# Appendix ES-1 Spelling of Hawaiian Names

| Place name | Hawaiian spelling |
|---|---|
| | |
| Aiea | ʻAiea |
| Aihualama | ʻAihualama |
| Aimuu | Aimuu |
| Alaiheihe | Alaiheihe |
| Alau | Alau |
| Ekahanui | ʻĒkahanui |
| Halawa | Hālawa |
| Haleauau | Haleʻauʻau |
| Halona | Hālona |
| Hawaii | Hawaiʻi |
| Hawaii loa | Hawaiʻiloa |
| Helemano/Halemano | Helemano/Halemano |
| Honolulu | Honolulu |
| Honouliuli | Honouliuli |
| Huliwai | Huliwai |
| Kaaikukai | Kaʻaikūkaʻi |
| Kaala | Kaʻala |
| Kaawa | Kaʻawa |
| Kaena | Kaʻena |
| Kahaluu | Kahaluʻu |
| Kahana | Kahana |
| Kahanahaiki | Kahanahāiki |
| Kaimuhole | Kaimuhole |
| Kaipapau | Kaipāpaʻu |
| Kaiwikoele | Kaiwikōʻele |
| Kalauao | Kalauao |
| Kaleleliki | Kaleleiki |
| Kalena | Kalena |
| Kaluaa | Kaluaʻā |
| Kaluakauila | Kaluakauila |
| Kaluanui | Kaluanui |
| Kamaileunu | Kamaileʻunu |
| Kamaili | Kamāʻili |
| Kamananui | Kamananui |
| Kapakahi | Kapakahi |
| Kapuna | Kapuna |
| Kauai | Kauaʻi |
| 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 Army Propagation Database

**Overview**

The Army Propagation Database (APD) 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 or 2010 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 10 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, 2012.

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

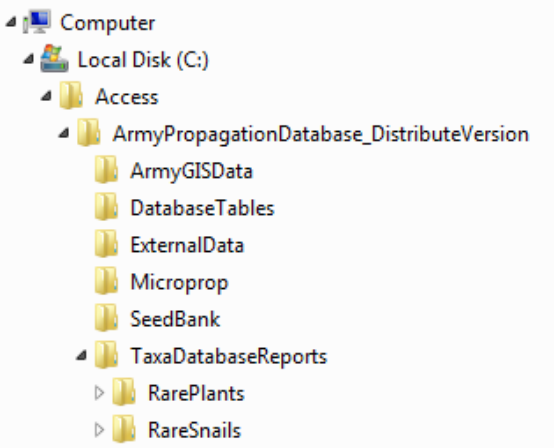
Krista Winger
Natural Resources Database/GIS Manager
Oahu Army Natural Resources Program
Email: krista.l.winger.ctr@mail.mil

# 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\ArmyPropagationDatabase_DistributVersion:

ArmyPropagationDatabase_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 APD is kept in the back-end data file (ArmyPropagationDataTables.mdb) located in the database tables subdirectory. Forms are locked and may only be used for viewing purposes.

C:\Access\ArmyPropagationDatabase\ArmyGISData\

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

C:\Access\ArmyPropagationDatabase\DatabaseTables
ArmyPropagationDataTables_DV.mdb

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

C:\Access\ArmyPropagationDatabase\Microprop
Microprop.mdb

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

C:\Access\ArmyPropagationDatabase\SeedBank
SeedBankDatabase.mdb

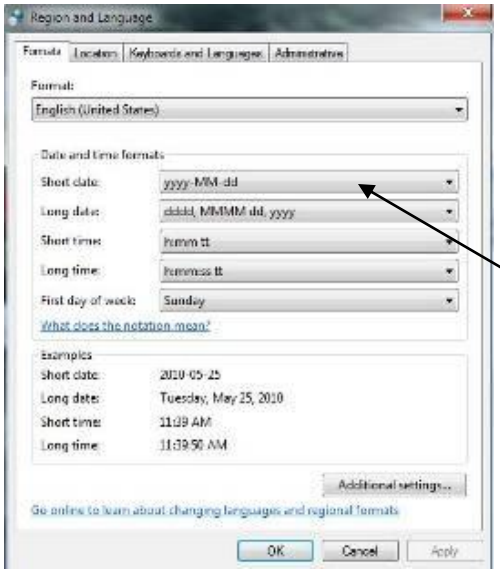
Army SeedLab Database. Contact Lauren Weisenberger for more information.

C:\Access\ArmyPropagationDatabase\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.



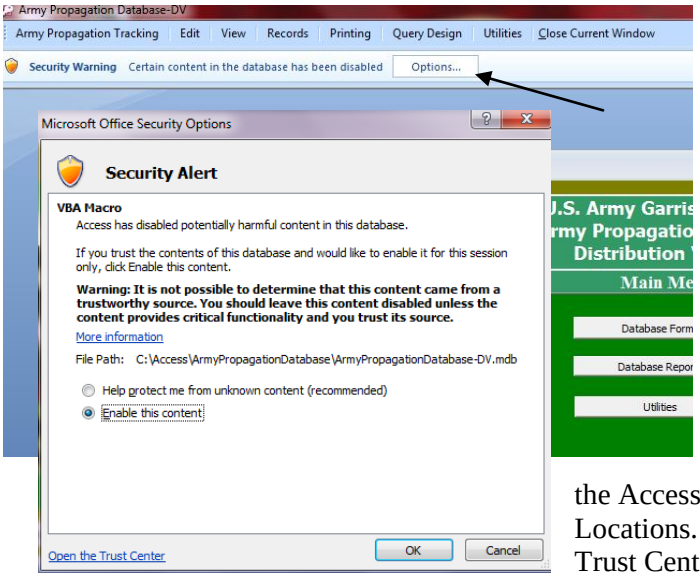

- Open Regional and Language Options by clicking the **Start** button, clicking **Control Panel**, clicking **Clock, Language, and Region**, and then clicking **Regional and Language.** Under the Formats, change the **Short Date** to **yyyy-MM-dd.**

Change to yyyy-MM-dd

## Security Warning

Security features in Microsoft Access 2007 and 2010 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 database content must be enabled when the Security Warning appears..



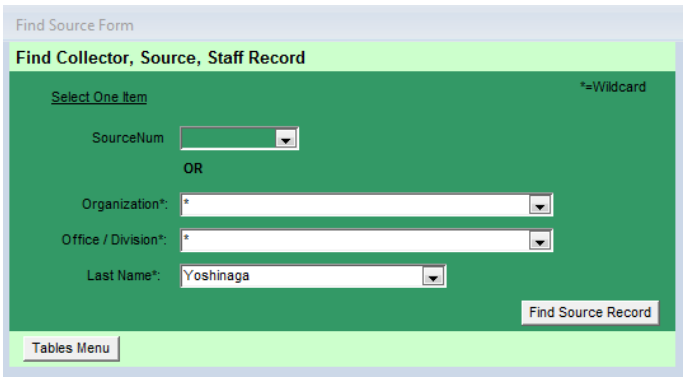

After opening the ArmyPropagationDatabase_DV.mdb file in Microsoft Access, click on Options when it appears at the top of your screen.

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.

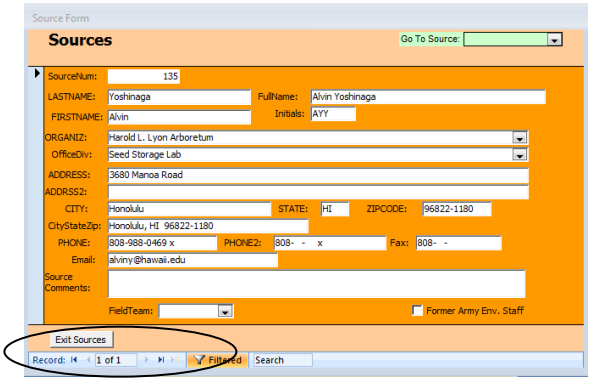
Enabling content will have to be done every time the database file is opened. You may avoid having this Security Warning appear if the Access subdirectory is added to the Trust Center Locations. Contact Roy Kam if you need to establish a Trust Center Location.

## 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.

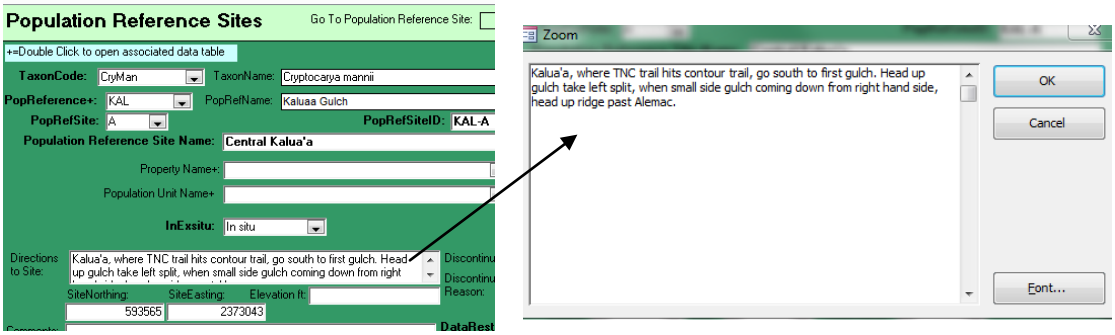



Using the * (asterisk), in a Find Form represents a wild card. Such as Organization *= Search for all Sources with any Organization. In this case, we will just search for the Last Name = Yoshinaga.

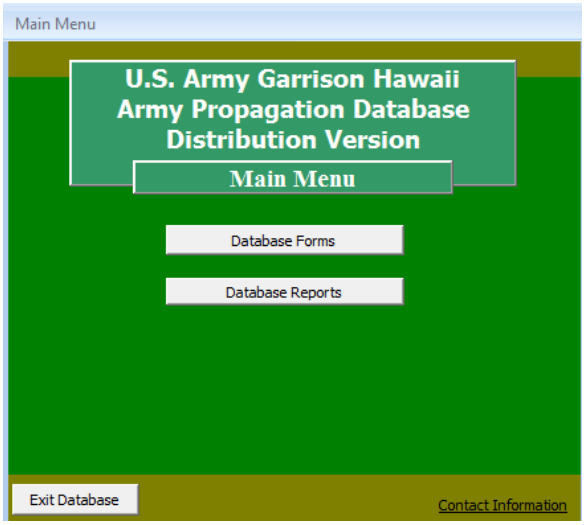



On the bottom of each Data entry form (such as the Sources Form), there are a set of Navigation buttons. These buttons allow you to go to the previous or next record. Pressing the tab or enter keys moves from one data field to another.

**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 **ArmyPropagationDatabase_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.

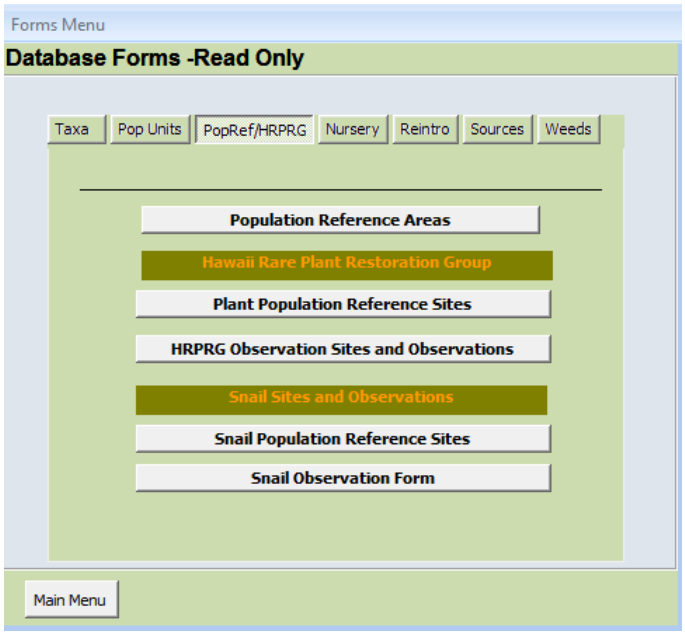
The database is broken up into 2 parts, Database Forms and Database Reports. We will primarily cover the Database reports. Database Forms are self-explanatory and is only for viewing purposes. The forms are provided for detailed review of individual observations. Only pertinent data fields will be discussed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

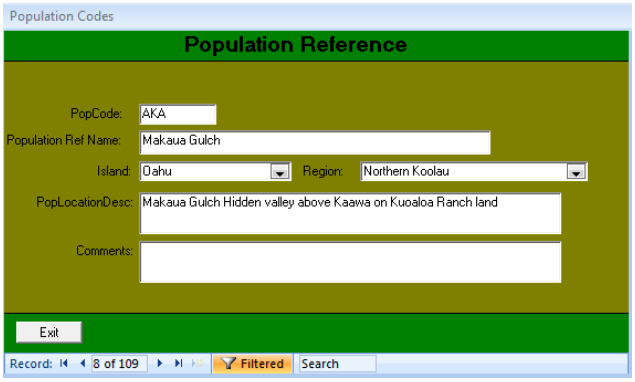
For the purpose of this tutorial, we will discuss forms of the PopRef/HRPRG tab with comprise of the Population Reference and Population Reference Sites. All other sections, are supplemental and self-explanatory.



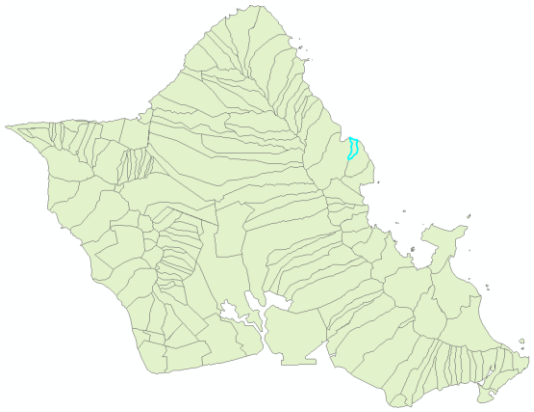

### PopRef, Sites, and Observations

Population information are 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.

