waianaeensis* is capable of self-pollination (Lammers 2005).

Delissea waianaeensis individuals have been documented between 245–760 m elevation, along the north facing slopes and gulch bottoms of the Waianae Mountain Range (Wagner et al. 1999). The historic geographic range and density are poorly understood and based primarily on qualitative field observations. In 1996, it was listed as federally endangered (USFWS 1998) and by 2005 *D. waianaeensis* was restricted to seven geographically isolated locations, with a meta-population of twenty-five plants (USFWS 2012). The cause of endangerment is unknown but herbivory by ungulates, slugs and rodents, competition by invasive vegetation, pollen limitation, fires, and climate change have been proposed to be likely causes of decline (USFWS 1998).

Study site

In 2002, *D. waianaeensis* was reintroduced to the Central Kaluaa Management Unit (40 ha), hereafter referred to as Central Kaluaa, which is located in the northern Waianae Mountains, on the island of Oahu (HON; 21° 28' N, -158°6' W) (Figure 2). The mean monthly rainfall is 52–171 mm (Giambelluca et al. 2013). The plant community is a tropical mesic forest, composed of mixed native and exotic flora and fauna. The dominant canopy species include *Acacia koa, Metrosideros polymorpha, Nestegis sandwicensis, Diospyros sandwicensis, Pouteria sandwicensis, Charpentiera obovata, Pisonia umbellifera, Psychotria mariniama, Antidesma platyphyllum.* The dominant understory species include *Alyxia stellata, Carex meyneii, Bidens torta, Coprosma foliosa,* and *Microlepia strigosa.* Dominant canopy exotic species include *Psidium cattleianum, Schinus terebinthifolius, and Toona ciliata.* The dominant exotic understory species include *Blechnum appendiculatum, Clidemia hirta, Melinis minutiflora* and *Cyclosorus dentatus* (OANRP 2011).

Map removed to protect rare resources

Figure 2: Location of a single population of *Delissea waianaeensis* in the Kaluaa Management Unit, in the Waianae Mountain Range on the island of Oahu.

Management history

In 2001, The Nature Conservancy constructed the Central Kaluaa (40 ha) fence, eradicated feral ungulates, and implemented invasive vegetation control for the protection of *D. waianaeensis* and other managed taxa (Figure 2). In 2002, The Nature Conservancy initiated reintroduction of *D. waianaeensis* into Central Kaluaa gulch (hereafter at Kal-C), starting with the clearing of invasive vegetation across the reintroduction location and the outplanting of 43 mature plants. This site was selected because it was an appropriate habitat for the target species, it was relatively accessible and it was within the historic geographic distribution (per comm., Dan Sailer).

The founders used for Kaluaa *D. waianaeensis* reintroduction were from a relictual geographically isolated population of five individuals, located 4000 meters from the outplanting site. Stock from the other six geographically isolated populations was not used for the Kal-C reintroduction to avoid potential outbreeding depression and the loss of local adaptations (Kawelo et al. 2012).

Seeds were collected and grown in a greenhouse for one growing season, prior to outplanting. The mean height at reintroduction was 56 cm. Six outplanting efforts were conducted from 2002 through 2012. The initial outplanting of 43 plants occurred in 2002. In 2004, the management of the reintroduction population was transferred to OANRP and incorporated into a larger conservation plan to offset the potential impact of military training operations on 89 rare plants and animals. OANRP outplanted an additional 303 plants from 2004–2012 (Table 1). The 2012 outplanting included representation from two additional founders that were discovered in close proximity to the five original founders used for the Kaluaa reintroduction.

Year Planted	Number Planted	Number Alive (2014)	% Remaining
2002	43	14	33%
2004	21	12	57%
2008	36	20	56%
2009	19	9	47%
2010	52	39	75%
2011	121	117	97%
2012	54	49	91%
Total	346	260	75%

Table 1: *D. waianaeensis* reintroduction effort from 2002–2012.

Data collection

Demographic data

Detailed demographic data collection started in January of 2010. A subset of plants was permanently tagged and will be monitored annually for five consecutive years. The life cycle of *D. waianaeensis* was categorized into four life stages: mature (reproducing individuals), large immature (> 35 cm and non-reproductive), small immature (2 cm – 35 cm), and seedling (less that 2cm). In each life stage a subset of 50 plants were randomly selected and permanently tagged. Plants > 10 cm in height were permanently marked with metal tags (wired to the base of each plant) and plants < 10 cm in height were marked using pin flags and metal tags, placed two inches upslope from each plant. Seedling clusters were tracked using plots; the boundaries were delineated with pin flags and orange string.

For each tagged plant, height to apical meristem (when possible), basal diameter, reproductive status, vigor, number of expanded leaves, and rooting substrate were recorded. The calculate fecundity, a subset of twenty mature plants will be randomly selected and tracked once a month during the 2015 fruiting season. To avoid double counting fruits, monitored infructescense will be tagged using orange sewing thread. In addition, the total number of plants in each life stage will be counted the final year of the study.

Pollination limitation data

To calculate the effect of pollen limitation on fecundity of *D. waianaeensis* necessary for matrix model simulation, I will use data from a pollination manipulation experiment conducted in 2009 and 2010 (Pender 2013b). Specifically, the mean seed set of the control treatment will be subtracted from the mean seed set of the plus-pollen treatment.

The pollination manipulation experiments were conducted at the Pahole Natural Area Reserve and Kahanahaiki Management Unit. The control and plus-pollen treatments were applied to a subset of plants at each population. For the control treatment the flowers were left unmanipulated and for the plus-pollen treatment flowers were supplemented with either pollen collected from the male-phase of the same plant and pollen from three or more plants in the same population. At Kahanahaiki the treatments were applied to 12 and 11 plants in 2009 and 2010 respectively. At Pahole the treatments were applied to 25 plants in 2010. The results of this study indicate that *D. waianaeensis* is pollen limited (Table 2). Pollen supplementation increased seed set by 38%, relative to the other treatments (F = 12.42, P = <0.05).

There is a potential bias in using pollination data that were not collected at the field site, such as differences in pollination networks. The genetic material used for the

Kahanahaiki and Pahole reintroduction sites was also from a different source population than the genetic material used for the Kaluaa reintroduction. However, the seed set of unmanipulated open-pollinated fruits collected at Kaluaa, Pahole, and Kahanahaiki were not significantly different (Lauren Weisenberger; unpublished data, Pender 2013b), indicating *D. waianaeensis* was pollen limited at all of the sites. Therefore, I will assume that pollen supplementation would have similar affects on seed set for plants at Kaluaa, relative to Pahole and Kahanahaiki.

Treatment	Control	Plus Pollen
Mean Seed Set	133	217
Sample Size	41	11

Table 2: Mean seed set from *Delissea waianaeensis* pollination study at Pahole and Kahanahaiki.

Rodent depredation data

Preliminary field trial – To determine if rodents depredate *D. waianaeensis* fruit, two motion-sensing cameras were installed during the peak fruiting season of 2014 for a total of fifteen trap nights. The cameras were aimed directly at two patches of mature plants (two and four plants in each patch). The only visitation recorded was by black rats. All photographs capturing black rats were during nighttime. Each night of the study black rats were photographed climbing *D. waianaeensis* plants and interacting with mature fruit, which suggests that black rats are a primary predator of mature fruit (Figure 3).

Figure 3: Black rat interacting with mature fruit.

Effect of rodent depredation on fecundity – To calculate the percentage of *D. waianaeensis* fruit depredated by rodents necessary for matrix model simulation, I will use a modified version of the monitoring methodology developed by Pender et al. (2013). I will install twenty-five tracking tunnels (50 cm x 10 cm x 10 cm; Connovation Limited, Auckland, New Zealand), with tracking cards inserted (The Black Trakka Gotcha Traps LTD, Warkworth, New Zealand), and place them throughout the study site during the 2015 peak fruiting season. Each tracking tunnel will be baited with one mature *D. waianaeensis* fruit. I will check the tracking tunnels two nights after installment and the total number of consumed fruit will be recorded. The tunnels will be baited and monitored twice during the 2015 fruiting season. I will then record the footprints left on the tracking tunnel cards to identify all animal species (using Oahu Army Natural Resources Program identification cards). I will scatter the remaining fruit in the tracking tunnels at the field site.

Data analysis

I will use field data collected for the demography of *D. waianaeensis* to develop yearly transition matrices and project the ambient population dynamics using the following matrix projection model:

$$\mathrm{n}(t+1) = \mathbf{A}\mathrm{n}(t)$$

where the vector $\mathrm{n}(t)$ represents the number of plants in four discrete life stage at time t and $\mathbf{n}(t+1)$ represents the number of plants in each life stage the following year. The projection matrix **A**, will be of the following form:

$$\boldsymbol{A} = \begin{pmatrix} \sigma_s(1-\gamma_s) & 0 & 0 & \sigma_m\varphi_m \\ \sigma_s\gamma_s & \sigma_{si}(1-\gamma_{si}) & 0 & 0 \\ 0 & \sigma_{si}\gamma_{si} & \sigma_{li}(1-\gamma_{li}) & 0 \\ 0 & 0 & \sigma_{li}\gamma_{li} & \sigma_m \end{pmatrix}$$

The matrix, **A**, is composed of 8 matrix elements (a_{ij}), which represent the transition probability of the *s* (seedlings), *si* (small immature), *sl* (large immature), *m* (mature) life stages from time t to t+1. The matrix, **A**, is parameterized in terms of the probability of surviving σ, the probability of growing to the next stage class γ, and the fertility term φ_m of each life stage. The fertility term is the product of the survival of mature plants, fecundity, the probability of fruiting and the germination and establishment rate.

To simulate the effect of black rat removal (i.e., no fruit depredation by rodents) on population dynamics, the establishment and germination rate of the fertility element in the ambient yearly transition matrices **A** will be increased by the mean fruit depredation by rodents. To simulate the affect of removing of pollen limitation on population dynamics the fecundity term of the fertility element in the ambient yearly transition matrices will be increased by the proportional difference in fecundity of the control and plus pollen treatments.

The yearly transition matrices for the two treatments (rodent depredation and pollen limitation) will then be used to project the short and long-term population dynamics and the results will be compared to the projected ambient population dynamics.

It should be noted that there is a potential bias of the pollen limitation and rodent depredation projections. Specifically, the simulations will not account for density dependence of seedlings. However, seedling survival of isolated seedlings and seedling clumps were not significantly different at the field sites (Lalasia Bialic-Murphy, unpublished data), which suggests that density dependence could be neglected in this system.

For the fruit depredation by rodent simulation I will assume that fruits following consumption are not deposited in favorable habitat. The purpose of this simulation is to gain a deeper insight into the potential impact of fruit depredation by rodents on population dynamics. If the results of this study indicate fruit depredation by rodents has a large impact on population dynamics and is an important determinant of population persistence (if seeds were deposited in unfavorable habitat following digestion), management may want to consider explicitly monitoring seed fate following digestion by rodents.

5 - Study Question # 3: How will climate change affect the population dynamics of critically endangered plants? A case study of an island endemic shrub, *Schiedea obovata.*

Background and rationale

Theoretical and empirical population ecology studies suggest that, in general, environmental stressors that influence fecundity and seedling establishment will have the largest proportional effect, if managed (i.e., conducting threat control management), on the population growth rate of short-lived herbaceous species (Morris et al. 2008; Silvertown et al. 1996). Seedlings are particularly sensitive to drought and soil moisture availability due to their limited root system; which are contained in the drier upper surface soil layer (Gerhardt 1996; Gilbert et al. 2001; Kobe et al. 1995; Poorter & Hayashida-Oliver 2000). Climate change is predicted to increase annual and inter-annual climatic variability, increasing the average length of drought periods and extreme rainfall events (Change 2007). Under such a scenario, short-lived (<10 years) species are projected to be disproportionally affected by climate change (Morris et al. 2008).

The effect of climate change on population persistence of plant populations remains unresolved (McLaughlin et al. 2002; Parmesan & Yohe 2003; Souther & McGraw 2014), particularly for species native to oceanic islands. For flora native to Hawai‘i, only one quantitative demographic study has been conducted to link weather patterns to population dynamics. Decline in the population size of *Argyroxyphium sandwicense*, a long-lived monocarpic plant, may be strongly associated with weather patterns (focusing on temporal changes in mean yearly precipitation) (Krushelnycky et al. 2013). However, the effect of weather patterns on vital rates was not explicitly isolated for this study. Given this, it is impossible to conclude that climate change was the cause of population decline.

The central focus of my research is to combine classical drought tolerance experiments with size-structured population projection modeling to understand the effect of climate change on population persistence of an endemic island plant, *S. obovata*. I will conduct a greenhouse experiment, manipulating soil water content availability to assess the effect of water availability on seedling survival and growth. These survivorship and growth data will be used to simulate how changing precipitation patterns could potentially alter population growth rate of four predetermined water treatments (which are described in detail below). Explicitly linking drought tolerance to population dynamics will provide better insight into the vulnerability of oceanic island species to the effects of climate change.

Material and methods

Study species

Schiedea obovata is a short-lived, perennial, herbaceous shrub endemic to the Waianae and Koolau Mountain Ranges, on the island of Oahu (Hawai‘i). Plants have been documented between 550–800 m elevation, primarily found along mesic ridgelines

(Wagner et al. 1999). The historic geographic range and density is poorly understood and based primarily on qualitative field observations. Over the past several decades *S. obovata* has experienced a severe reduction in geographical range and by 1991 it was listed as federally endangered (USFWS 1998). To date, there are three known naturally occurring population left, with a total of one, 403, and 3117 plants.

Schiedea obovata is a suberect or ascending branched shrub, reaching 0.3–1 cm tall (Wagner et al. 2005). Fruit are capsules and the sepals are fleshy and dark purple. Floral characteristics suggest that *S. obovata* is a facultative selfer and purple berries are indicative of frugivorous bird dispersal. The cause of endangerment is unknown but habitat fragmentation, competition with invasive ecosystem-altering vegetation, predation by ungulates, rodents and slugs, climate change, and fire are implicated (USFWS 1998).

Study site

The study site is located in the Kahanahaiki Management Unit (Figure 4). Location and forest community composition of this area is described in detail in the *study site* section of 3.1.

Map removed to protect rare resources

Figure 4: Location of a single population of *Schiedea obovata* in the Kahanahaiki Management Unit, in the northern Waianae Mountain Range on the island of Oahu.

Management history

In 1996, prior to reintroduction, the Kahanahaiki fence was constructed and ungulates were removed for protection of *S. obovata* and eleven other endangered species. Since 1998 ecosystem level suppression of rodents and invasive plants has been conducted for the protection of *S. obovata* and other vulnerable resources (OANRP 2009) (Figure 4).

The reintroduction, referred to hereafter as MMR-G, is representative of a single founder from Kahanahaiki. Site selection was based on the following criteria: appropriate habitat and associated species within the historic geographic distribution and similar topography relative to naturally occurring populations (OANRP 2003a). Stock from the other six source populations was not used for the MMR-G reintroduction to avoid potential outbreeding depression and the loss of localized adaptations (Kawelo et al. 2012). This decision was partially supported by recent research that was conducted to examine the risk of inbreeding and outbreeding depression of mixing founder stock (Weisenberger 2012). Inbreeding and outbreeding depression were not detected. However, plants from maternal source populations furthest from the Kahanahaiki population had the lowest progeny fitness when outplanted at Kahanahaiki (which is the driest and lowest elevation reintroduction site), which may indicate local adaptation. Alternatively, reduced progeny fitness may be the effect of the numerical small population size and genetic drift. Management recommendation of that study for the reintroduction of *S. obovata* at Kahanahaiki was: "propagules that originate from higher elevations should not be moved to lower elevations. Kahanahaiki progeny are the only plants that should be planted into Kahanahaiki gulch."

Seeds used for the reintroduction were collected and grown in a greenhouse for one growing season, prior to outplanting. The mean height at reintroduction was 58 cm. Six outplanting efforts were conducted from 1999 through 2011.

Year Planted	Number Planted	Number Alive (2014)	% Remaining
1999	4	0	0%
2000	6	0	0%
2006	66	2	3%
2009	80	29	36%
2011	102	66	64%
Total	258	97	38%

Table 3: *S. obovata* reintroduction effort from 1999–2011.

Starting in 2011, localized suppression of exotic slug (*Stylommatophora*, Limacidae and *Systellommatophora*, Veronicellidae) has been conducted at the MMR-G reintroduction site. The slug suppression methodology is hand broadcast of Sluggo (Neudorff Co., Fresno, California) molluscicide at a monthly application rate. Sluggo application does not occur in the summer months, when slug density is low (Stephanie Joe, pers. comm.). The justification for this management action was based on a study conducted by (Joe &

Daehler 2007). The results of that study indicated that slugs had a significant effect on *S. obovata* seedlings, with a fifty percent reduction in survivorship over a six-month period.