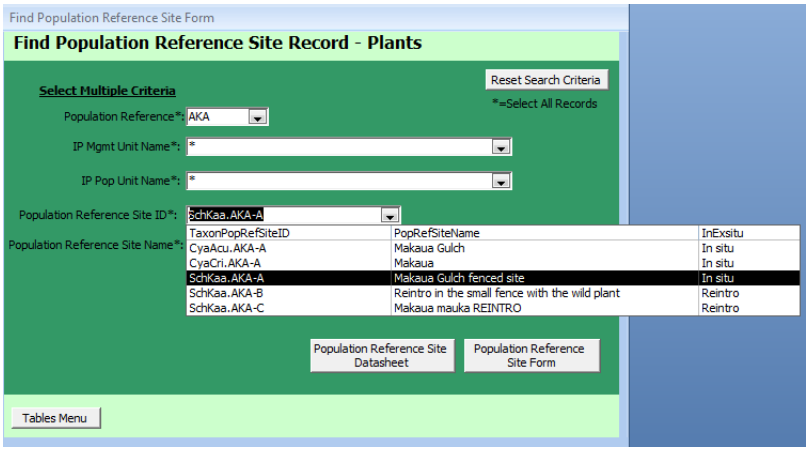


It should be noted that the Population Reference is not necessarily the name for any given population. It is only used as an identifier to compile different plant or animal populations within a given area. For example: Makaua on the Windward Koolau of Oahu (highlighted in blue). The GIS boundary is based 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)

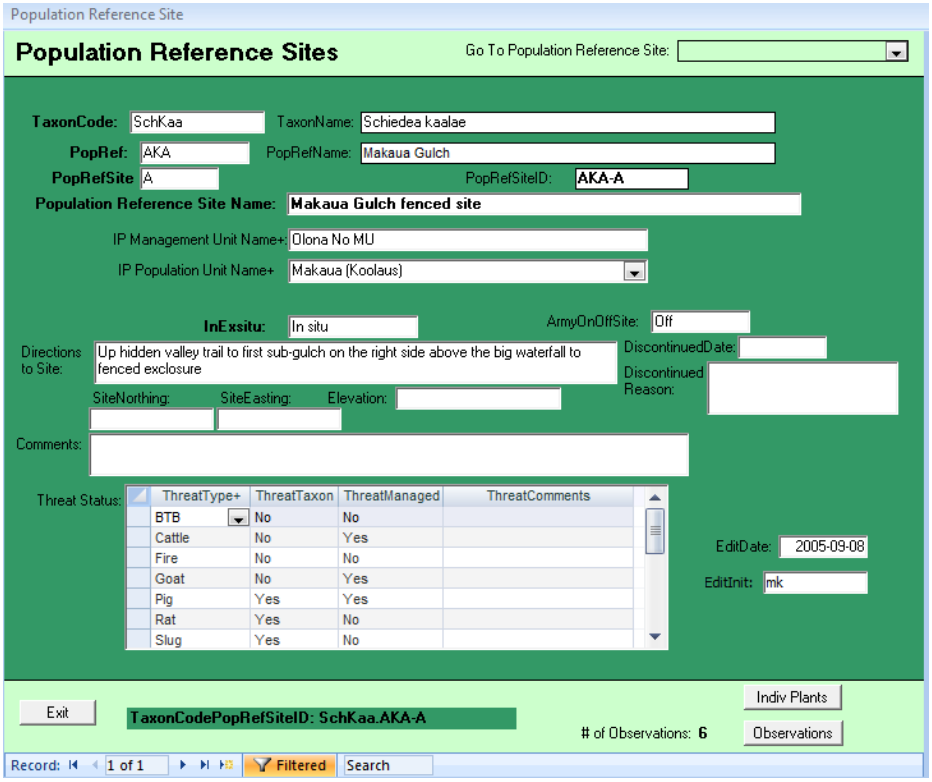
The Population Reference Site (PopRefSite) is the primary data table in establishing plant or animal population sites. The PopRefSite identifies the Population Name, whether it is In situ, Ex situ or Reintro, and provides directions to the site, etc. The PopRefSite is only site information; observation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




**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.

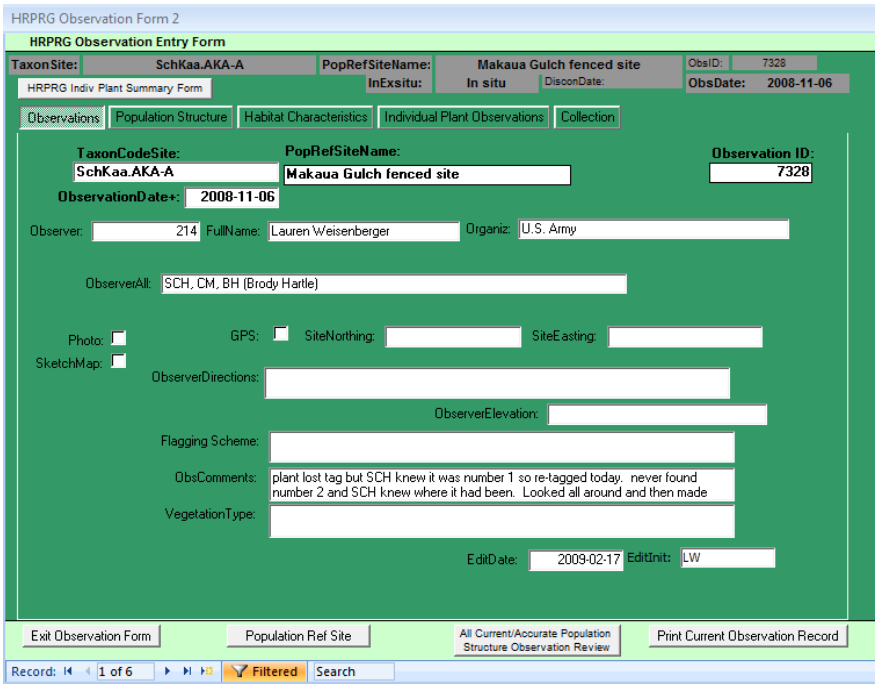
**IP Population Unit Name (PopUnit):** The PopUnit is used when several PopRefSites need to be tracked together. Such as a taxon with several sites throughout the Northern Waianae Mountains, Northern Waianae could be used as a PopUnit Name.

**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

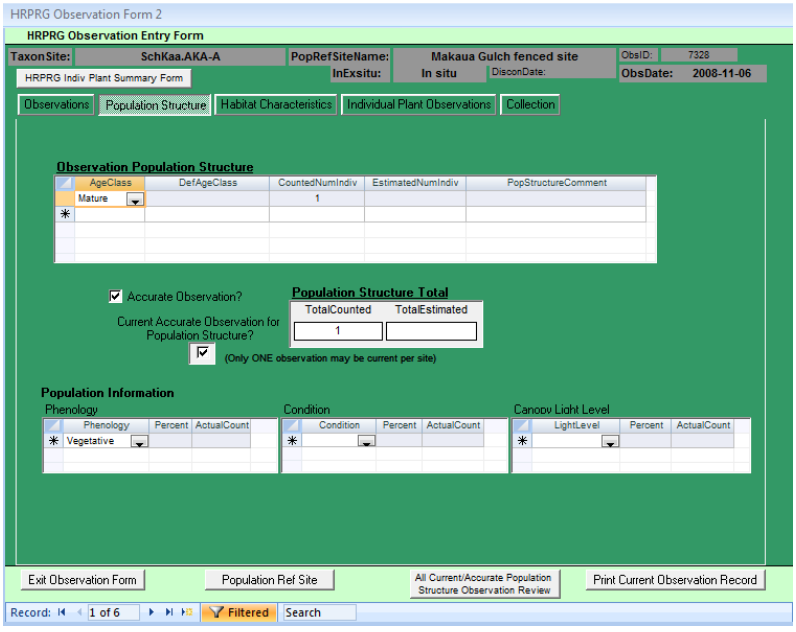



Clicking the Observations button on the bottom of the PopRefSite Form will open up the corresponding Observations.

**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.

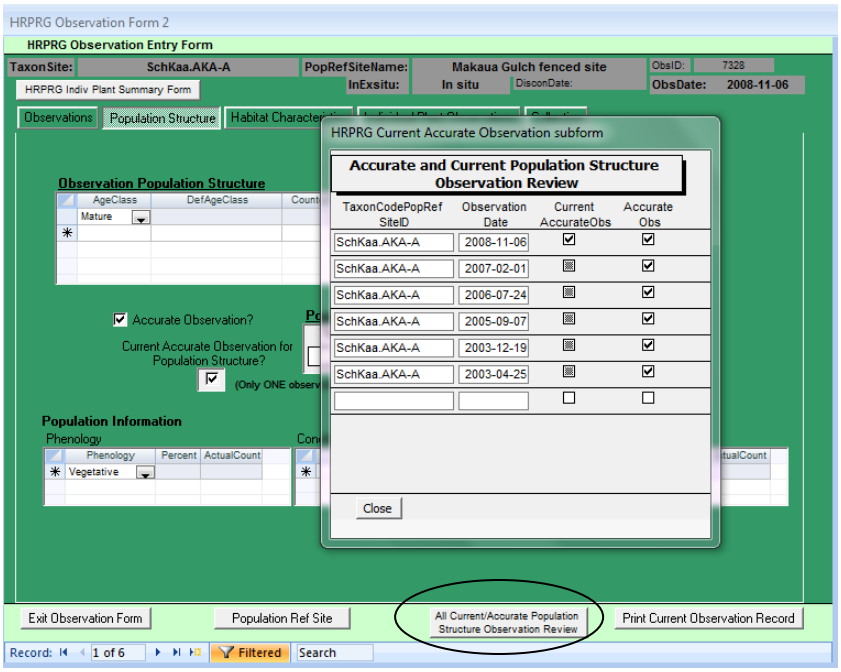
**Population Structure**
The Population Structure should are always entered for any observations, even if the number of plants observed are incomplete (not all plants observed).




**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.

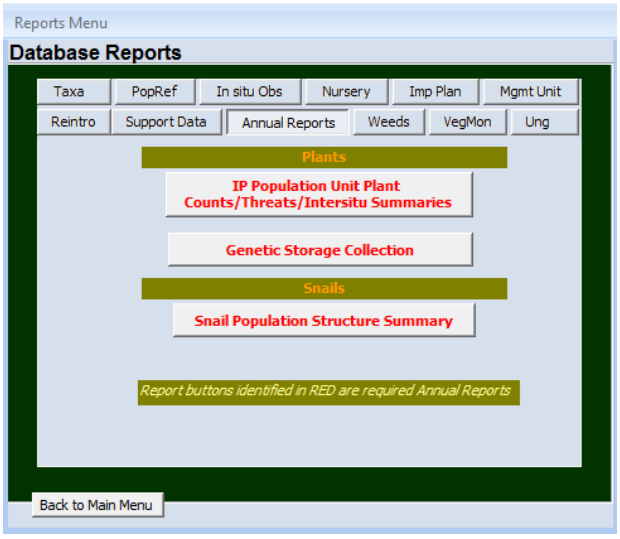



As opposed to the Accurate Observation check box, the **Current Accurate Observation** check off box may only have one observation checked. The Current Accurate represents the population structure that is considered both current and accurate. The most recent observation may not always be the Current 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. Database Reports

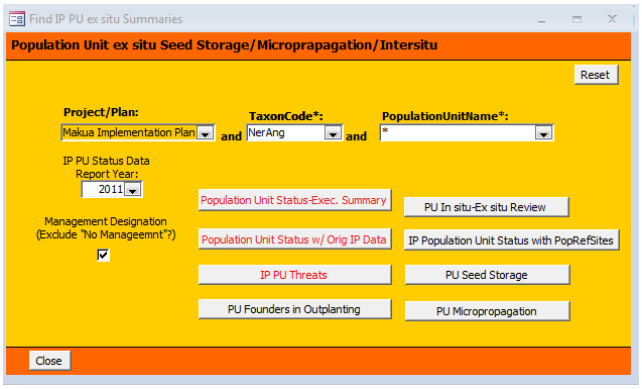
Starting from the Main Menu, click on the Database Reports button. The Database Reports menu provides reports for various sections of the database.




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. Select 2011 for the report year. Report Year is defined below.

## Executive Summary

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

**Makua Implementation Plan - Executive Summary - Plants**

# of Stable IP Population Units: 1 of 4

= 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 2011 | # Plant in Original Report | % Completed Genetic Storage | % of Plants Protected from Ungulates | PU Met Goal? | # PU Met Goal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Neraudia angulata | 100 | | | | | | | | | | | |
| | | Kaluakauila | 164 | 164 | 0 | 0 | 118 | 0 | 0% | 100% | Yes | |
| | | Makua | 39 | 24 | 15 | 1 | 74 | 29 | 18% | 100% | No | |
| | | Manuwai | 0 | 0 | 0 | 0 | 0 | 12 | 29% | 0% | No | |
| | | Waianae Kai Mauka | 20 | 16 | 4 | 0 | 20 | 46 | 27% | 100% | No | |
| | | Neraudia angulata Total: | 223 | 204 | 19 | 1 | 212 | 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 | Original IP Total Mature | Original IP Total Imm | Original IP Total Seedling | Total Mature 2011 | Total Immature 2011 | Total Seedling 2011 | Current Mature (Wild) | Current Immature (Wild) | Current Seedling (Wild) | Current Outplanted Mature | Current Outplanted Immature | Current Outplanted Seedling | Total Current Mature | Total Current Immature | Total Current Seedling | PU LastObs Date | Population Trend Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kaluakauila | Manage reintroduction for stability | | | | 118 | 0 | 0 | 0 | 0 | 0 | 164 | 0 | 0 | 164 | 0 | 0 | 2012-03-22 | More plants were added to the reintroduction site |
| Kapuna | Genetic Storage | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2012-09-12 | The last remaining wild plant died in the last year |
| Makua | Manage for stability | 29 | 0 | 22 | 73 | 1 | 1 | 19 | 15 | 1 | 5 | 0 | 0 | 24 | 15 | 1 | 2012-08-26 | Small changes were noted during monitoring in the last year |
| Punapohaku | Genetic Storage | | | | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2012-08-28 | Monitoring showed no change |
| | In Total: | 30 | 0 | 22 | 192 | 1 | 1 | 20 | 15 | 1 | 169 | 0 | 0 | 189 | 15 | 1 | | |

**Action Area: Out**

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

| Population Unit Name | Management Designation | Original IP Total Mature | Original IP Total Imm | Original IP Total Seedling | Total Mature 2011 | Total Immature 2011 | Total Seedling 2011 | Current Mature (Wild) | Current Immature (Wild) | Current Seedling (Wild) | Current Outplanted Mature | Current Outplanted Immature | Current Outplanted Seedling | Total Current Mature | Total Current Immature | Total Current Seedling | PU LastObs Date | Population Trend Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Halona | Genetic Storage | 15 | 0 | 0 | 30 | 4 | 0 | 30 | 4 | 0 | 0 | 0 | 0 | 30 | 4 | 0 | 2006-05-22 | No monitoring since 2006 |
| Leeward Puu Kaua | Genetic Storage | 3 | 0 | 0 | 9 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 2006-11-21 | No monitoring since 2006 |
| Makaha | Genetic Storage | 56 | 14 | 0 | 6 | 7 | 0 | 6 | 7 | 0 | 0 | 0 | 0 | 6 | 7 | 0 | 2011-04-27 | No monitoring in the |

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'.