Data collection

Demographic data

Field monitoring was initiated in April of 2014 and will be conducted annually for three consecutive years. At the start of the study a total of 14 1x1m permanent plots were installed throughout the outplanting site. We delineated the plot boundaries with pin flags in the upper left and lower right corners (when facing uphill) for tracking purposes. Plants, within each plot, that were > 8cm in height were permanently tagged (using OANRP's standard metal tags and wire method). For plants in the seedling (<8cm with cotyledons) and small immature (<8cm with no cotyledons) life stages a subset of five randomly selected plants were permanently tagged within each plot. To avoid damage, immature plants <8cm were marked using pin flags and color coded wire (placed two inches upslope from the plants) or color coded wire (wrapped around the base of the main stem). Seedling clusters were tracked using subplots (within the 1x1 m plots); pin flags and orange string delineating the plot boundaries.

For each tagged plant height to apical meristem, reproductive status and vigor data were recorded. To calculate the mean buds and flowers per plant, which will be used to estimate the fecundity term, a subset of twenty mature plants will be randomly selected and tracked once a month during the 2015 fruiting season. The total number of buds and flowers on each infructescence will be recorded. To avoid double counting, the monitored infructescence will be tagged using orange sewing thread. Fecundity will be the product of the mean "fruits per flower" and " seeds per fruit", which were data obtained from a previous study that was conducted at Kahanahaiki in 2009 (Weisenberger 2012), and the mean buds and fruits per plant. The following abiotic and biotic environmental parameters will also be monitored: annual precipitation, rooting substrate, and percent cover of non-native vegetation. These data will be used to investigate how annual precipitation, rooting substrate, and percent cover of non-native vegetation are associated with temporal variation in vital rates and population dynamics. In addition, a water content reflectometer (CS-616 Water Content Reflectometer, Campbell Scientific, Inc.)

will be used to calculate the mean gravimetric soil water content (GSWC) at the field site during the dry season, June and August, at Kahanahaiki (Giambelluca et al. 2013). Field GSWC measurements will be taken twice a week for six weeks, six measurements in June and six in August of 2014.

Drought and soil moisture data

To isolate the potential effect of pre-determined climate change scenarios (focusing on precipitation) on seedling survival necessary for matrix model simulation, I will conduct a greenhouse experiment. The experiments will be conducted in the Botany Greenhouses at the University of Hawaiʻi at Manoa in the spring of 2015.

The four water treatments will be: 1) "ambient" GSWC, mimicking mean field GSWC during the driest months, which are June and August (Giambelluca et al. 2013), 2) a 20% daily decrease in water, relative to the ambient water treatment 3) a 20% daily increase in water, relative to the ambient water treatment 4) a 60% daily decrease in water treatment, relative to the ambient water treatment (to mimic a persistent decrease in precipitation that is consistent with current and predicted climate change in Hawaiʻi) (Chu et al. 2010).

For each treatment the sample unit will be individual seedlings. A sample of 20 plants will be used for each treatment, with a total of N=80 plants. The seeds that will be used for the study were collected from five randomly selected mature plants at the field site in the spring of 2014. The seeds were dried at 24° C and 43% relative humidity for one month and then stored at -18°C and 20% relative humidity. In the spring of 2015, I will germinate the seeds on 1% water agar (Sigma-Aldrich A1296) in Petri dishes. Following germination, seedlings will be transplanted to 10 cm-diameter pots. Field soil (extracted from a location in close proximity to the field population) will be used for the experiment. Equal amounts of soil will be weighted and added to each pot. To recover from transplant shock, seedlings will be placed on greenhouse benches and watered daily for 1–2 weeks. The seedlings will then be randomly assigned to one of the four water treatments. Plants will be watered, using the pre-determined watering treatment, every other day for two months. Mortality data will be recorded each visit. At two months I will record data on height to the apical meristem and total number of expanded leaves. At the end of the two-month watering treatments I will stop water all of the plant to mimic extreme drought conditions. The plants will be monitored every other day until all plants have died. Mortality data will be recorded each visit.

Data Analysis
Integral projection model

I will use continuous individual plant vital rate data to project the ambient population dynamics, using an integral projection modeling (Easterling et al. 2000):

$$\mathrm{n}(y, t+1) = \int_{\Omega} \mathrm{k}(y, x)\mathrm{n}(x, t)dx \qquad (1)$$

with the integration being over all possible plant height Ω. The function $\mathrm{n}(y, t+1)$ describes the number of individuals of size y at time $(t+1)$. The function $\mathrm{k}\ (y, x)$ is a kernel, which is similar to a stage structured matrix, comprised of fecundity and survival-growth of individual plants. $\mathrm{n}(t, x)$ summarizes the population state at time t. Unlike a stage structured matrix, which represents the transition probability of discrete life stages, a kernel represents a nonnegative surface of all possible transitions (i.e., survival, growth and fecundity) of individual plants from size x at time (t) to size y at time (t+1).

The function k is composed of survival-growth $\mathrm{p}(x, y)$, which is the probability of individuals of size x growing to size y (2).

$$p(x, y) = s(x)g(x, y) \qquad (2)$$

Fertility $\mathrm{f}(x, y)$ is composed of the probability of mature survival $s(x)$, probability of fruiting $\mathrm{f_f}(x)$, number of fruits $\mathrm{f_d}(y)$ and the probability of a seed germinating and establishing $\mathrm{p_g p_e}$.

$$f(x, y) = s(x)f_f(x)p_g p_e f_d(y) \qquad (3)$$

I will use the kernel (k) to project the long-term population growth rate. A population growth rate <1 indicates a declining population, a population growth rate = 0 indicates a stable population and a population growth rate >1 indicates a growing population.

I will also conduct elasticity analysis to identify how different areas of the kernel (individual plant vital rates) influence the population growth rate following Easterling et al. (2000), which is:

$$e(z_1, z_2) = \frac{k(z_1,z_2)}{\lambda}\frac{v(z_1)w(z_2)}{\langle w,v \rangle} \quad (4)$$

The interpretation of elasticity, using an IPM approach, is similar to that of a structured matrix model. However, the proportional relative importance of λ to a small change in a vital rate is calculated for a small disk center in the kernel rather than for a discrete life stage.

To simulate the affect of the drought treatments on population dynamics, I will construct four additional sets of yearly transition kernels, substituting the $p(x, y)$ function by the mean survival and growth of each watering treatment and the probability of establishment and germination $p_g p_e$ of the fertility function by the proportional difference in the establishment rate of each watering treatment, relative to the ambient (i.e., field) establishment rate. I will then compare the population dynamics of the drought simulation to the ambient projection.

The simulations do not take into account density dependence, which may create a potential bias of the projections. To assess if density dependence is a driving factor of seedling survival and growth, additional analysis will be conducted. Specifically, tagged plants each year of the study will be categorized as either: 1) isolated seedlings or 2) seedling clumps. Analysis will then be conducted to determine if survival and growth of seedlings clumps and isolated plants is significantly different. If seedlings clumps have a significantly lower survival rate or slower growth it will indicate density dependency. If density dependence is detected, I will account for it by developing a density dependent IPM, which means I will incorporate the density of seedlings in the fertility function of the IPM eqn (1).

6 - Study Question #4: For plant reintroductions, are the vital rates of outplanted individuals and the first filial generation different? If so, does the transition from an outplanted to a naturally occurring population affect short and long-term population dynamics?

Background and rationale

Preventing extinction and reversing negative population trends of rare species is a primary focus of conservation biology (IUCN 2013). This is particularly challenging for the rarest species, which are most at risk of extinction. For these taxa, urgent conservation management is needed. Population reintroduction into natural environments protected from development is the primary strategy used by responsible conservation agencies worldwide to prevent biodiversity loss (IUCN 2013; Maschinski & Haskins 2012; Soorae 2013). The end goal is to achieve self-sustaining populations and promote meta-population dynamics (Falk et al. 1996; Pavlik 1996). However, few detailed demographic studies have been conducted to evaluate if reintroductions result in the desired end goal (Maschinski & Haskins 2012). Thus, there is a vital need to advance our understanding of what makes plant reintroductions effective and when it is an appropriate conservation tool.

Of the few demographic studies that have been conducted, habitat conversion was listed as the primary cause of endangerment (Bell et al. 2003; Colas et al. 2008; Liu et al. 2004; Maschinski & Duquesnel 2007). Those studies suggest that population reintroductions can be an effective management tool when outplanting in native-dominated ecosystems. Those studies also illustrate that survival, growth and fecundity of outplanted populations often differ significantly from those of naturally occurring populations (Bell et al. 2003; Colas et al. 2008; Liu et al. 2004; Maschinski & Duquesnel 2007).

Differences in vital rates between outplanted and naturally occurring populations can result in different population level dynamics and the required number of individuals to maintain a self-sustaining population. The mechanism driving the differences in vital rates is unknown, although spatial variation in habitat quality was likely a contributing factor. Increased genetic diversity of outplanted individuals may also explain higher fecundity of outplanted individuals for one of the taxa (Colas et al. 2008). These studies illustrate the risk of basing numerical size and demographic structure goals on studies conducted on naturally occurring populations.

Two of the primary knowledge gaps of plant reintroduction are: 1) When there are multiple environmental threats, not all of which can be managed, and the remaining suitable habitat has been altered significantly, will population reintroduction and the suppression of the primary threats be enough to achieve self-sustaining populations? 2) Are there differences in vital rates of outplanted individuals and first filial generation? If so, will the transition from an outplanted to a naturally occurring population affect the population growth rate and what is the initial reintroduction size needed to result in a self-sustaining population? To address these knowledge gaps, I will conduct a detailed demographic study of two reintroduced plant populations, *S. obovata* and *D. waianaeensis*, following two decades of active threat control management and multi-year intensive reintroduction efforts.

Material and methods

For a detailed description of the study systems, study site and management history refer to sections 2.2 and 2.3.

Data collection

Demographic data

I will use field data collected for the demography of *S. obovata* and *D. waianaeensis* studies.

Fecundity data

To calculate the difference in fecundity of *S. obovata* and *D. waianaeensis* reintroduced individuals and the naturally recruited cohort necessary for matrix model simulation, a subset of twenty mature plants per taxon (ten F1 individuals and ten reintroduced individuals) will be randomly selected and tracked once a month during the 2015 fruiting season. To avoid double counting, monitored infructescense will be tagged using orange sewing thread. For analytical purposes, age and size will be included as covariates to control for the influence they may have on fecundity.

Data analysis

I will follow the approach described in the data analysis section of 2.1 of this document to construct the yearly transition matrices and project the ambient population dynamics.

To simulate the affect of artificial cohort transition on population dynamics, I will construct two addition sets of yearly transition matrices: 1) only outplanted individuals and 2) only naturally recruiting cohorts. Specifically, the fecundity term of the fertility element in the ambient yearly transition matrices, **A***,* will be altered by the proportional difference in fecundity of outplanted and naturally occurring cohort plants. The results of these two simulations will then be compared to the ambient treatment.

This method does not take into account density dependency, which may create a potential bias of the projections. However, *D. waianaeensis* seedling survival of isolated seedlings and seedling clumps were not significantly different at the field sites (Lalasia Bialic-Murphy, unpublished data), which suggests that density dependence could be neglected in our system. Similar analysis will be conducted for *S. obovata* and considered when interpreting the results.

7 - Timeline

	Spring 2014	Fall 2014	Spring 2015	Fall 2015	Spring 2016	Fall 2016
Literature Review						
Oral Defense						
Dissertation						
C. dentata						
Data Collection						
Manuscripts						
D. waianaeensis						
Data Collection						
Rodent Monitoring						
Manuscripts						
S. obovata						
Data Collection						
Greenhouse Experiment						
Manuscripts						

References:

Banko, W., P. Banko, T. Pratt, C. Atkinson, P. Banko, J. Jacobi, and B. Woodworth. 2009. Historic decline and extinction. Conservation Biology of Hawaiian Forest Birds: Implications for Island Avifauna. Yale University:25-58.

Bell, T., M. Bowles, and A. McEachern. 2003. Projecting the success of plant population restoration with viability analysis. Pages 313-348. Population viability in plants. Springer.

Bierzychudek, P. 1982. The demography of jack-in-the-pulpit, a forest perennial that changes sex. Ecological monographs **52**:335-351.

Burd, M. 1994. Bateman's principle and plant reproduction: the role of pollen limitation in fruit and seed set. The Botanical Review **60**:83-139.

Busby, P. E., P. Vitousek, and R. Dirzo. 2010. Prevalence of Tree Regeneration by Sprouting and Seeding Along a Rainfall Gradient in Hawai'i. Biotropica **42**:80-86.

Carpenter, F. L. 1976. Plant-pollinator interactions in Hawaii: pollination energetics of Metrosideros collina (Myrtaceae). Ecology:1125-1144.

Caswell, H. 1989. Matrix population models. Wiley Online Library.

Caswell, H. 2001. Matrix population models: construction, analysis, and interpretation, 2001. Sinauer, Sunderland.

Caswell, H. 2007. Sensitivity analysis of transient population dynamics. Ecol Lett **10**:1-15.

Change, I. P. O. C. 2007. Climate change 2007: The physical science basis. Agenda **6**:333.

Colas, B., F. Kirchner, M. Riba, I. Olivieri, A. Mignot, E. Imbert, C. Beltrame, D. Carbonell, and H. Fréville. 2008. Restoration demography: a 10-year demographic comparison between introduced and natural populations of endemic *Centaurea corymbosa* (Asteraceae). Journal of Applied Ecology **45**:1468-1476.

Cole, R. J., C. M. Litton, M. J. Koontz, and R. K. Loh. 2012. Vegetation Recovery 16 Years after Feral Pig Removal from a Wet Hawaiian Forest. Biotropica **44**:463-471.

Crone, E. E., E. S. Menges, M. M. Ellis, T. Bell, P. Bierzychudek, J. Ehrlen, T. N. Kaye, T. M. Knight, P. Lesica, W. F. Morris, G. Oostermeijer, P. F. Quintana-Ascencio, A. Stanley, T. Ticktin, T. Valverde, and J. L. Williams. 2011. How do plant ecologists use matrix population models? Ecol Lett **14**:1-8.

Cuddihy, L. W., and C. P. Stone 1993. Alteration of native Hawaiian vegetation; effects of humans , their activities and introductions. University of Hawaii Press, Honolulu.

Denslow, J. S. 1980. Gap partitioning among tropical rainforest trees. Biotropica.

Dostálek, T., and Z. Münzbergová. 2013. Comparative population biology of critically endangered Dracocephalum austriacum (Lamiaceae) in two distant regions. Folia Geobotanica **48**:75-93.

Easterling, M. R., S. P. Ellner, and P. M. Dixon. 2000. Size-specific sensitivity: applying a new structured population model. Ecology **81**:694-708.

Ehrlén, J., and O. Eriksson. 1995. Pollen Limitation and Population Growth in a Herbaceous Perennial Legume. Ecology **76**:652-656.

Eriksson, O., and J. Ehrlen. 1992. SEED AND MICROSITE LIMITATION OF RECRUITMENT IN PLANT-POPULATIONS. Oecologia **91**:360-364.
Falk, D. A., C. I. Millar, and M. Olwell 1996. Restoring diversity: strategies for reintroduction of endangered plants. Island Press.
Fetcher, N., B. R. Strain, and S. F. Oberbauer. 1983. Effects of light regime on the growth, leaf morphology, and water relations of seedlings of two species of tropical trees. Oecologia **58**:314-319.
Fox, G. A., and J. Gurevitch. 2000. Population numbers count: tools for near ‐ term demographic analysis. The American Naturalist **156**:242-256.
García, M. B. 2003. Demographic viability of a relict population of the critically endangered plant Borderea chouardii. Conservation Biology **17**:1672-1680.
García, M. B., and J. Ehrlén. 2002. Reproductive effort and herbivory timing in a perennial herb: fitness components at the individual and population levels. American Journal of Botany **89**:1295-1302.
Gerhardt, K. 1996. Effects of root competition and canopy openness on survival and growth of tree seedlings in a tropical seasonal dry forest. Forest Ecology and Management **82**:33-48.
Giambelluca, T. W., Q. Chen, A. G. Frazier, J. P. Price, Y.-L. Chen, P.-S. Chu, J. K. Eischeid, and D. M. Delparte. 2013. Online Rainfall Atlas of Hawai‘i. Bull. Amer. Meteor. Soc.
Gilbert, G. S., K. E. Harms, D. N. Hamill, and S. P. Hubbell. 2001. Effects of seedling size, El Niño drought, seedling density, and distance to nearest conspecific adult on 6-year survival of Ocotea whitei seedlings in Panamá. Oecologia **127**:509-516.
Gillespie, R. G., and D. A. Clague 2009. Encyclopedia of islands. Univ of California Press.
Gilpin, M. E., and M. E. Soule 1986. Minimum viable population: Processes of species extinction. Sinauer Associates, Inc, Sunderland, Massachusetts.
Haridas, C. V., and S. Tuljapurkar. 2007. Time, transients and elasticity. Ecol Lett **10**:1143-1153.
Harper, J. L. 1977. Population biology of plants. Population biology of plants.
HPPRCC. 2011. Revised recovery objective guidelines: Hawaii and Pacific Plants Recovery Coordinating Committee., U.S. Fish and Wildlife Service Pacific Island Ecoregion, Honolulu, Hawaii.
IUCN. 2013. The IUCN Red List of Threatened Species. http://www.iucnredlist.org/about/summary-statistics.
Kellner, J. R., G. P. Asner, K. M. Kinney, S. R. Loarie, D. E. Knapp, T. Kennedy-Bowdoin, E. J. Questad, S. Cordell, and J. M. Thaxton. 2011. Remote analysis of biological invasion and the impact of enemy release. Ecological Applications **21**:2094-2104.
Kobe, R. K., S. W. Pacala, J. A. Silander Jr, and C. D. Canham. 1995. Juvenile tree survivorship as a component of shade tolerance. Ecological Applications:517-532.
Koons, D. N., J. B. Grand, B. Zinner, and R. F. Rockwell. 2005. Transient population dynamics: Relations to life history and initial population state. Ecological Modelling **185**:283-297.
Krushelnycky, P. D., L. L. Loope, T. W. Giambelluca, F. Starr, K. Starr, D. R. Drake, A. D. Taylor, and R. H. Robichaux. 2013. Climate ‐ associated population declines