**Original IP Total 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

**Current Mature, Immature, Seedling (Wild):** These second 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.

**Current Mature, Immature, Seedling Outplanted:** 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.

**Total Mature, Immature and Seedling 2011:** 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.

**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 | 348 | Partial 99.43% | Partial 95.40% | Partial 31.03% | 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 | 125 | Partial 98.40% | Yes | Yes | No | No | No |
| Makaha and Waianae Kai | Manage for stability | 13 | Partial 61.54% | Partial 61.54% | No | No | No | No |
| South Huliwai | Genetic Storage | 17 | No | Yes | 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

**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.

**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. OANRP will develop this threat table in the next year to account for other potential threats such as arthropods other than the BTB, the fungal rust (*Puccinia psidii*) and other plant pathogens as they are identified and the threat evaluated.

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

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

2012-11-16



**Genetic Storage Summary**

| Population Unit Name | # of Potential Founders | | | Partial Storage Status | | | | Storage Goals | | | | Storage Goals Met |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Current Mature | Current Imm. | NumWild Dead | # 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 |
| **Neraudia angulata** | | | | | | | | | | | | |
| Halona | 30 | 4 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 7 | 7 |
| Kapuna | 0 | 0 | 2 | 1 | 1 | 0 | 2 | 0 | 0 | 0 | 2 | 2 |
| Leeward Puu Kaua | 9 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 |
| Makaha | 6 | 7 | 12 | 2 | 1 | 0 | 12 | 1 | 0 | 0 | 11 | 11 |
| Makua | 19 | 15 | 75 | 2 | 2 | 0 | 23 | 1 | 0 | 0 | 20 | 20 |
| Manuwai | 0 | 0 | 7 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 2 |
| Punapohaku | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Waianae Kai Makai | 45 | 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Waianae Kai Mauka | 16 | 4 | 13 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 9 | 9 |
| | **Total Current Mature** | **Total Current Imm.** | **Total NumWild Dead** | **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** |
| | 126 | 65 | 109 | 5 | 4 | 0 | 58 | 2 | 0 | 0 | 52 | 52 |

**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.

**Storage Goals Met:** 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.

## Snail Population Status Summary

### Number of Snails Counted

| Population Reference Site | Management Designation | Total Snails | Date of Survey | Size Classes | | | | Threat Control | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Large | Medium | Small | Unk | Ungulate | Weed | Rat | Euglandina rosea | Jackson's Chameleon |
| **Achatinella mustelina** | | | | | | | | | | | | |
| **ESU: A** | **Pahole to Kahanahaiki** | | | | | | | | | | | |
| **MMR-A** Kahanahaiki Exclosure | Manage for stability | 54 | 2012-07-24 | 35 | 10 | 9 | 0 | Yes | Yes | Yes | Yes | |
| **MMR-C** Maile Flats | Manage for stability | 99 | 2012-05-17 | 68 | 23 | 8 | 0 | Yes | Yes | Yes | No | |
| **PAH-B** Pahole Exclosure | Manage for stability | 55 | 2011-09-27 | 32 | 16 | 7 | 0 | Yes | Yes | Yes | Yes | |
| | **ESU Total:** | 208 | | 135 | 49 | 24 | 0 | | | | | |

Size Class Definitions

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

= 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.

**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.

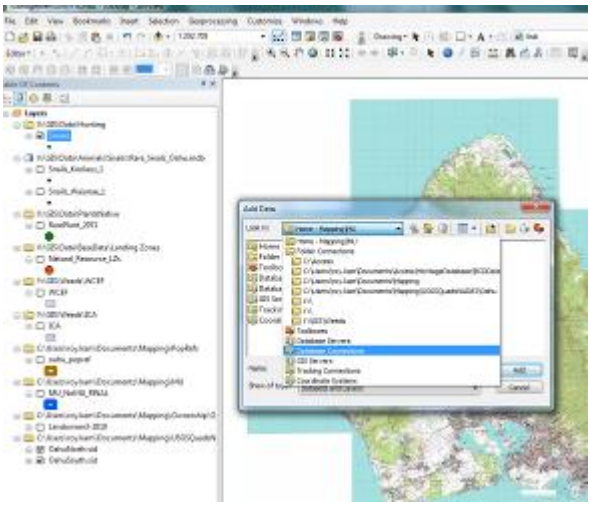
**Management Designation**: In the next column, the management designation is listed for each field site. The tables used in this report only display the sites chosen for MFS, where NRS is actively conducting management. These sites are generally the most robust sites in terms of snail numbers, habitat 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

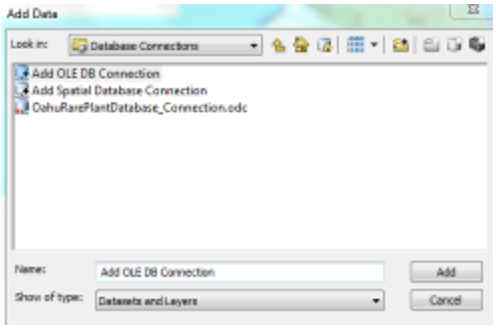
**R. Kam**



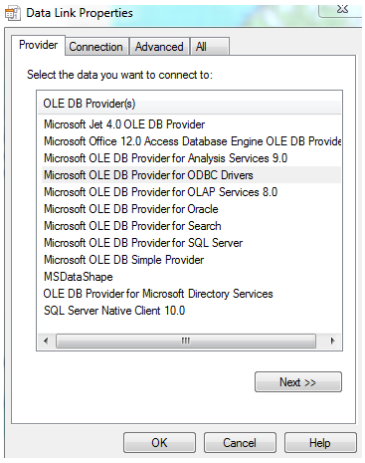
There may be times that information found in the Access database is needed in a GIS map. The following shows you how to link a query from Access into an ArcGIS project. The Population Reference Site query will be used as an example. Note there are several steps needed to bring in an Access Database query.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

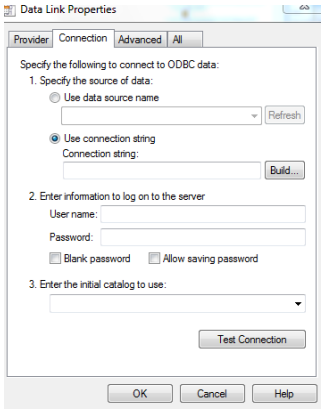
Click on the Add Button , and choose *Database Connections*.



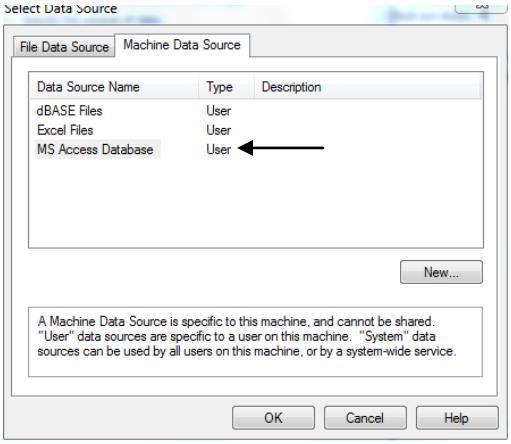

Then select *Add OLE Database Connection*, and click on Add.



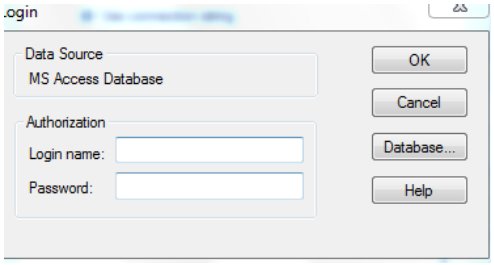

A Data Link Properties window will appear. Select *Microsoft OLE DB Provider for ODBC Drivers*.




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*.

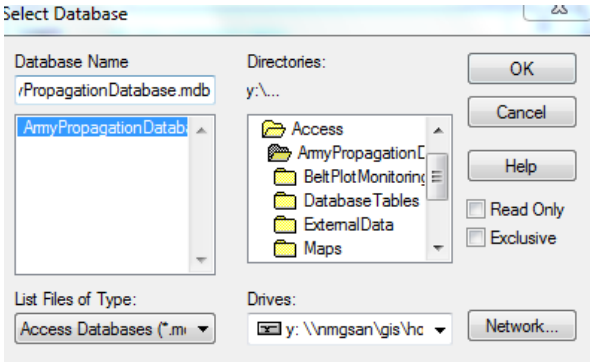



In the Select Data Source window, select the *Machine Data Source* tab, and select *MS Access Database then* click *OK*.

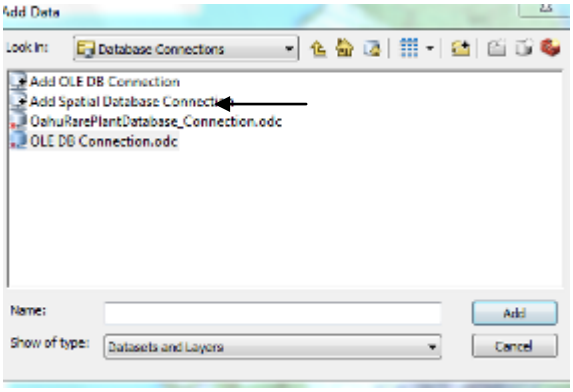



In the LogIn Window, Click on the *Database* button (leave Login Name and Password blank).

In the Select Database, change the Drives to C: and browse to C:\Access\ ArmyPropagationDatabase_DistributeVersion\ ArmyPropagationDatabase_DV.mdb

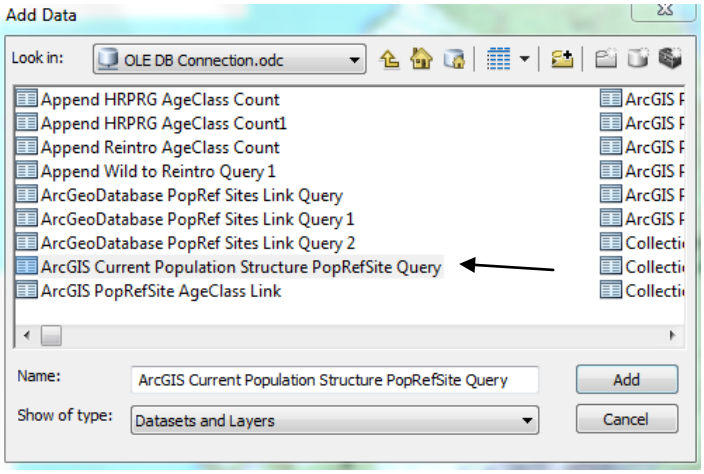


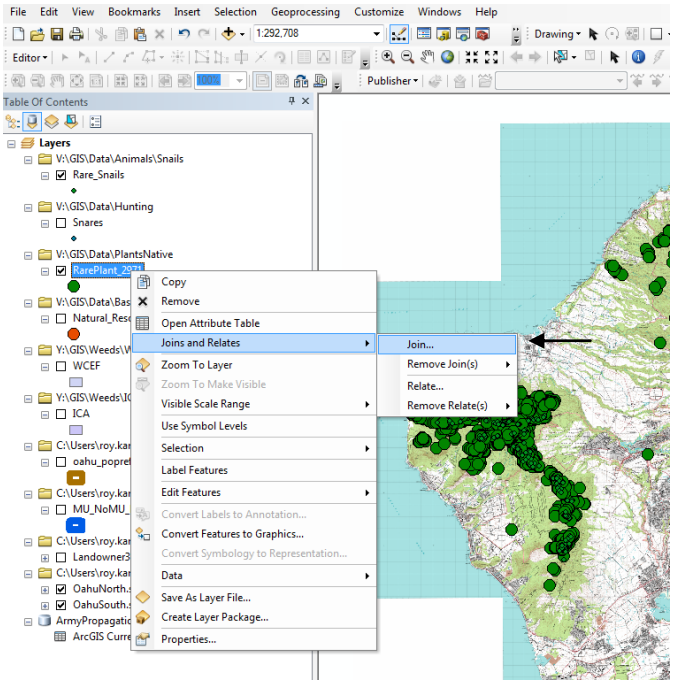

Click Ok to close the windows, until you are back at the Add Data window. You will now see a new OLE DB Connection.odc listed.



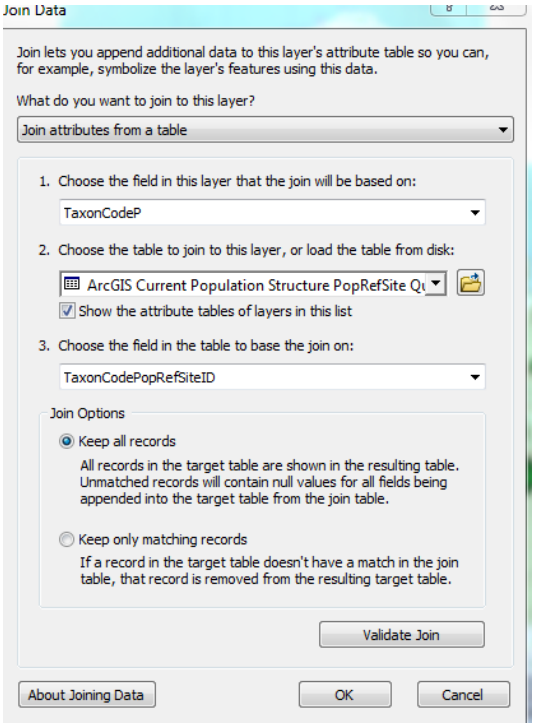

Double click on the OLE DB Connection.odc. The window will then open the Access Database and list all tables and queries.

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.

**Keaau Forest Reserve Fire Memorandum for Record**
April 30 – May 1, 2012

APVG-GWV (200-3) 9 May 2012

**MEMORANDUM FOR RECORD**

**SUBJECT:** Memorandum for record regarding Keaau Forest Reserve Fire April 30 – May 1, 2012.

**Background**

The fire started at approximately 1000 on April 30, 2012 in the Makua Keaau Forest Reserve in the Waianae Mountains, Oahu. The cause of the fire is unknown, however, a suspicious individual was questioned and released by a State of Hawaii DOCARE officer. This individual was observed by AirOne while responding to the fire and was apprehended leaving the scene. The OANRP fencing staff, who were driving out to begin their field day in the Makua Military Reservation, observed the fire and called back to base to report. Base notified Joby Rohrer at about 1030 and preparations were made to dispatch staff, mobilized helicopter support and briefed the USAG Natural Resource Manager and OANRP Program Manager.

The fire was burning inside the Forest Reserve boundary through dry fuels dominated by *Uchaloa maximum, Leucaena leucephala,* and *Prosopis pallida*. The fire posed a threat to native dry forest including rare and federally listed endangered species located approximately 500 meters to the north in the Keaau Management Unit. Fire is the largest threat to dry forest ecosystems in Hawaii which have become dominated by invasive grass such as *U. maximum*. The Endangered plant taxa threatened by this fire include *Hibiscus brackenridgei* subsp. *mokuleianus*, *Gouania vitiifolia*, and *Spermolepis hawaiiensis*. Both *H. brackenridgei* and *G. vitiifolia* are stabilization taxa in the Makua Military Reservation Implementation Plan and these populations represent a significant portion of the known remaining individuals. The Oahu Army Natural Resource Program works to conserve these species including the plants at the Keaau management Unit and have plans for stabilizing these populations.

The weather at the time was dry (66% rH), hot ( >85 F) and windy (5-20mph) out of the northeast. These conditions favored the rapid spread through the dry steep terrain of Waikomo Gulch towards the Keaau Management Unit located northwest of the fire. These conditions and the proximity to rare endangered plants prompted OANRP to respond to the fire to assist DOFAW and provide helicopter support for transporting crews and water drops.


Figure 1: Map showing the extent of the burn and proximity to the Keaau Management Unit.

**April 30, 2012**

755.8 (approximately as OANRP was not on site): 1130 Airborne start water bucket loads
756.6: 1230 Airborne start 3 PAX loads (DOFAW crew) to LZ1 and LZ2 on the fire line
757.1: 1315 Airborne gas from HFD truck
757.3: 1330 Airborne start 5 slings to DOFAW crew on fire line
757.7: 1430 Airborne end slings. Then moved two PAX on the fire line then went to Poamoho LZ. Gas at DMR.

758.6: 1630 Airborne Back at Keaau Beach Park, attached bucket for water drops
760.1: 1745 Airborne gas from HFD truck
760.2: 1800 Airborne resume water bucket drops
760.4: 1815 Airborne Begin 5 PAX from LZ1 & LZ2 to Keaau Beach Park
760.8: 1845 Airborne Depart for HNL.

| Staff | Time | Total Hours |
|---|---|---|
| Justin Luafalemana, Romualdo, Simoi Luafalemana, Josiah Jury | 1015-1200 | 7 |
| Matthew Keir | 1200-1930 | 7.5 |
| Joby Rohrer | 1830-2030 | 2.0 |

| Company & Pilot | Time | Total Hours |
|---|---|---|
| Airborne Aviation (Jon Fryer) | ~1130-1815 (minus Koolau extract time) | 5.0 Hobbs |
| AirOne (Steve Aiu) | ~1100-1800 | 7.0 Flat time ,All water drops |
| Paradise (Josh Lang) | ~1215-1430 | 2.25 2 PAX worth |

Sequence of Events

1030: OANRP staff (fence crew) reports a fire in the Keaau Forest Reserve. HFD is on site performing water drops…..

1100: OANRP staff (Matthew Keir) departs from the Schofield Barracks baseyard for Keaau Beach Park.

1130: Airborne Aviation (Jon Fryer) on scene at Keaau Beach Park to begin bucket loads with AirOne (Steve Aiu).

1200: Matthew Keir arrives at Keaau Beach Park and the fence crew departs. AirOne and Airborne flying buckets. Checked in with IC HFD Chief and Ryan Peralta (DOFAW Ops Manager), gave them map of the resources and redirected water drops to the northeast corner of the fire to prevent the fire from spreading north into Waikomo Gulch.

1205: Paradise Helicopters (Josh Lang) arrives at Keaau Bach Park

1230: Airborne stops bucket loads to begin PAX loads. Airborne takes 3 PAX and Paradise takes 2 PAX. The ground crew consisted of a total of 15 personnel from Army Wildlad Fire and DOFAW. The Wildland fire crew was: (Jake, Keahi, Shannon). The DOFAW crew was: Ryan Peralta, Jason Misaki, Marigold Zoll, Irene Specher, Michelle Jones, Fred Bannan, Mark Maxy, Terrence Noguchi, Susi Iott, Chris Miller, Sid Kawahakui, Sean Demello. The DOFAW logistics coordinator at Keaau Beach Park was Aaron Lowe and Dave Smith arrived later to assist and coordinate if needed.

1330: Once the 5 PAX were complete, Airborne attached his long-line and Paradise switched unsuccessfully to water drops. Airborne moved five slings from the Keaau Beach Park to the ground crews while Josh lost his bucket in the ocean and AirOne retrieved it. Paradise returns to Turtle Bay to fix the Bambi Bucket.

1430: Once sling loads were complete, Airborne moved two PAX loads then went to Poamoho Road to pick up OANRP staff at Lower Opaeula. AirOne continues to drop buckets. Ground crews on the northern fire line report starting a back burn to slow or stop the fire from cresting

the ridge with Waikomo gulch. DOFAW Ops Manager Ryan Peralta reported beginning a backburn along the ridgetop to remove fuels from the south face before the fire got there.

1445: AirOne back on water drops for about 20 minutes then has a battery problem and is grounded.

1530: Fire begins to flame up with afternoon down-slope winds and begins 330 backing down the north side of the gulch bottom and up to the Waikomo ridge. A wall of 12 ft flames began moving slowly downhill with the down-slope winds.

1615: Airborne back and resumes water buckets. It was just Airborne fighting it for a while then wind shift upslope. During this period Airborne reports almost losing the fire as it burned aggressively down slope. AirOne returns with a new battery and resumes water drops.

1730: Paradise returns with a functioning Bambi bucket and resumes water drops. Three ships work it for 20min.

1815: Airborne begins 5 PAX loads to retrieve the ground crews.

1845: Airborne departs for HNL and Paradise dropping water until ~1900.

1845: Debrief with Army Wildland Fire, HFD, DOFAW, OANRP

Fire behavior

The initial ignition point was located away from the Hwy at about 700 ft on rough terrain in the middle of the gulch. From there, the fire spread upslope to the east and crested the ridges to the north and south. Nearly the full extent of the footprint of the fire was already burned when observed by OANRP on scene at 1220. Initial helicopter drops on the northeast corner near the Waikomo ridge stopped it from progressing further upslope and into the gulch to the north. Between 1200 and 1530 the fire was mostly moving slowly along the edges and moving makai towards Puu 1439. This was doused by water drops and the fire slowed considerably until 1530 when downslope winds increased causing a new front to flame up and begin to move downslope to the west. This front extended from the middle of the gulch up to the Waikomo ridge and was moving slowly downhill. Water drops and a change to upslope winds slowed this front considerably and it was back to smoldering by approximately 1745. The only remaining smoke was coming from the southwest corner and from larger material remaining in the middle of the black. The fire was determined to be 75% contained by DOFAW.

Figure 2: Photo taken from the Hwy looking east. Note the unburned fuels between the Hwy and the burn as a result of the remote initial ignition point.

Figure 3: Photo from the Hwy looking east showing the fire backing down the left side of the gulch. The HFD crews can be seen near the initial ignition point just to the right of the middle of the gulch.

Figure 4: Photo taken along the Hwy looking east. Note the heavy fuel load in Waikomo gulch to the left of the fire. The Keaau Management Unit is just out of frame to the right. The front of the fire is advancing southwest towards Puu 1429.

Figure 5: The view from the IC at Keaau Beach Park showing the smoke from the fire while it was advancing towards Puu 1429.

Figure 6: Aerial photo looking west showing the extent of the burned area.

Potential Safety Problems Observed

- Radio communication was problematic. Army Wildland Fire ground crew could not talk with the DOFAW ground crew or helicopters. No mobile radio was available for by OANRP helicopter manager on the LZ at Keaau Beach Park but was available in the DOFAW support trailer. The Paradise helicopter was unable to talk with ground crews or the helicopter manager or DOFAW logistics. All helicopters could talk with each other.
- DOFAW Bambi Bucket used by Paradise had the rope brake leaving the bucket in the ocean for HFD to retrieve. Paradise Bambi Bucket had drawstring malfunction, so no water drops performed.
- Lots of slinging over road and no traffic control from HPD.

**May 1, 2012**

761.3: 0806 Airborne start at Keaau Beach Park. Ground Crews were dropped to LZ1 and LZ2.
762.4: 0930 Airborne start slingloads of water blivets and hand tools.
762.5: 1015 Airborne straight to DMR with sling on for gas then Nike for Ohikilolo Ops

763.9: 1205 Airborne start water buckets resume
765.0: 1312 Airborne water bucket off, went for gas at DMR

765.2: 1345 Airborne back and shut down at Keaau Beach Park to stand-by in case needed
765.2: 1530 Airborne begins: aerial surveys and photos with JR
765.3: 1 sling
765.4: 1 PAC load
765.5: 1600 Airborne to DMR for gas
765.7: 1635 Airborne return; 1 sling,
765.9: 4 PAC loads, 1 Survey
766.3: 1715 Airborne Depart HNL

0640: Matthew Keir arrives at the fire. Only small puffs of smoke are observed from the southwest corner of the burn, below the initial ignition site. No other smoke is seen.

0715: Army Wildland Fire crews and DOFAW crews arrive to set up gear and brief the operation.

0745: OANRP briefs the helicopter operation.

0800: Helicopter operations begin to move ground crews up to the fire. Ground crews are broken into three crews. Crew 1: Mark Maxy, Sid Kawahakui, Sean Demello, Marigold Zoll, Irene Specher; Crew 2: Reuben Mateo, Chris Miller, Terrence Noguchi, Susi Iott, Michelle Jones; Crew 3 Jake, Keahi, Shannon (Army Wildland Fire).

0800-1200: Ground crews cleared a handline, monitored smoldering sites, broke up burning material and prepared for water drops. OANRP monitored the fire from the Hwy with Army Wildland Fire (Jon) and from the IC.

1205: Airborne returns and begins water drops on some smoldering areas as directed by Ryan Peralta. Crew 3 worked the bottom (west) line and Crew 1 & 2 worked along the north front on the Waikomo ridge. Water drops were used to put out smokers and smoldering logs.

1400: OANRP coordinator Joby Rohrer arrives at Keaau Beach Park IC. Ground crews are monitoring the situation in case the winds stoke up any more smoldering areas. Matthew Keir returns to base and Joby stays at IC to coordinate helicopter support.

1530: Airborne begins aerial surveys and extracts ground crews.

1715: Airborne departs for HNL. Ground crews return to IC for debrief.

1830: OANRP departs Keaau Beach Park and operations are complete.

Fire behavior

The fire was observed by OANRP staff at 0640. Only minor smoldering was observed along the southwest corner and in the middle of the burned area. Ground crews were deployed and worked the margins uncovering hot areas throughout the morning and into the early afternoon. No significant flames were observed and the fire was contained.

| Staff | Time | Total Hours |
|---|---|---|
| Matthew Keir | 0630-1445 | 8.25 |
| Joby Rohrer | 1400-1600 | 2.0 |

| Company & Pilot | Time | Total Hours |
|---|---|---|
| Airborne Aviation (Jon Fryer) | ~1130-1815 (minus Koolau extract time) | 5 (including 3 stand-by) |
| | | |
| | | |

Lessons Learned:
DLNR Oahu District Forester Mr. Ryan Peralta reported the following: “OARNP was a valuable cooperating agency on this fire. The program contracted invaluable air support which was a key element for fire suppression tactics. The program also integrated into our Incident Command System by providing staff to fill the position of Helibase Manager. Additionally, the program aided in the planning efforts by supplying maps that contained critical information such as property boundaries, locations of rare plants and progression of the fire itself.”

Figure 7: Full extent of burn taken from the coast looking East

Figure 8: Full extent of burn Taken from top edge looking West. Note the incomplete burn along the bottom edge of the picture and on the left side.

**Lualualei Naval Magazine/Waianae Kai Forest Reserve Fire**
June 4-June 11, 2012
**MEMORANDUM FOR RECORD**

Compiled June 26, 2012 to document agency response required for the fire, the damage to State and Federal natural resources, safety concerns, and lessons learned to improve fire plans and responses.

**Summary**

The fire started at approximately 12:40 p.m. Monday June 4th in Lualualei Naval Magazine near the intersection of Radford St. and Kolekole Road in the Waianae Mountains, Oahu at an elevation of 200 ft. The cause of the fire was undetermined according to Federal Fire investigators. The size of the fire, its rapid spread, and the proximity to rare endangered plants prompted OANRP to respond by providing helicopter support for water drops and aerial reconnaissance, and assisting with maps of threatened natural resources and acreage burned.

The fire burned through approximately 1100 acres of dry fuels dominated by *Panicum maximum, Leucaena leucephala, Prosopis pallida,* and other alien grasses. The weather over the course of the week was mainly dry (40-85% rH), hot ( >80 degree F) and windy (5-25+mph) out of the northeast. These conditions favored an extremely rapid spread of fire through the dry, light fuels of Lualualei Valley and into heavier fuels in Waianae Kai Valley Forest Reserve particularly late on Monday afternoon, Monday evening and early Tuesday morning. Fire was declared fully contained by State Division of Forestry and Wildlife personnel on June 11, 2012.