reverse recovery and threaten future of an iconic high‐elevation plant. Global change biology **19**:911-922.
Lammers, T. G., and C. E. Freeman. 1986. Ornithophily among the Hawaiian Lobelioideae (Campanulaceae): evidence from floral nectar sugar compositions. American Journal of Botany:1613-1619.
Liu, G. h., J. Zhou, D. s. Huang, and W. Li. 2004. Spatial and temporal dynamics of a restored population of Oryza rufipogon in Huli Marsh, South China. Restoration Ecology **12**:456-463.
Loh, R. K., and J. T. Tunison. 1999. Vegetation recovery following pig removal in'Ola'a-Koa Rainforest Unit, Hawaii Volcanoes National Park.
Maschinski, J., and J. Duquesnel. 2007. Successful reintroductions of the endangered long-lived Sargent's cherry palm, *Pseudophoenix sargentii*, in the Florida Keys. Biological Conservation **134**:122-129.
Maschinski, J., and K. E. Haskins 2012. Plant reintroduction in a changing climate: promises and perils. Island Press.
McLaughlin, J. F., J. J. Hellmann, C. L. Boggs, and P. R. Ehrlich. 2002. Climate change hastens population extinctions. Proceedings of the National Academy of Sciences **99**:6070-6074.
Menges, E. S. 1990. Population viability analysis for an endangered plant. Conservation biology **4**:52-62.
Morris, W. F., and D. F. Doak 2002. Quantitative conservation biology. Sinauer Associates Sunderland, Massachusetts, USA.
Morris, W. F., C. A. Pfiser, T. Shripad, C. V. Haridas, C. Boggs, M. S. Boyce, E. M. Bruna, D. R. Church, T. Coulson, D. F. Doak, S. Forsyth, J.-M. Gaillard, C. C. Horvitz, S. Kalisz, B. E. Kendall, T. M. Knight, C. T. Lee, and E. S. Menges. 2008. Longevity can buffer plant and animal populations against changing climatic varibility. Ecology **89**:19-25.
OANRP. 2009. Status reprot for the Makua and Oahu Implementation Plans. Pacific Cooperative Studies Unit, Honolulu, Hawaii.
OANRP. 2011. Status reprot for the Makua and Oahu Implementation Plans. Pacific Cooperative Studies Unit, Honolulu, Hawaii.
Parker, I. M. 1997. Pollinator limitation of Cytisus scoparius (Scotch broom), an invasive exotic shrub. Ecology **78**:1457-1470.
Parmesan, C., and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature **421**:37-42.
Pavlik, B. 1996. Defining and measuring success. Restoring diversity: strategies for reintroduction of endangered plants **127**:155.
Pender, R. 2013a. Floral Trait Evolution and Pollen Ecology in the Hawaiian Lobeliad Genus, Clermontia (Campanulaceae) Botany. University of Hawaii at Manoa, ProQuest LLC (2013).
Pender, R. J. 2013b. Floral trait evolution and pollination ecology in the Hawaiian lobeliad genus Clermontia (Campanulaceae). UNIVERSITY OF HAWAI'I AT MANOA.
Pender, R. J., C. W. Morden, and R. E. Paull. 2014. Investigating the pollination syndrome of the Hawaiian lobeliad genus Clermontia (Campanulaceae) using floral nectar traits. American journal of botany **101**:201-205.

Pender, R. J., A. B. Shiels, L. Bialic-Murphy, and S. M. Mosher. 2013. Large-scale rodent control reduces pre-and post-dispersal seed predation of the endangered Hawaiian lobeliad, Cyanea superba subsp. superba (Campanulaceae). Biological invasions **15**:213-223.

Picó, F. X., and M. Riba. 2002. Regional-scale demography of Ramonda myconi: remnant population dynamics in a preglacial relict species. Plant Ecology **161**:1-13.

Pisanu, S., E. Farris, R. Filigheddu, and M. B. García. 2012. Demographic effects of large, introduced herbivores on a long-lived endemic plant. Plant Ecology **213**:1543-1553.

Poorter, L., and Y. Hayashida-Oliver. 2000. Effects of seasonal drought on gap and understorey seedlings in a Bolivian moist forest. Journal of Tropical Ecology **16**:481-498.

Ramula, S., M. Rees, and Y. M. Buckley. 2009. Integral projection models perform better for small demographic data sets than matrix population models: a case study of two perennial herbs. Journal of Applied Ecology **46**:1048-1053.

Ren, H., G. Ma, Q. Zhang, Q. Guo, J. Wang, and Z. Wang. 2010. Moss is a key nurse plant for reintroduction of the endangered herb, Primulina tabacum Hance. Plant ecology **209**:313-320.

Ruffino, L., K. Bourgeois, E. Vidal, C. Duhem, M. Paracuellos, F. Escribano, P. Sposimo, N. Baccetti, M. Pascal, and D. Oro. 2009. Invasive rats and seabirds after 2,000 years of an unwanted coexistence on Mediterranean islands. Biological invasions **11**:1631-1651.

Shaffer, M. L. 1981. Minimum population sizes for species conservation. BioScience **31**:131-134.

Shiels, A. B. 2010. Ecology and impacts of introduced rodents(Rattus spp. and Mus musculus) in the Hawaiian islands.

Shiels, A. B., and D. R. Drake. 2011. Are introduced rats (Rattus rattus) both seed predators and dispersers in Hawaii? Biological Invasions **13**:883-894.

Shiels, A. B., W. C. Pitt, R. T. Sugihara, and G. W. Witmer. 2014. Biology and Impacts of Pacific Island Invasive Species. 11. Rattus rattus, the Black Rat (Rodentia: Muridae). Pacific Science **68**:145-184.

Silvertown, J., M. Franco, and E. Menges. 1996. Interpretation of Elasticity Matrices as an Aid to the Management of Plant Populations for Conservation. Conservation Biology **10**:591-597.

Soorae, P. S. 2013. Global Re-introduction Perspectives: 2013. Further case studies from around the globe

IUCN/SSC Re-introduction Specialist Group and Abu Dhabi, UAE: Environment Agency-Abu Dhabi, Gland, Switzerland.

Souther, S., and J. B. McGraw. 2014. Synergistic effects of climate change and harvest on extinction risk of American ginseng. Ecological Applications.

Towns, D. R., I. A. Atkinson, and C. H. Daugherty. 2006. Have the harmful effects of introduced rats on islands been exaggerated? Biological invasions **8**:863-891.

Traveset, A., M. Nogales, J. A. Alcover, J. Delgado, M. López-Darias, D. Godoy, J. M. Igual, and P. Bover. 2009. A review on the effects of alien rodents in the Balearic

(Western Mediterranean Sea) and Canary Islands (Eastern Atlantic Ocean). *Biological Invasions* **11**:1653-1670.
USFWS. 1998. Recovery Plan for Oahu Plants in U. S. F. a. W. Service, editor, Portland, OR.
USFWS. 2012. Endangered species http://www.fws.gov/pacificislands/species.html, Portland, OR.
Vitousek, P. M. 1996. Biological invasions and ecosystem processes: towards an integration of population biology and ecosystem studies. Pages 183-191. Ecosystem Management. Springer.
Wagner, W. L., D. R. Herbst, and S. H. Sohmer 1999. Manual of the flowering plants of Hawai'i, Vols. 1 and 2. University of Hawai'i and Bishop Museum Press.
Wagner, W. L., S. G. Weller, and A. Sakai. 2005. Monograph of Schiedea (Caryophyllaceae-Alsinoideae).
Weisenberger, L. A. 2012. Inbreeding depression, outbreeding depression and heterosis in rare species in the genus Schiedea (Caryophyllaceae) on O`ahu. Page 188. University of Hawai'i at Manoa, Ann Arbor.
Whittaker, R. J., and J. M. Fernández-Palacios 2007. Island biogeography: ecology, evolution, and conservation. Oxford University Press.
Wilcove, D. S., D. Rothstein, J. Dubow, A. Phillips, and E. Losos. 1998. Quantifying threats to imperiled species in the United States. BioScience:607-615.