The fire also burned through remnant native shrubland, native cliff communities and small remnant patches of native dry forest. In the remant native shrubland and cliff community dividing Lualualei and Waianae Valley, the only known population of a federally listed endangered species (*Chamaesyce kuwaleana*) was significantly damaged by fire. Significant portions of its designated critical habitat also burned. At least 57 individuals of *C. kuwaleana* were killed by the fire (out of an estimated remaining population of 250 individuals). Of those 57, about 10 individuals were located on the Lualualei side and the remainder burned on the Waianae Valley side. A small population of another endangered species, *Spermolepis hawaiiensis* was not apparently damaged although we failed to locate it during our damage assessment. This species is an annual and not likely to be seen in the dry summer months. The fire posed a threat to the dry native vegetation communities mentioned above which include a number of other rare and federally listed endangered species at higher elevations to the northwest of the fire in Waianae Kai Valley and along the crestline dividing Waianae from Schofield West Range. The fire also significantly damaged several farms in Waianae Valley and directly threatened two housing areas in Lualualei and Waianae Valley (coming within 20 yards of some homes). Munition storage bunkers in Lualualei were apparently undamaged. Estimated total costs to property and natural resources from fire damage, and agency staffing costs are unknown at this time. Previous fires of comparable size, duration, and level of response cost around $150,000. Calculated costs to Oahu Army Natural Resources Program (OANRP) as follows:

| | |
|---|---|
| Staffing costs: | $2500 |
| Helicopter fuel costs: | $1200 |
| Helicopter time costs: | $10,500 |
| **Total cost:** | **$14,200** |

**Background**

Fire is the largest threat to dry forest and dry shrubland ecosystems in Hawaii which are often now dominated by invasive grass such as *Panicum maximum*. The endangered plant taxa threatened by this large fire included *Spermolepis hawaiiensis, C. kuwaleana, Tetramolopium filiforme, Cenchrus agrimonioides var. agrimonioides, Nototrichium humile, Neraudia angulata var. dentata, Dubautia herbstobatae, Gouania vitifolia, Hesperomannia arbuscula, Schiedea hookeri,* and *Alectryon macrococcus var. macrococcus*. With the exception of *Spermolepis hawaiiensis, Chamaesyce kuwaleana, and Schiedea hookeri*, the remaining species are all stabilization taxa in the Makua Military Reservation Implementation Plan (MIP) and these populations represent a significant portion of the known remaining naturally occurring individuals. Fortunately, no MIP populations were affected. The Oahu Army Natural Resource Program works to conserve these MIP species in four small fences built by OANRP in Waianae Kai Valley. Other rare plant and snail populations are also located below and at the crestline area to the east of the fire in Schofield West Range. Fences in Waianae Kai Forest Reserve are located in the northwestern portion of the valley.


Figure 1: Map showing the extent of the burn and proximity to rare and endangered MIP resources in Waianae Kai and Schofield Barracks West Range. 250.34 acres of Waianae Kai Forest Reserve burned.

## June 4th, 2012

| Staff | Time | Total Hours |
|---|---|---|
| Parker Paredes | 1:00 pm | n/a |
| Matt Keir | 6:00-6:30 pm | 0.5 |
| Mike Walker | 5:30-7:30 pm | 2.0 |

| Company & Pilot | Time | Total Hours |
|---|---|---|
| AirOne (Lincoln Ishii) | ~3:00-6:00 pm | ~3.0 Flat time, All water drops |

### Sequence of Events

1240: Navy Federal Fire reports and responds to the fire near one of their storage bunkers at Radford St. on Lualualei Naval Magazine.

1300: OANRP staff (Parker Paredes) observes the fire from the crestline of the Waianae Mountains at Puu Hapapa and reports the fire to Army Range Control. Army Wildland Fire also notified. Parker also gives his report to other OANRP staff, Dan Sailer and Matt Keir.

1500: During an OANRP helicopter sling load operation at Puu Hapapa, pilot John Fryer from Airborne Aviation reports that the fire appears to be spreading out of control. At some point around this time, Navy Federal Fire personnel request additional support from HFD and Air One bucketing operations begin with one or two helicopters.

1700: Dense smoke in Lualualei and Waianae Valley hinders bucketing operations and evacuations begin in nearby affected housing and farming areas. Fire spreads very rapidly in several directions across large front.

1700-1900: OANRP staff station themselves at Kolekole Pass as lookouts, various personnel are notified of the fire, and a response plan is made for Tuesday. OANRP was notified that Airborne Aviation was being released from the fire on Kauai and would be able to free up both helicopters for fire fighting on Oahu on Tuesday. The fire continues to spread upwind into higher elevations as a large backing fire along the border dividing Lualualei and Waianae Kai Valley as well as makai and downwind toward farms and residences.

### Fire Behavior

Numerous spot fires, rapid spread through light, flashy fuels, and strong gusty winds quickly spread the fire out of the initial ignition area of about 5 acres to approximately 500 acres in a matter of 6 hours. The fire spread in a generally west/north west direction across a broad front from 200 ft. in elevation to as much as 1400 ft. in elevation. Fire intensity varied from high intensity areas of complete burns with about 40 foot flame lengths to large areas with incomplete burns due to low intensity fire and low flame lengths.

### Safety Concerns

Dense smoke and cliff terrain apparently made the initial attack by HFD helicopters very difficult. Residential areas and farms were evacuated on Monday night due to the dense smoke and fire threat which came within 20 yards of some homes and burned several farms.

## Tuesday, June 5th

| Staff | Time | Total Hours |
|---|---|---|
| Dan Sailer | 7:00 am – 8:00 pm | 15 |
| Mike Walker | 7:00 am – 8:00 pm | 15 |
| Scott Yamasaki (Army Wildland Fire) | 9:00 am – 10:00 am? | ? |
| Jane Beachy | 10:00 am- 12:00 pm | 2 |
| Sonja Bigalke-Bannan | Varied w/ other duties | |
| Julia Lee | 1:00 – 3:00 pm | 2 |

Among the DOFAW crew were: Dave Smith, Marigold Zoll, Aaron Lowe, Chelsea Arnott, Susi Iott, Terrence Noguchi, Mark Maxy, and Chris Miller. M. Zoll is DOFAW Incident Commander (IC).

| Company & Pilot | Time | Total Hours |
|---|---|---|
| AirOne (Chief Steve Aiu) | 8:00- 5:00 pm | ~9.0 Flat time, All water drops |
| AirTwo (n/a) | 8:00- 10:00 am | 2.0 (maintenance issue) |
| NPA Airborne Aviation (John Fryer): OANRP contract | 9:00 am -5:30 pm | 6.5 (given Koolau work for USGS) |
| 0PA Airborne Aviation (Jim Huffs): DOFAW contract | ~10:30 am- 6:30 pm | 8 |
| CH-53 Sea Stallion (Navy/Marines) | Varied (off and on fire throughout day) | |

### Sequence of Events

HFD and FFD worked aggressively throughout the previous night to hold fire perimeter along southern, western, and northern flanks. HFD IC during evening operations is Chief Camara. Fire had burned to its largest extent for the most part on Monday night into Tuesday morning due to unusually strong evening trade winds around 9 pm. Evacuation of farms continued and HPD closed access roads into the back of Waianae Valley. HFD had elevated its response to Level 3 meaning approximately half of the entire HFD's resources on Oahu were committed to the fire and HFD paramedic response services were curtailed.

0800 DOFAW agrees to contract 0PA for fire operations and OANRP uses NPA fire operations. NPA involved in USGS Koolau operation till 0850.

0830 Jane Beachy sent to Kolekole Pass as lookout for southeastern flank of fire which threatened Puu Kumakalii area Monday night.

0850- 0905 Airborne Aviation NPA ship with pilot J. Fryer begins aerial reconnaissance flight with Mike Walker (OANRP), Marigold Zoll (DOFAW), and Scott Yamasaki (Army Wildland Fire). Actively burning areas restricted primarily to mauka edge of fire in Waianae Kai Forest Reserve and near end of Waianae Valley Road in the Kaala Farm area. NPA helicopter leaves for USGS job and then begins bucketing operations at approximately 0930 after refueling at Dillingham and picking up his bucket.

1000 M. Walker, D. Sailer, M. Zoll and Dave Smith arrive at the Incident Command Center at Kaupuni Park in Waianae Valley for fire size up and briefing with HFD to coordinate air response with HFD and the Navy. Overall HFD IC during Tuesday daytime operations is Chief Lawton. Park is large enough to accommodate landing of CH-53 and two Hughes 500 helicopters. DOFAW does not deploy any ground forces other than lookouts as most DOFAW crew is still on Kauai. Aaron Lowe and Chelsea Arnott from DOFAW provide logistical support. Susi Iott also from DOFAW manages 0PA ship.

1000-1800 Chief Aiu (HFD) directs air operations. HFD Air One buckets along western perimeter closest to farms and housing in Waianae Valley as well as Lualualei as needed. CH-53 buckets in Lualualei and more mauka perimeter closer to Kaala Farms throughout the day, drawing water from ocean. NPA and OPA from Airborne Aviation concentrate bucketing along northwestern perimeter in Waianae Kai Forest Reserve to stop fire from further advancing into forested area and at highest elevation along boundary between Lualualei and Waianae Valleys. The swimming pool at Waianae Camp closer to the fireline services the small helicopters in addition to the water buoy at the park.

1100-1500 U.S. Airforce and a contractor conduct a training operation at the IC with a fixed wing Cessna plane (that circled the fire at a high altitude) to provide real time thermal and visual imagery.

FFD continues firefighting in Lualualei to protect nearby housing and bunkers. Army Wildland Fire resources are not requested by Navy Fed Fire and do not respond for the remainder of the fire.

1000 HFD AirTwo ship leaves given 100 hour maintenance requirement and battery issue.
1030 0PA with pilot Jim Huffs arrives from Kauai and begins bucketing operations. Fueling for NPA is approved at Wheeler Army Airfield. OPA refuels at Dillingham throughout the day. NPA fuels at Wheeler twice.
1200 Jane Beachy departs Kolekole Pass lookout, replaced by Julia Lee at 1300.
1345 NPA departs for another job (USGS Koolau operation).
1510 NPA returns and conducts an aerial reconnaissance with M. Walker and D. Sailer.
1521 NPA resumes bucketing.
1530 Julia Lee departs Kolekole lookout area at remaining hotspots at higher elevations are no solely on Waianae Kai valley side.
1530 HFD AirOne also departs due to a mechanical issue (running hot), leaving 3 helicopters on scene.
1530-1900 Susi Iott (DOFAW)/M. Walker (OANRP) coordinate water drops with HFD ground personnel.
1730 NPA departs as pilot J. Fryer reaches his duty day restriction. 0PA and CH-53 continue bucketing.
1800 Tradewinds increase and a flareup occurs near Waianae Camp, 0PA brought from Waianae Kai forest area to assist in wildland/urban interface area.
1845 0PA departs back to Dillingham. CH-53 continues bucketing until 1900.
1900 DOFAW/OANRP conducts debriefing at end of operational period

**Safety Concerns**

- Radio communication between HFD and contract ships was problematic. HFD would request drops with Mike W. (OANRP) and he would then relay instructions to DOFAW and 0PA. All helicopters could talk with each other. DOFAW often had difficulty at times talking with 0PA on Tactical 1 frequency.
- HFD AirOne helicopter apparently began running hot at 1530 and departed for Honolulu.
- Initially no traffic/crowd control from HPD at Kaupuni Park.
- HFD AirOne had a close call with the basketball backboard and fence as their bucket and line came close to hitting it.
- At 1800 a flareup occurred near the housing area by Waianae Camp, fortunately HFD tankers were close by and 0PA was also still available to assist with bucketing.
- Throughout early Tuesday morning and into Tuesday night fire repeatedly came close (e.g. 150 yards) to crossing the firebreak along streams and dirt roads in Waianae Valley but was stopped by aggressive response by HFD and air support. Holding this perimeter was critical to preventing the fire from burning out of control again across the western 2/3rds of Waianae Valley.

**Fire Behavior**

In general, fire activity during Tuesday daylight hours significantly decreased throughout the day because of air operations, lighter winds, and generally overcast conditions with higher humidity at times (particularly during afternoon hours). Fire perimeter changed significantly during the course of the day as about 40 additional acres burned on Tuesday in the area above Kaala Farms. Active burning with some 20 ft.+ flame lengths in heavier fuels (satin leaf, olive, silky oak, and wiliwili trees) was restricted to the mauka forested areas in the Waianae Kai Forest Reserve and the haole koa scrubland/Kaala Farm area directly below. An evening flareup occurred in alien grass/shrubland near Waianae Camp. OANRP could not see most of the bucketing activity in the Waianae Kai Forest Reserve from our vantage point at the park. Fire behavior was unknown in the makai portion of Lualualei. Mauka portions of Lualualei had largely burned out with only smoldering hotspots in blackened areas by 1600. Burning trash piles, tires, and farm structures also contributed to flare-ups in the agricultural saddle area between Lualualei and Waianae Valley.

**Wednesday, June 6th**

| Staff | Time | Total Hours |
|---|---|---|
| Dan Sailer | 3:00 pm – 8:00 pm | 5 |
| Sonja Bigalke-Bannan | Varied with other duties | |

Among the DOFAW crew were: Dave Smith, Marigold Zoll, Aaron Lowe, Chelsea Arnott, Susi Iott, Terrence Noguchi, Mark Maxy, Chris Miller, Ryan Peralta, Jason Misaki, Fred Bannan, Sid Kawahakui, Sean Demello, Michelle Jones, and Reuben Mateo. R. Peralta is DOFAW IC.

| Company & Pilot | Time | Total Hours |
|---|---|---|
| AirOne (n/a) | n/a | n/a |
| NPA Airborne Aviation (John Fryer): OANRP contract | 2:00 pm – 6:00 pm | 4 |
| 0PA Airborne Aviation (Jim Huffs): DOFAW contract | ~8:00 am – 6:00 pm | ~10 |
| CH-53 Sea Stallion (Navy/Marines) | ~8:00 am – 6:00 pm | ~10 |

**Sequence of Events**

0800 – 1800 A large number of DOFAW and HFD personnel conducted fire suppression along northwestern flank in Waianae Kai Forest Reserve extending several hundred meters down below Kaala Farm area. The objective was to continue holding the fireline at the stream by putting out all hotspots along the fire perimeter in this area and to continue to protect Kaala Farm and neighboring structures. R. Mateo (DOFAW) also worked throughout the day improving the old dirt roads directly west of the stream as an additional fire break using heavy equipment.

Fuels mostly consist of haole koa/guinea grass with Christmas berry/kukui/silky oak/satin leaf/wiliwili trees and aalii bushes burning at upper elevation.

Helibase is mostly moved to the BWS supply road lower water tank and adjacent landing zone in Waianae Kai Forest Reserve. Kapuana Park continues to serve as HFD/DOFAW Incident Command location.

Navy Federal Fire also continued largely mop up operations in Lualualei Valley throughout the day.

1300 R. Peralta requests that OANRP assist with air support using NPA to supplement bucketing operations.
1400 NPA piloted by J. Fryer begins bucketing and continues to 1730
1500 D. Sailer (OANRP) arrives to support air operations by NPA.
1630 NPA leaves to fuel at Wheeler and is denied fuel at WAA despite assurances early in the day that he was okay to fuel there. He fuels instead at Dillingham Airport. Later investigations by OANRP reveal that Directorate of Logistics personnel had incorrectly invalidated Airborne Aviations fueling agreement.
1730 NPA conducts aerial reconnaissance with DOFAW and HFD staff (R. Peralta, J. Misaki, and Capt.Terry Seelig).
1745 NPA departs for HNL.
1830 0PA completes bucketing and departs to Dillingham.
1900 DOFAW/OANRP conducts debriefing at Kaupuni Park.

**Safety Concerns**

0PA pilot Jim Huffs did not like bucketing from the smaller, and shallower DOFAW water buoy located at the BWS tank. He primarily used the HFD buoy in Kaupuni Park. Low water pressure also prevented more rapid refilling. Other pilot, John F. did not mention having a problem with the dip pond.

DOFAW staff also reported that using the same radio channel for ground operations and ground to air communication was difficult at times given the amount of radio traffic.

Around 1700, the CH-53 ship got very close to dropping their water directly on DOFAW staff and fanned flames from their rotor wash.

**Fire Behavior**

By late afternoon, only small smoldering areas were occasionally visible from the helibase and operations had shifted to mop up actions. Bucketing by contract aircraft and the CH-53 throughout the day was very useful to douse hot spots in heavier fuels given the distance from any other water sources. Fire was declared 75% contained by DOFAW at end of operational period. HFD declared the fire fully contained and focused their air and ground efforts instead on a separate, unrelated brush fire lower down in Waianae Valley for the next several days. This other fire started in two separate locations on different days and burned several hundred acres over the holiday weekend.

**Thursday, June 7th to Monday, June 11th**

OANRP did not respond at all with staff or air support during this period as no support was requested by DOFAW. At the end of Thursday's operational period R. Peralta reported that the fireline turned out to be much hotter than expected requiring extensive mop up operations and assistance by 0PA bucket drops in the Waianae Kai Forest Reserve area. Mop up operations by DOFAW continued till Monday.

**Lessons Learned**

The very large and aggressive response by HFD and DOFAW on Monday through Wednesday prevented the fire from burning more of Waianae Valley both in the mauka forested areas and makai in the residential areas. Significant effort was also expended by DOFAW on Thursday through the following Monday to fully extinguish the fire and prevent any flare-ups.

A missing resource to help extinguish this fire was Army Wildland Fire as they were not requested by Navy Federal Fire personnel. Both the initial attack and HFD's and DOFAW's extended mop up operations would have undoubtedly greatly benefitted from their additional manpower and expertise given the terrain and size of the fire perimeter.

Any future large fires happening simultaneously on several islands or on the same island will likely again overextend agency air and DOFAW staff resources. Contingency planning is needed to minimize delays caused by the unavailability of helicopters and pilots and ensure adequate numbers of staff are trained and equipped for fire responses. A second unrelated large fire that started lower down in Waianae Valley during the Lualualei/Waianae Kai fire is another example of the degree of threat posed by fires during dry periods in leeward areas.

A lack of direct radio communication between HFD ground crews and Airborne Aviation pilots during a flareup made directing water drops difficult. This problem likely resulted from the fact

that Chief Aiu who was directing all air operations had to leave given a maintenance issue with his aircraft. OANRP and DOFAW personnel were tasked by the HFD IC to help direct the contract aircraft to support HFD ground crews, a task which they performed well at despite the difficulties of handling multiple radios and multiple requests for water drops from ground crews given the intensity of the flare up.

There was some miscommunication initially HFD junior personnel and Airborne Aviation pilots on Tuesday regarding the authorization to fuel from the HFD tender (gas truck). As OANRP and DOFAW staff arrived on scene on Tuesday, we were informed by our pilots the HFD had given their approval to fuel from the HFD tender as needed. OPA fueled once from the tender and later Chief Aiu questioned us as to who authorized the fueling since he was the only person who could authorize the fueling and did not do so. In the future, OANRP will continue to use Wheeler Army Airfield for fueling during an emergency response given its central location. The issue with the improperly voided fueling agreement at Wheeler AAF was resolved.

DOFAW/BWS existing firebreaks in Waianae Valley were located well away from this fire given the history of fires coming up from center and western sides of the valley. While fires had burned the saddle area between Lualualei and Waianae Valley's before, this particular fire was much higher in elevation when it crossed into Waianae Kai Forest Reserve and came from the east. Additional pre-suppression actions are needed in the future to plan for this event again. Staff from Kaala Farms made the case that more farming in the the haole koa area that burned will help buffer the forested areas mauka and to the west.

A significant percentage of individuals of the only known location of an endangered plant species (*Chamaesyce kuwaleana*) burned in this fire. Steep cliffs prevented the fire from burning more of these plants. This example underscores the importance of genetic storage collections and establishing multiple populations of a species in naturally defensible locations given the unpredictability of large fires.

Figure 2: Fire burning out of control late Monday afternoon upward towards Puu Kumakalii at upper right of photo and into Waianae Kai Forest Reserve at center of photo. Note direction of smoke as this portion of the fire backed up the ridge dividing the two valleys at an elevation of about 1400 feet.


Figure 3: Aerial shot looking east on Tuesday afternoon. Note stream area and Kaala Farm at center of photo where HFD and DOFAW personnel held the fire from spreading into the grassland beyond. The fire came as close as 60 feet in some areas to reaching the other side of the natural fire break. *Chamaesyce kuwaleana* plants and critical habitat burning in upper right of photo.

Figure 4: Freshly burnt haole koa shrubland above Kaala farms looking east on Tuesday afternoon. Native aalii shrubland and remant native dry forest area also burned near top of photo.

Figure 5: Lualualei Naval Magazine looking west. Ignition point of fire is near lower left of photo. Damaged farms are in the flat saddle area between the two valleys.


Figure 6: Locations of historic and current distribution of *C. kuwaleana*. The lower left population was recently observed at Puu Maunakuwale and was damaged in the fire. The area at the upper right dot was extensively burned and no plants were found. The middle location was largely unburned, but not visited during a recent damage assessment as the area is flanked by steep cliffs making access difficult. The rare *Panicum beecheyi* grass areas was also not visited but also significantly damaged by the fire.

Figure 7: Puu Maunakuwale area looking east towards Puu Kumakalii at crestline. Note the largely unburnt large Puu in the center of the photo protected by vertical cliff areas. Damaged plants were directly below the FWS and OANRP staff in the photo. Also note the somewhat intact native aalii shrubland at lower left that apparently recovered from a previous fire in 2003.

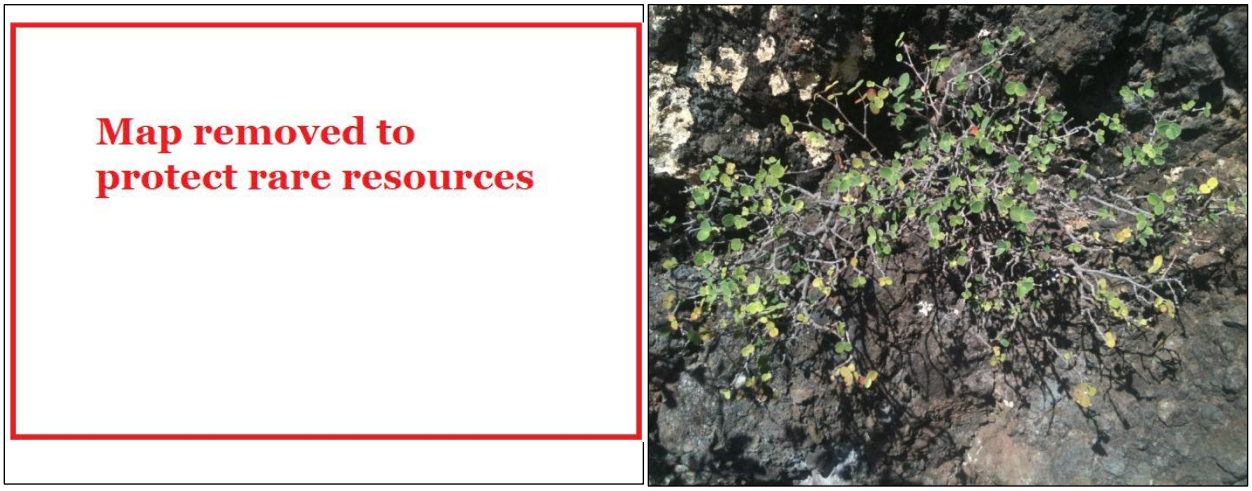



Figure 8: Habitat and a healthy *C. kuwaleana* plant in Puu Maunakuwale area looking west. Fire came within 50 feet of burning this core population. Note bare rock surrounding the plant acting as a natural protection from fire in the right hand photo.

Figure 9: Fire damaged *C. kuwaleana* plants below the northwestern flank of Puu Maunakuwale.

Figure 10: Waianae Kai Forest Reserve area damaged by fire. A number of native wiliwili trees burned in the center area of this photo.

Figure 11: Farms damaged by fire. During the damage assessment survey a week after the main fire was extinguished, another small brushfire started shortly after this photo was taken near the unburnt area in the righthand side of the photo, but was quickly extinguished by HFD.

Figure 12: Kaala Farms area at lower left and Waianae Kai Forest Reserve at upper right.

**Waianae Kai Forest Reserve Fire Memorandum for Record**
July 26, 2012

APVG-GWV (200-3) 27 July 2012

**MEMORANDUM FOR RECORD**

**SUBJECT:** Memorandum for record regarding Waianae Kai Forest Reserve Fire July 26, 2012.

**Background**

The fire started at approximately 1355 on July 26, 2012 on private land below the Waianae Kai Forest Reserve in the Waianae Mountains, Oahu. The Oahu Army Natural Resource Program (OANRP) staff, where conducting management work in cooperation with DLNR staff when the fire was spotted. Crews working on the Kuamipo ridge crest saw two points of ignition that began to burn next to the access road. DLNR staff called 911 to make a report. OANRP base notified Joby Rohrer at 1400 and preparations were made to dispatch staff, contact DLNR Forestry, alert Army Wild Land Fire, prepare to mobilize helicopter support and brief the USAG Natural Resource Manager and the OANRP Program Manager.

The weather at the time was dry, hot ( >80 F) and windy (5-20mph) blowing northwest. These conditions favored the rapid spread through the dry terrain. These conditions and the proximity to rare endangered plants prompted OANRP to respond to the fire. The fire was burning through dry fuels dominated by *Uchaloa maximum* and *Leucaena leucephala*. Fortunately there area has been grazed and fuels were not heavy. Observers monitored the fire and HFD response. The fire spread rapidly northwest from the road with a steady wind behind it and crews photographed its spread from the road.

Status of fire at 1400 soon after ignition

Status of fire at 1415

Status of fire at 1430

HFD was on scene by 1410 and Air one arrived at approximately 1430. Army Wild Land Fire also responded to the fire and where on seen by 1430. On site, Army Wild Land Fire was not able to establish communication with HFD and after an initial assessment returned to Schofield. After consultations with both DLNR Forestry and Army Wild Land Fire, OANRP called for helicopter support from Airborne helicopters and Jim Huff was dispatched from Kauai and Joby Rohrer left for Waianae Kai to manage operations. Of particular importance in this decision was DLNR Forestry's communication with National Weather Service that indicated winds may turn North in the later afternoon. If this were to occur the fire could be pushed into the Forest Reserve and directly impact additional endangered species.

The fire posed a threat to federally listed endangered species located approximately 1000 meters to the northwest along the Kamaileunu ridge. Fire is the largest threat to dry forest ecosystems in Hawaii which have become dominated by invasive grass such as *U. maximum*. The Endangered and rare plant taxa threatened by this fire include *Euphorbia celastroides* var. *kaenana, Nototrichium humile, Neraudia angulata, Lobelia niihauensis* and *Melanthera tenuis.*


Figure 1: Map showing the extent of the burn and proximity to the endangered species.

**July 26, 2012**

1600 OANRP staff on scene (Joby Rohrer)
1650 Airborne start water bucket loads
1800 Airborne stop water drops and begins aerial recon
1815 Airborne departs

| Staff | Time | Total Hours |
|---|---|---|
| Joby Rohrer | 1400-1830 | 4.50 |

| Company & Pilot | Time | Total Hours |
|---|---|---|
| Airborne Aviation (Jim Huff) | ~1600-1900 | 3.00 |
| HFD AirOne (Steve Aiu) | ~1430-1900 | 4.5 |

Sequence of Events

1355: OANRP and DLNR staff reports a fire below the Waianae Kai Forest Reserve.

1410: HFD on site.

1430: AirOne (Steve Aiu) on scene.

1430: Army Wildland Fire on scene.  Return to Schofield at 1515.

1600: OANRP Joby Rohrer on scene, makes contact with IC Roland Harvest and prepares for helicopter management

1650: Airborne Aviation Jim Huff on scene, begins water drops with air one

1800: Airborne Aviation stops water drops and begins aerial recon with OANRP

18:15: Airborne Aviation departs.

1830: OANRP Joby Rohrer de-briefs with IC and departs.

Fire extent

# Population genetics of *Schiedea* species (Caryophyllaceae) of conservation concern on U.S. Army lands, O‘ahu.

Hawaii Biological Survey

**Final Report**

**September 2012**

**Cover image:**
*Schiedea obovata* (Scherff) W.L.Wagner & Weller
Photographer: Lauren A. Weisenberger

# **Population genetics of *Schiedea* species (Caryophyllaceae) of conservation concern on U.S. Army lands, O‘ah**u.

Final report prepared for:
O‘ahu Army Natural Resource Program (OANRP)
Schofield Barracks, Hawaii

Prepared by:
Shelley A. James

Hawaii Biological Survey &
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Honolulu HI 96817, USA

September 2012

Contribution No. 2012-019 to the Hawaii Biological Survey

# Population genetics of *Schiedea* species (Caryophyllaceae) of conservation concern on U.S. Army lands, O‘ahu.

## Introduction

*Schiedea* (Caryophyllaceae) is a morphologically variable monophyletic genus endemic to the Hawaiian Islands. The genus consists of 32 extant species, all of which arose from a single initial colonization of the island chain (Wagner *et al.* 2005; Willyard *et al.* 2011). Unfortunately, largely due to land degradation and the impacts of invasive species, 15 species of *Schiedea* are now federally listed as endangered and two species are now extinct.