ASSESSMENT OF EFFECTS OF RODENT REMOVAL ON ARTHROPODS, AND DEVELOPMENT OF ARTHROPOD MONITORING PROTOCOLS, ON CONSERVATION LANDS UNDER US ARMY MANAGEMENT

Annual Statement of Work, November 2014

Dr. Paul Krushelnycky
Dept. of Plant and Environmental Protection Sciences
University of Hawaii
3050 Maile Way, Gilmore 310
Honolulu, HI 96822
Phone: 808-956-8261
Email: pauldk@hawaii.edu

Background

Invasive black rats are believed to exert severe predatory pressure on native arthropod species, but the effects of this pressure on arthropod populations has not been quantified in the field. Because rats are now nearly ubiquitous in natural areas of Hawaii, the most effective way to assess their impacts on arthropod species and communities is to monitor the response of arthropods to rat removal. The Oahu Army Natural Resource Program (OANRP) has implemented rat removal operations in several areas in the Waianae Mountains. In conjunction with these efforts, I have been conducting standardized, quantitative arthropod sampling before and after rat removal in two of these areas (Kahanahaiki and Palikea), as well as in adjacent control sites where rats will not be immediately removed, to measure arthropod responses and estimate the impacts of rats on native and introduced arthropod populations. This sampling will also serve as an arthropod inventory, providing important information on the biodiversity of these management areas. Thirdly, the sampling conducted in this project will be used to help develop broader arthropod monitoring protocols for the OANRP management units, as desired under the Makua and Oahu Implementation Plans.

FY14 progress

During fiscal year 2014, work on this project included the second year of once-annual (as opposed to seasonal) monitoring at Palikea, during July 2014. This represents the fourth year of post-rodent trapping monitoring, and will provide a good picture of medium-term response of arthropod communities to this management action. Sampling at Kahanahaiki was terminated in late FY12, as new rat trapping technology was implemented at the adjacent control site (Pahole Natural Area Reserve) for the Kahanahaiki monitoring. The record of arthropod response therefore includes monitoring data up to three years post-rodent trapping at this site.

A total of 144 standardized samples were collected in the course of the July 2014 monitoring event, including pitfall traps, leaf litter extraction, daytime vegetation sweeping and nighttime vegetation sweeping. This sampling was conducted within OANRP's vegetation monitoring plots, allowing analysis of relationships between plant community composition and arthropod community composition. In addition, *Rhynchogonus* beetle monitoring was conducted at 50 points during the monitoring event.

Sample sorting and specimen identification progressed during FY14. All samples up through the July 2013 monitoring event have been sorted at least to taxonomic order, and specimen identification to lower taxonomic levels has proceeded for much of this material. Sorting of samples from the July 2014 monitoring event has begun.

All specimens from all monitoring events at Kahanahaiki/Pahole, and from all monitoring events from the first three years at Palikea (three seasonal events each for the year prior to rodent trapping initiation and the first two years after trapping), have now received final treatment. Final determinations have been made and biomass measurements have been completed. A total of over 270,000 specimens belonging to over 570 taxa have now been databased in the project. This has allowed for final dataset compilation and analysis to begin for these monitoring events.

<u>Partial results</u>

Preliminary results for Kahanahaiki have been reported in previous summaries, so I will focus on the most recent results for the Palikea site in this summary.

Changes in arthropod abundances

Relative changes in abundance for the major orders collected, and some subgroups within these orders, at one year and two years post trapping are tabulated for arboreal and terrestrial arthropod communities in Table 1. The numbers presented are the median increase or decrease in abundance, per plot, over time at the rat removal site relative to the control site (no rat trapping) over the same time period. Positive values correspond to increases in abundance at the removal site relative to the control site, and negative values indicate the opposite trend. Also presented are the associated p values for the Wilcoxon Signed Rank Test assessing the probability of these medians differing from zero (i.e. no relative change in abundance). Medians significantly different from zero at an α of 0.05 are highlighted in bold and color coded green for relative increases and red for relative decreases at the removal site. These analyses were performed on the annual totals for each plot, pooling the data from the three seasonal sampling events during each year. Because of the large number of statistical tests conducted in each table, some spurious significant results arising from sampling error can be expected, and focus should be directed at recurring patterns rather than individual outcomes.

For arboreal arthropod communities (assessed with day and night vegetation sweeping), native Hemiptera increased significantly at the removal site at one year post-trapping, and showed a similar magnitude of increase in the second year but greater variation among plots produced a statistically insignificant result for the second year. Hymenoptera increased in abundance in both years, and this increase resulted in substantial part from positive changes in the abundance of native *Sierola* wasps (although the change in *Sierola* alone was not quite significant). Most of the remainder of the increase can be attributed to unidentified parasitic Hymenoptera (not shown). *Eupithecia* caterpillars (mainly the predatory species *E. orichloris*) increased significantly in year two, consistent with patterns obtained in terrestrial samples at Palikea (below) and results from Kahanahaiki (not shown). Lepidoptera more generally did not show patterns of increase in the arboreal samples, in contrast to preliminary results from Kahanahaiki. Like Kahanahaiki, Psocoptera showed consistent patterns of decreasing abundance at the removal site relative to the control site.

One of the strongest patterns has been an increase in abundance in Orthoptera at the removal site after trapping began. For the first two years, this increase has been statistically significant only for native *Laupala* crickets (family Gryllidae), although native *Banza* katydids (family Tettigoniidae) showed non-significant trends towards recovery as well. This pattern has persisted and strengthened in the third year post-trapping, in which the increase in *Banza* was also statistically significant (see Figure 1; note that trends for years 1 and 2 were assessed for the entire annual datasets, whereas the trend for year 3 compares only July of 2010 with July of 2013 due to the termination of seasonal sampling in 2013). The post-trapping increases shown in Figure 1 correspond to an approximate doubling in abundance of *Laupala* crickets and a three- to four-fold increase in abundance of *Banza* katydids.

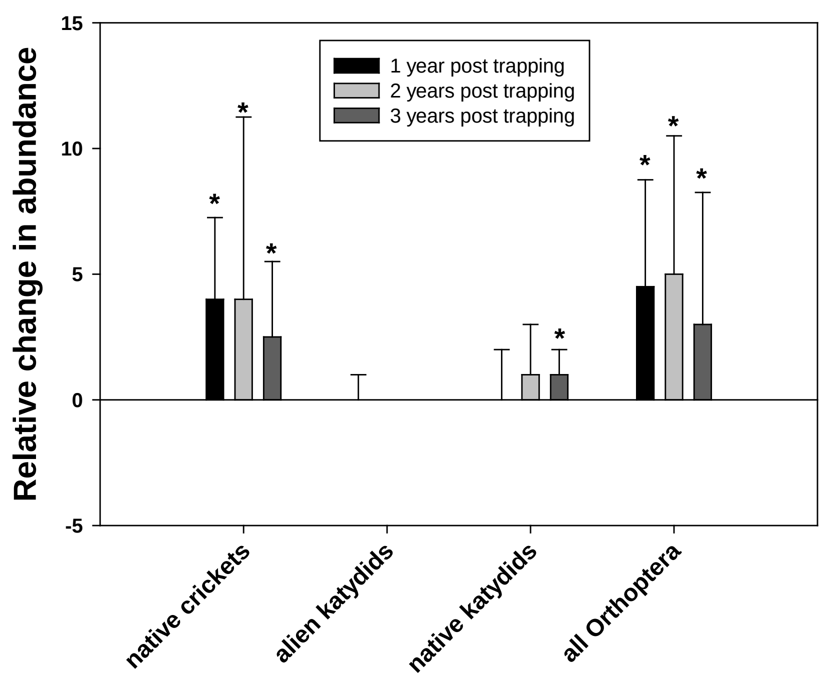


Figure 1. Changes in median abundances, per plot, of Orthoptera at the rodent removal site relative to the control site, at one, two and three years after trapping began. Note that year 3 median changes are not directly comparable to years 1 and 2 in magnitude, because data represent only one sampling event in year 3 but pool 3 seasonal events for years 1 and 2. Relative changes significantly different from zero marked with asterisk ($p < 0.05$), bars indicate 75th percentile of values.

For terrestrial arthropod communities (assessed with pitfall traps and leaf litter extraction), millipedes (Diplopoda) and, as mentioned above, *Eupithecia* caterpillars consistently increased after rat trapping. *Hyposmocoma* case-making caterpillars also showed signs of increasing after trapping, mainly after two years, but caterpillars as a whole and Lepidoptera overall significantly decreased in ground samples at two years post-trapping. Spiders, particularly adventive species, and to a lesser extent adventive amphipods, showed a recurring pattern of decreasing at the removal site after trapping began.