Six endangered species of *Schiedea* are currently found on U.S. Army lands on O‘ahu, of which three are the focus of this study: *Schiedea kaalae*, *S. nuttallii*, and *S. obovata*. Phylogenetic analyses using morphological and nrDNA ITS and ETS regions show that *S. nuttallii* and *S. kaalae* are closely related members of the *S. nuttallii* clade (section *Mononeura*) (Wagner *et al.* 2005; Willyard *et al.* 2011). They have fleshy stems, large leaves with a single vein, and attenuate to caudate, strongly reflexed sepals. *S. obovata* is part of the basal clade of the genus (*S. membranacea* clade, section *Alsinidendron*), having broad, multi-nerved leaves with ciliate or toothed margins.

*Schiedea kaalae* Wawra is a long-lived (>10 years) perennial herb with a hermaphroditic breeding system (Wagner *et al.* 2005). *S. kaalae* was federally registered as an endangered species in 1991 (Ellshoff *et al.* 1991, USFWS 2008). The species was once distributed throughout the Wai‘anae and northern Ko‘olau Mountains, but less than 30 mature individuals currently remain within three extant wild populations in the Wai‘anae Mountains, two with only a single individual, and three in the Ko‘olau Mountains, one with only a single individual (Keir and Weisenberger 2011). However, outplanted individuals survive in three populations in the Wai‘anae Mountains and recruitment and vegetative reproduction have been observed, and most founders from extirpated populations are represented in living and seed collections. All plants in the Wai‘anae Mountains are now protected by fencing from habitat destruction caused by ungulates. Invasive plant species, slug, rat and mouse predation, drought, and fire continue to threaten the survival of the species (U.S. Army Garrison 2007, USFWS 2008). Morphological

differences between the Koʻolau and Waiʻanae Mountain populations have been observed (L. Weisenberger, pers. comm. 2012).

*Schiedea nuttallii* Hook. is an outcrossing hermaphroditic subshrub. Historically, the range of the species extended from Oʻahu, Molokaʻi, to West Maui (Wagner *et al.* 2005), but it is now restricted only to Oʻahu. At the time of federal listing, only a single population of 25 extant individuals in the Waiʻanae Mountains was known (Russell and Bruegmann 1996), but the discovery of a second population at Kahanahāʻiki in 1999 doubled the number of known individuals (U.S. Army Garrison 2007, USFWS 2007a). As of 2007, 47 wild individuals were known from two populations (Kahanahāʻiki and Kapuna-Keawapilau Ridge), and four outplanting sites were established (U.S. Army Garrison 2007, USFWS 2007a). Currently, only one extant population (Pahole) and one isolated individual (Kahanahāʻiki) occur in mesic habitat in the northern Waiʻanae Range (Keir and Weisenberger 2011). *Schiedea nuttallii* has previously been characterized as having low isozyme variability, low heterozygosity and percentage of polymorphic loci, and demonstrates inbreeding effects due to small population size (Wagner *et al.* 2005; Weller *et al.* 1996). According to the USFWS (2007a, 2009), *Schiedea nuttallii* is in a phase of quasi-extinction with numbers declining to the point where demographic or environmental events alone could result in its extirpation.

*Schiedea obovata* (Sherff) W.L.Wagner & Weller is a shrub with a hermaphroditic, facultative autogamy breeding system (Wagner *et al.* 2005). While historically found along the entire Waiʻanae Mountain range, the species was restricted to three populations in the northern Waiʻanae Mountains of Oʻahu (U.S. Army Garrison 2007, USFWS 2007b) but has subsequently been reduced to one extant wild population (NW Makaleha) of approximately 100 individuals (30 mature) and a few isolated individuals in surrounding areas (Keawapilau and West Makaleha) (L. Weisenberger, pers. comm. 2012). *S. obovata* was federally listed under the synonym, *Alsinidendron obovatum* Sherff., as endangered in 1991 (Ellshoff *et al.* 1991). As for the other two *Schiedea* species in this study, *S. obovata* is threatened by small population sizes, and habitat degradation and damage due to invasive plant and animal species (USFWS 2007b). While *S. nuttallii* and *S. obovata* occur in sympatry in the Waiʻanae Mountains, differences in

breeding systems have prevented interspecific gene flow between these species and the development of hybrids (Willyard *et al.* 2011).

For all three species, natural recruitment remains poor, and extant populations continue to be threatened by reduced reproductive vigor due to small number individuals and populations (Keir and Weisenberger 2011). Weller *et al.* (1996), using allozyme analysis, found extremely low levels of polymorphism and heterozygosity in all three species, but particularly for the autogamous *S. obovata*. Future management actions for *Schiedea* and determining whether reintroductions or population augmentation of species within their historic range should represent a single population or multiple populations will be based on multiple factors, including inter-population and intra-population genetic variation, and variation in habitats between populations. The goals of this study are to assess the level of genetic variation within and among founder populations of three *Schiedea* species located on U.S. Army lands, namely *S. kaalae*, *S. obovata*, and *S. nuttallii*, using microsatellite analysis, and compare this variation to the geographic distribution of purported populations to assist with developing management actions for population reintroduction and/or augmentation.

## Materials and Methods

### *Sampling*

Immature leaf material of *Schiedea kaalae*, *S. obovata*, and *S. nuttallii* were obtained from shade-house-grown individuals at the Pahole Mid-elevation Nursery in Mokulēʻia Forest Reserve (656 m elevation) by Oahu Army Natural Resources Staff. *Schiedea* individuals were derived from distinct wild (founder) population units in the Waiʻanae Mountain Range, Oʻahu, namely ʻĒkahanui (EKA), Huliwai (HUL), Kaluaʻā (KAL), Makaleha (LEH), Kahanahāʻiki (MMR), Pahole (PAH), and Pālāwai (PAL), Keawapilau (PIL), and four Koʻolau Mountains populations, Makaua (AKA), Kahana (KNA), Maʻakua (MAA), and Kaipapaʻu (PAP) (Appendix 1). Leaf tissues were rapidly dehydrated in silica gel and frozen at 80 °C. Genomic DNA was extracted from 6-10 mg dried plant material using a DNeasy Plant Mini Kit (QIAGEN Inc.) following the recommended protocol. Tissues and extracted genomic DNA have been accessioned within the collections of the Pacific Center for Molecular Biodiversity, Bishop Museum (accession numbers 2009.199 and 2011.084) and are stored at 80 °C.

### *Microsatellite analysis*

DNA samples were analyzed in multiplexed reactions that incorporated the fluorescent labeling of forward primers during PCR (adapted from Schuelke 2000) following the protocol of Culley *et al.* (2008). Each microsatellite region was amplified using an unlabelled reverse primer, a forward primer incorporating a unique sequence added to the 5' end, and a third primer composed of this same unique sequence but with a fluorescent label (either WellRED D2, D3 or D4) attached to the 5′ end (Table 1). Primers were developed by Culley *et al.* (2008) specifically for *Schiedea* species and had been previously noted to be polymorphic for the three species in this current study. The four unique sequences used were M13(-21) (D4-TGTAAAACGACGGCCAGT), two modifications (M13A: D2-TAGGAGTGCAGCAAGCAT, M13B: D4-CACTGCTTAGAGCGATGC) and T7term (D3-CTAGTTATTGCTCAGCGGT). The forward primer was provided at one-fourth the amount (0.5 μM) of the reverse and fluorescently labeled primers (2 μM). PCR was performed in 10 μL reaction volumes using a QIAGEN Multiplex kit (QIAGEN Inc.) as follows: 5 μL Multiplex PCR Master Mix, 1 μL 10x primer mix, 0.5 μL DNA and 3.5 μL $dH_2O$. Primers were run in one of four sets (Table 1) or individually. Multiplex PCR consisted of 95 °C for 15 min, followed by 30 cycles each of 94 °C for 30 s, 57 °C for 45 s, and 72 °C for 45 s, and then with eight cycles each of 94 °C for 30 s, 53 °C for 45 s, and 72 °C for 45 s. A final extension consisted of 72 °C for 10 min. Product was run on a Beckman Coulter CEQ8000 genetic analysis system with DNA size standard 400.

**Table 1**: Primers used in this study.

| Primer | Forward | Reverse | Set |
|---|---|---|---|
| SA04 | M13-AAGCGAATAGCGGAGTAACG | AGGAACAACAGAACGAAGCA | 1 |
| SA05 | T7-TGTCAACCTCATGACATGGT | AGAGCAGCAACAGGGAGAAG | 1 |
| SA06 | M13A-CCCACCTGCATGAATACTGA | TACTGCCCAACTGCCCTATC | 1 |
| SA15 | M13A-CCCACTAAATCACTAGCACATTTC | ACCATCACTGCCTCAGATCC | 2/3 |
| SA16 | M13B-AACGAGCACGACCAAATACC | GGGTGGAACGATTAAGGTGA | 1 |
| SA31 | T7-GGCGATTATTGACTCATCTCCA | CCACTCTCACCTCACCCAAC | 2/4 |
| SA32 | M13-CGCCTTCGACTCGTCTTAGT | CACTGCTACGACTCGGCTTA | 1 |
| SA35 | M13B-GGAGGATGAAGGTCAGGAGA | GCGTGAGACCAATGCATAAT | 2/3 |
| SA36 | M13-CATCTTTAATTGACGCCTTGG | AACCGAAATGTCGAATCATTG | 2/3 |
| SA38 | M13B-TCAAACCAAGTCCAGTATTCG | TGAGAACTCGGGTTATGCTG | 2/4 |

### *Data analysis*

Microsatellite fragments were visually scored. A Bayesian analysis of the microsatellite data with STRUCTURE 2.3.3 was used to assign individuals to putative genetic groups (Hubisz *et al.*

2009). An admixture ancestry model was assumed, and 10 replicates for *K* from 1 to (number populations + 2) was analysed using a burn-in period of 10,000, 50,000 and 100,000, and a Markov chain Monte Carlo (MCMC) simulation of 10,000, 50,000 or 100,000 iterations, respectively. As results for all three models were similar, only the 10,000 iteration analysis is reported here. The number of genetic clusters in the dataset was estimated by examining the posterior probabilities (ln Pr($X|K$)) for the varying values of *K*.

Observed (Ho) and expected (He) heterozygosities and percent polymorphic loci (%P) were estimated using GenAlEx 6.1 (Peakall and Smouse 2006). The heterozygosity values obtained range from 0 to 1, with 0 inferring that all individuals are genetically identical. Percent polymorphic loci for all individuals combined and for each population (where more than one individual was analyzed) were determined as an estimate of the amount of genetic variation within the populations. *Fst* and AMOVA using R-statistics analysis were calculated using GenAlX 6.1. *Fst*, a measure of the amount of genetic differentiation occurring among populations, is calculated as:

$$Fst = \frac{(Ht - Hs)}{Ht},$$

where an *Fst* value of 0 infers a high degree of gene flow among population, and a value of 1 indicates a considerable degree of differentiation among populations, i.e. genetically isolated populations. *Rst* is an analog of *Fst* based on allele size differences, and is considered to provide less biased estimates of demographic parameters for a population than will *Fst* as it takes into account the mutation rates at microsatellite loci (Slatkin 1995). It is a parameter defined as the correlation of allele sizes (rather than allelic states) between genes sampled within populations. Principal Coordinate Analysis was undertaken using the software GenAleX 6.1 using Gower similarity co-efficient (Gower 1966).

## Results

### *Schiedea kaalae*

Individuals of the predominantly outcrossing *Schiedea kaalae* were from two geographically separated mountain ranges on O‘ahu, the Ko‘olau and Wai‘anae Mountains (Figure 1), within 13 separate populations, namely (from north to south), PAP-A, MAA-A, AKA-A, and KNA-A within the Ko‘olau Mountains, and PAH-B, PAH-A, KAL-A, HUL-A, EKA-D, EKA-C, EKA-B, EKA-A, and PAL-A within the Wai‘anae Mountains. The Ko‘olau and Wai‘anae populations were assumed to be genetically different as they have been observed to be morphologically variable (L. Weisenberger, pers. comm., 2012). STRUCTURE analysis indicated an optimal K value of 2 to 3, separating the geographically disjunct Wai‘anae and Ko‘olau Mountain populations (Figure 2). This was further demonstrated by the Principal Coordinate Analysis (PCO) of the microsatellite data (Figure 3). Individuals from the two mountain ranges were separated along the second PCO axis, with the Ko‘olau populations at the positive end of the axis. The Ko‘olau populations, and to a lesser extent, the Wai‘anae populations, were also distributed from south to north along the first axis. The percentage of the variation explained by PCO was 37.9% for the first axis and 26.3% for the second axis. Observed and expected heterozygosity was higher for the Ko‘olau populations (Ho: 0.32 ± 0.09; He: 0.45 ± 0.12) than the Wai‘anae populations (Ho: 0.08 ± 0.03; He: 0.25 ± 0.08), and percent polymorphism ranged from 16.7% for Wai‘anae populations EKA-D, PAL-A and HUL-A, to 83.3% for three Ko‘olau populations, KNA-A, MAA-A and PAP-A. Average heterozygosity for the species as a whole was low (0.21) (Table 2). *Fst* for the species averaged 0.48, indicating limited gene flow between the populations (Table 2).


**Figure 1**: Locations of *Schidaea kaalae* populations, both extant and historic (pre-1984) in the Koʻolau (right) and Waiʻanae (left) Mountains, Oʻahu. Map provided by OANRP.