Changes in total arthropod abundances were generally non-significant, with the exception of an increase in native terrestrial arthropods (taken as a group) two years after trapping. Because there was also a nearly significant increase in arboreal native arthropods after two years, it will be interesting to see if this pattern strengthens in years three and four.

The results to date suggest that a few taxonomic groups tend to respond to rodent trapping at each site, while many do not. Comparison with preliminary results from Kahanahaiki also suggests that the same groups do not always respond in the same way at different sites. Some responses may result from direct release from rodent predation, while other responses may arise through indirect pathways, wherein the direct effects caused by changes in rodent densities cascade to other groups through changes in intermediate predator or competitor densities (potentially including both arthropod and vertebrate intermediate predators). Measured responses among Psocoptera, Hymenoptera, Collembola and small Hemiptera seem especially likely to have resulted through the latter mechanism. Between-site differences in the larger biological community may contribute to differences assessed among arthropods.

Changes in species richness

Relative changes in richness, per plot, are presented in Table 2 for groups that are diverse and that were identified to the level of species/morphospecies across all samples. These are the orders Araneae (spiders), Coleoptera (beetles) and Hemiptera (true bugs), plus the native moth genus *Hyposmocoma*, for arboreal communities, and Araneae, Coleoptera and *Hyposmocoma* for terrestrial communities. Remaining orders either had relatively few species, or were sorted only to higher taxonomic levels for most samples (the latter category includes Diptera, Psocoptera, Hymenoptera, and Lepidoptera). Median changes in relative richness and their p values were calculated in the same manner as for abundances, described above.

Spiders exhibited a relatively consistent pattern of decreasing richness in both arboreal and terrestrial communities. This pattern was strongest among native arboreal species, but declines in total spider richness were also significant one year after trapping in arboreal samples and two years after trapping in ground samples. Conversely, Hemiptera had a fairly consistent pattern of increasing richness after trapping began. Coleoptera only showed evidence of increasing richness at two years post-trapping among terrestrial communities, with the change in overall richness being significant, and changes in both native and adventive subsets of species being relatively close to statistically significant.

Evidence for increases in total community species richness after trapping was strongest for native terrestrial arthropods, with some indication of increasing adventive species richness in arboreal communities after two years. Overall, changes in richness were relatively small in magnitude, and tended to mirror the changes in abundances that were measured.

Changes in trophic structure

Relative changes in biomass, categorized by trophic group, and relative changes in percent composition of arthropod communities by trophic group, are given in Table 3. Median biomass is presented in mg of dry weight, while median changes in percent composition are given in the lower portion of the table. Presentation and analyses are as described above for abundances and species richness.

There were no significant changes in biomass over time for any of the trophic groups in either arboreal or terrestrial communities. The percent composition by trophic group, however, did change significantly at two years post-trapping. In arboreal communities, the herbivore fraction increased significantly at the removal site relative to the control site, mainly at the expense of the carnivore fraction. In terrestrial communities, the herbivore fraction declined significantly, mainly in concert with a relative increase in detritivores. These trophic shifts were fairly small in magnitude, however, and are illustrated graphically in Figures 2 and 3.

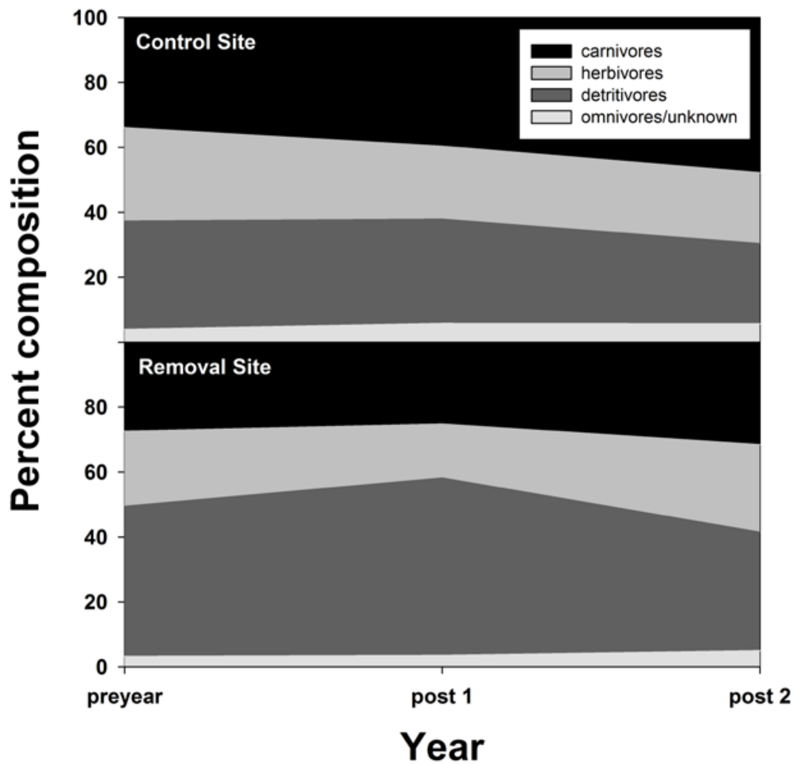


Figure 2. Changes in trophic structure over time in arboreal arthropod communities at the Palikea rodent removal and control sites. Percent composition of trophic groups is measured in biomass and averaged over all plots at each site.

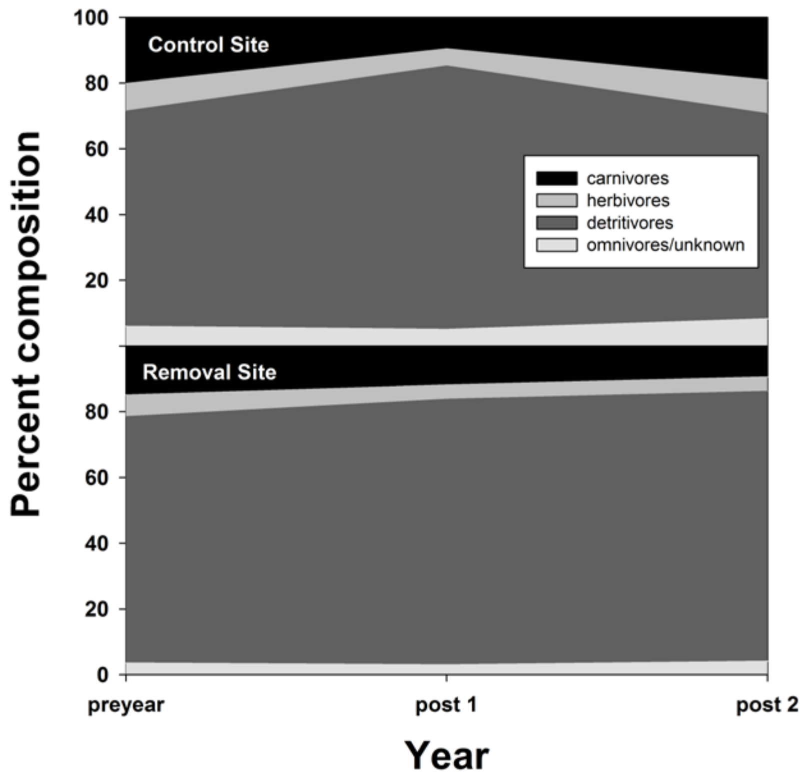


Figure 3. Changes in trophic structure over time in terrestrial arthropod communities at the Palikea rodent removal and control sites. Percent composition of trophic groups is measured in biomass and averaged over all plots at each site.

While trophic shifts over time were moderate, the graphs do indicate large differences in trophic composition between arboreal and terrestrial communities, with terrestrial communities dominated by detritivores, and arboreal communities more evenly split between carnivores, herbivores and detritivores.

FY15 plans

Funding for FY15 will allow continued identification of the July 2013 monitoring material, and the sorting and identification of the July 2014 monitoring event samples. This will allow an assessment of the response of arthropod communities up to four years after rodent trapping was implemented. Analysis, synthesis and write-up of final datasets for the first three years of post-trapping data for both sites is planned for FY15. (Reference to this project, and some preliminary results, were made in the 2013 publication: Medeiros, M.J., J.A. Eiben, W.P. Haines, R.L. Kaholoaa, C.B.A. King, P.D. Krushelnycky, K.N. Magnacca, D. Rubinoff, F. Starr and K. Starr. 2013. The importance of insect monitoring to conservation actions in Hawaii. Proceedings of the Hawaiian Entomological Society 45: 149-166).

FY15 plans also include initiation and significant progress on the new *Solenopsis* component of the project. Plans include conducting bait preference tests to determine optimal baits for both non-destructive monitoring and for suppression/control; determination of field plot locations for pre- and post-control monitoring of arthropod communities; and initiation of *Drosophila* rearing and monitoring methods specific to the goals of the project.

Table 1. Relative changes in median abundance, per plot, of arthropods at the Palikea rodent removal site relative to the control site, at one and two years after rodent trapping was initiated. See text for details.

	Palikea							
	Vegetation sampling				Ground sampling			
	1 year		2 years		1 year		2 years	
Group	**median**	**p**	**median**	**p**	**median**	**p**	**median**	**p**
Chilopoda total	1.00	0.088	-1.00	0.245	-1.00	0.586	-2.00	0.381
Diplopoda total	5.00	0.394	-3.00	0.535	**18.00**	**0.002**	**17.00**	**0.001**
Amphipoda total	1.50	0.064	**-0.50**	**0.050**	-22.50	0.384	**-54.50**	**0.007**
native Amphipoda	0.00	0.593	-0.50	0.063				
adventive Amphipoda	1.50	0.075	0.00	0.638	-22.50	0.384	**-54.50**	**0.007**
Isopoda (all adventive)	-5.00	0.571	-1.50	0.760	-53.50	0.486	-63.50	0.360
Acari	-50.00	0.058	2.00	1.000	-5.50	1.000	133.00	0.486
Araneae total	-16.50	0.384	16.50	0.223	**-19.00**	**0.003**	-9.00	0.065
native Araneae	-19.00	0.184	7.00	0.472	0.00	0.979	-1.00	0.381
adventive Araneae	-1.00	0.679	-0.50	0.811	**-12.00**	**0.005**	**-6.00**	**0.044**
Archaeognatha (all native)	-0.50	0.107	0.00	0.260				
Blattaria (all adventive)	-2.00	0.368	-1.50	0.570	0.00	1.000	0.00	0.181
Coleoptera total	-0.50	0.868	1.50	0.695	0.50	0.965	8.00	0.108
native Coleoptera	0.50	0.879	-0.50	0.868	-0.50	0.959	3.00	0.139
adventive Coleoptera	0.50	0.647	2.50	0.163	1.00	1.000	**2.50**	**0.041**
Collembola total	58.00	0.433	**62.50**	**0.045**	-108.50	0.139	-101.00	0.191
Dermaptera total					-1.00	0.528	1.00	0.758
native Dermaptera					0.00	0.374	-0.50	0.507
adventive Dermaptera					-0.50	0.287	0.50	0.460
Diptera total	-1.00	0.856	3.50	0.601	10.00	0.082	-1.50	0.728
Hemiptera total	14.50	0.074	17.00	0.258	-1.00	0.695	0.50	0.717
native Hemiptera	**12.50**	**0.043**	10.00	0.177	0.50	0.776	0.50	0.410
adventive Hemiptera	1.50	0.616	2.50	0.663	0.50	0.623	0.00	0.959
Hymenoptera total	**11.00**	**0.045**	**22.00**	**0.009**	0.50	0.433	-1.00	0.215
native Hymenoptera (mainly Sierola)	5.00	0.053	4.00	0.148	0.00	0.100	0.00	0.465
adv Hymenoptera (mainly Formicidae)	1.50	0.132	1.50	0.221	0.00	0.730	**-1.50**	**0.028**
Lepidoptera total	1.00	0.948	0.50	0.887	-7.50	0.601	**-26.50**	**0.041**
immature Lepidoptera total	0.00	0.897	1.50	0.096	-13.00	0.459	**-32.50**	**0.006**
immature Hyposmocoma	-4.00	0.327	-2.00	0.670	4.00	0.267	**8.50**	**0.039**
immature Eupithecia	0.00	0.878	**1.00**	**0.026**	**0.50**	**0.050**	**0.50**	**0.022**
Neuroptera total	0.00	0.294	-0.50	0.221				
native Neuroptera	0.00	0.181	0.00	0.059				
adventive Neuroptera	0.00	0.893	0.00	0.787				

Orthoptera total	**4.50**	**0.007**	**5.00**	**0.008**	0.00	0.859	0.00	0.889
native Orthoptera	**4.00**	**0.015**	**6.00**	**0.005**	0.00	0.859	0.00	0.889
adventive Orthoptera	0.00	0.236	0.00	0.116				
Gryllidae (all native Laupala)	**4.00**	**0.022**	**5.00**	**0.008**	0.00	0.859	0.00	0.889
Tettigoniidae total	1.00	0.233	0.00	1.000				
native Tettigoniidae (Banza)	0.50	0.363	1.00	0.196				
adventive Tettigoniidae	0.00	0.236	0.00	0.116				
Psocoptera total	**-24.50**	**0.010**	**-18.00**	**0.017**	9.00	0.118	-7.50	0.177
Thysanoptera total	4.50	0.102	5.50	0.098	-9.00	0.571	-14.00	0.327
Arthropoda total	36.50	0.896	93.50	0.207	-182.00	0.663	-194.50	0.327
native Arthropoda	5.00	0.862	32.00	0.068	1.50	0.636	**10.00**	**0.037**
adventive Arthropoda	6.00	0.647	4.00	0.795	-86.00	0.372	-120.00	0.267
unknown status Arthropoda	45.00	0.777	72.50	0.163	-83.00	0.828	-19.50	0.965

Table 2. Relative changes in median species richness, per plot, of arthropods at the Palikea rodent removal site relative to the control site, at one and two years after rodent trapping was initiated. See text for details.

	Palikea							
	Vegetation sampling				**Ground sampling**			
	1 year		**2 years**		**1 year**		**2 years**	
Group	**median**	**p**	**median**	**p**	**median**	**p**	**median**	**p**
Araneae total	**-2.50**	**0.007**	-1.50	0.106	-0.50	0.587	**-1.50**	**0.016**
native Araneae	**-2.00**	**0.018**	**-1.50**	**0.004**	0.00	0.754	-0.50	0.266
adventive Araneae	-0.50	0.569	0.50	0.286	0.00	0.737	-1.00	0.109
Coleoptera total	-0.50	0.518	1.00	0.379	1.00	0.156	**3.00**	**0.041**
native Coleoptera	0.50	0.501	0.50	0.623	1.00	0.103	1.00	0.088
adventive Coleoptera	-0.50	0.508	0.50	0.777	0.00	1.000	1.00	0.058
Hemiptera total	**3.00**	**0.010**	3.00	0.052				
native Hemiptera	**2.50**	**0.010**	2.00	0.313				
adventive Hemiptera	1.00	0.267	**2.00**	**0.050**				
immature Hyposmocoma	-1.00	0.066	-1.00	0.142	0.50	0.308	1.00	0.074
Arthropoda total	-1.00	0.879	3.00	0.218	2.00	0.223	4.50	0.071
native Arthropoda	0.00	0.962	-1.00	0.372	**2.00**	**0.030**	**3.00**	**0.031**
adventive Arthropoda	0.50	0.828	**3.00**	**0.028**	-0.50	0.551	1.00	0.245
unknown status Arthropoda	-1.00	0.449	0.00	0.977	1.00	0.281	0.50	0.538

Table 3. Relative changes in median biomass and trophic composition, per plot, of arthropods at the Palikea rodent removal site relative to the control site, at one and two years after rodent trapping was initiated. Biomass is in units of mg dry weight; lower portion of table indicates changes in percent composition of trophic groups (according to biomass contributions). See text for additional details.

	Palikea							
	Vegetation sampling				**Ground sampling**			
	1 year		**2 years**		**1 year**		**2 years**	
Group	**median**	**p**	**median**	**p**	**median**	**p**	**median**	**p**
carnivore biomass	13.60	0.571	-26.75	0.207	11.72	0.695	-20.43	0.514
herbivore biomass	4.50	0.571	7.58	0.695	-3.76	0.728	-16.09	0.127
detritivore biomass	54.86	0.191	-21.04	0.191	-12.28	0.965	31.60	0.728
omnivores and unknown biomass	-1.17	0.296	0.90	0.571	1.04	0.965	3.48	0.760
total biomass	63.97	0.127	-22.90	0.571	53.13	0.486	4.31	0.965
percent carnivore	-8.13	0.191	-13.96	0.055	3.40	0.601	-5.42	0.296
percent herbivore	2.59	0.433	**11.67**	**0.019**	1.13	0.514	**-3.42**	**0.050**
percent detritivore	5.69	0.384	0.20	0.931	-6.12	0.177	9.36	0.098
percent omnivore and unknown	-1.26	0.089	0.64	0.601	0.75	0.384	-0.68	0.663