**Table 2**: Average values of molecular variability for species (** indicates P<0.01); for *Fst* and *Rst,* only populations with more than one individual were included in analyses.

| | *Fst* | *Rst* | %P | Ho | He |
|---|---|---|---|---|---|
| *S. kaalae* | 0.48 ± 0.05 | 0.177** | 48.7 ± 7.2 | 0.21 ± 0.04 | 0.21 ± 0.03 |
| *S. obovata* | 0.88 ± 0.02 | 0.774** | 3.57 | 0.01 ± 0.008 | 0.01 ± 0.01 |
| *S. nuttallii* | 0.22 ± 0.04 | -0.007 | 58.3 ± 8.3 | 0.24 ± 0.06 | 0.25 ± 0.05 |

**Table 3**: Percentage of molecular variance among populations, among individuals, and within individuals for the three *Schiedea* species, determined by AMOVA using R-statistics analysis.

| | Among Pops (%) | Within Indiv. (%) | Among Indiv. (%) |
|---|---|---|---|
| *S. kaalae* | 18 | 49 | 33 |
| *S. obovata* | 78 | 14 | 8 |
| *S. nuttallii* | 0 | 3 | 97 |

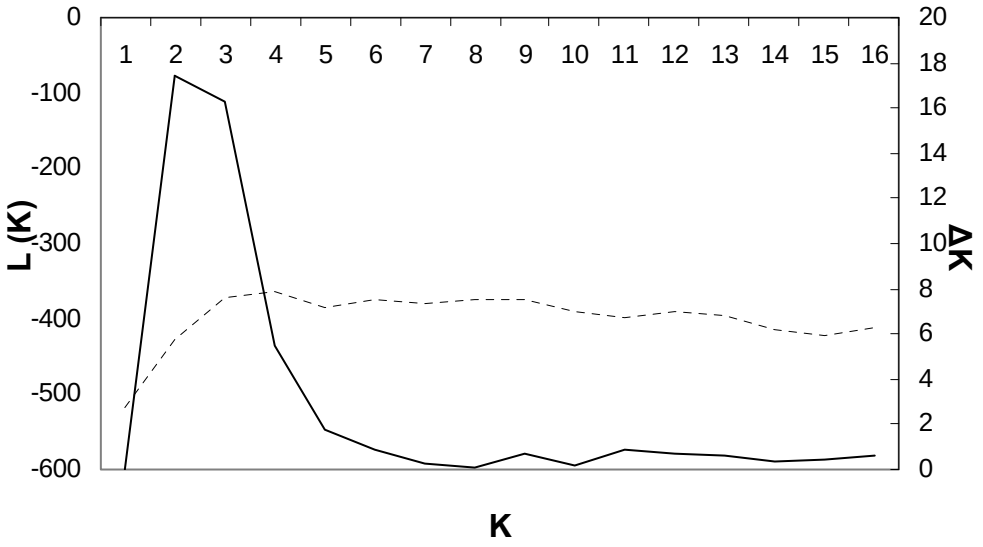


**Figure 2**: STRUCTURE analysis of *Schiedea kaalae* samples, 10,000 burn-in and MCMC simulation, suggesting the samples fall within 2-3 populations (K).

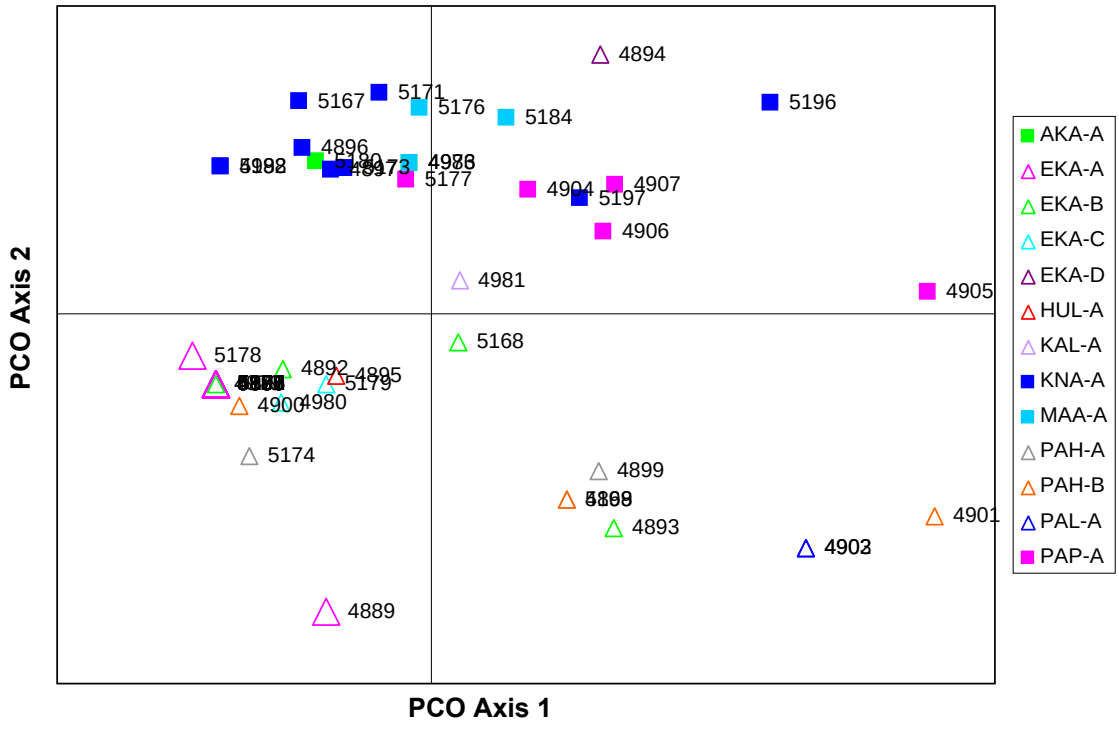


**Figure 3**: Principal Coordinate Analysis of microsatellite data for individuals from 13 *Schiedea kaalae* localities. Individuals from the Ko‘olau Mountain range are indicated by solid squares; Wai‘anae Mountain individuals are indicated with open triangles.

***Schiedea nuttallii***

Individuals of the predominantly outcrossing *Schiedea nuttallii* were obtained from three founder populations within the Wai‘anae Mountains, namely (north to south) MMR-B, PAH-A, and PAH-B (Figure 4). STRUCTURE analysis indicated optimal K values of 2 or 5 (Figure 5). Principal Coordinate Analysis (PCO) of the microsatellite data did not, however, indicate separation of the *S. nuttallii* individuals into population groups (Figure 3), and AMOVA detected little variation among populations (Table 3). The percentage of the variation explained by PCO was 36.8% for the first axis and 25.0% for the second axis. Observed heterozygosity was highest for the PAH-B population, which consisted of two individuals, namely a clone of the founder and progeny from that plant (He: 0.38 ± 0.16), and least for the MMR-B population (Ho: 0.12 ± 0.07), and percent polymorphism ranged from 50% for the MMR-B and PAH-B populations to 75% for the PAH-A population. Average heterozygosity for the species as a whole was low (0.24) (Table 2). *Fst* for the species averaged 0.22, indicating high gene flow between the populations (Table 2).


**Figure 4**: Locations of *Schiedea nuttallii* populations, both extant and historic (pre-1984), within the northern Wai‘anae Mountains, O‘ahu. Map provided by OANRP.

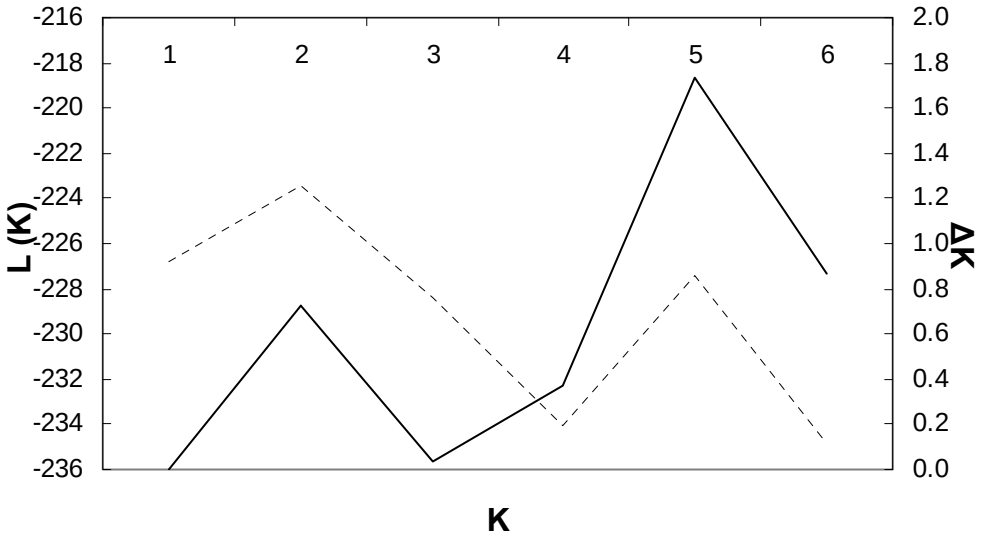


**Figure 5**: STRUCTURE analysis of *Schiedea nuttallii* samples, 10,000 burn-in and MCMC simulation, suggesting the samples fall within 2 or 5 populations (K).

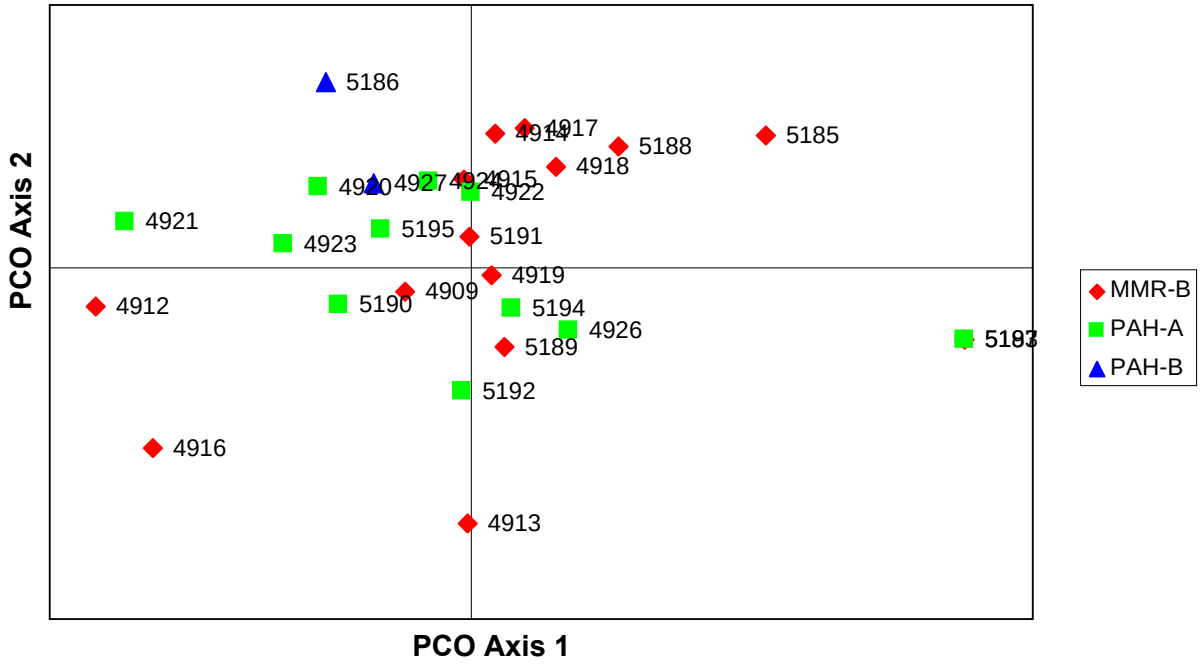


**Figure 6**: Principal Coordinate Analysis of microsatellite data for individuals from three *Schiedea nuttallii* localities.


**Figure 7**: Locations of *Schidea obovata* populations, both extant and historic (pre-1984), within the northern Wai‘anae Mountains, O‘ahu. Map provided by OANRP.

***Schiedea obovata***

Individuals of the predominantly selfing *Schiedea obovata* were obtained from seven founder population localities within the Wai‘anae Mountains, (from north to south) MMR-A, PAH-C, PAH-A, PIL-A, PIL-B, LEH-B, and LEH-A (Figure 7). STRUCTURE analysis indicated an optimal K value of 9 (Figure 8), with very little population structure (Figure 9). Principal Coordinate Analysis (PCO) of the microsatellite data, however, indicated separation of the *S. obovata* individuals into three population groups based on geography, with the southern-most population (LEH-A) being separated to the positive end of axis 2 (Figures 7, 10). AMOVA also indicated a high percentage of molecular variation among populations (78%) (Table 3). The percentage of the variation explained by PCO was 93.7% for the first axis and 6.3% for the second axis. *S. obovata* within populations showed very little genetic variation (Table 2), with only PAH-C exhibiting any observed heterozygosity (0.08) and polymorphism (25%). High average *Rst* and *Fst* for the species (Table 2) and extremely low observed heterozygosity for each of the populations indicates a high degree of isolation, and that the individuals within the

populations are genetically very similar, reflecting the autogamous breeding system of *S. obovata* and the geographic separation of the small population sizes.

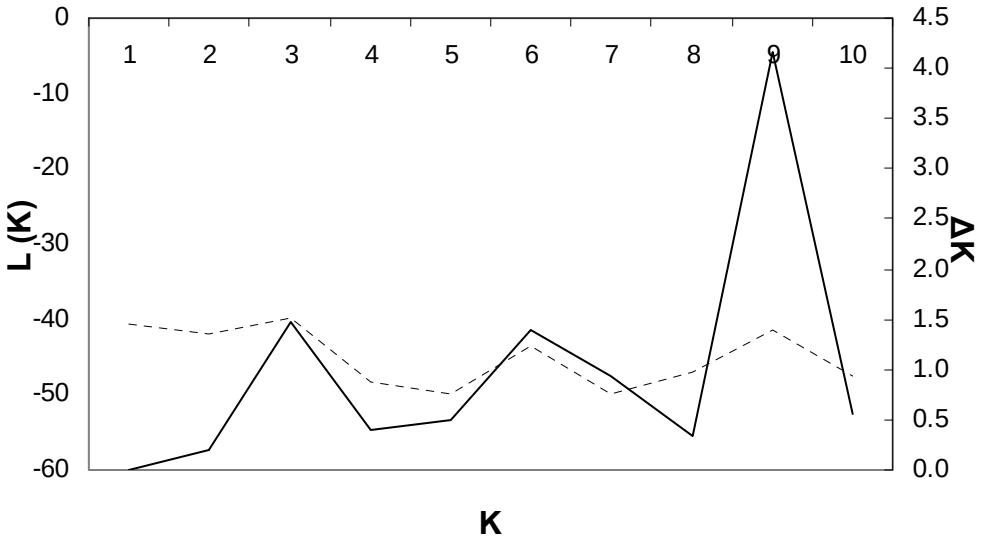


**Figure 8**: STRUCTURE analysis of *Schiedea obovata* samples, 10,000 burn-in and MCMC simulation, indicating limited population structure.

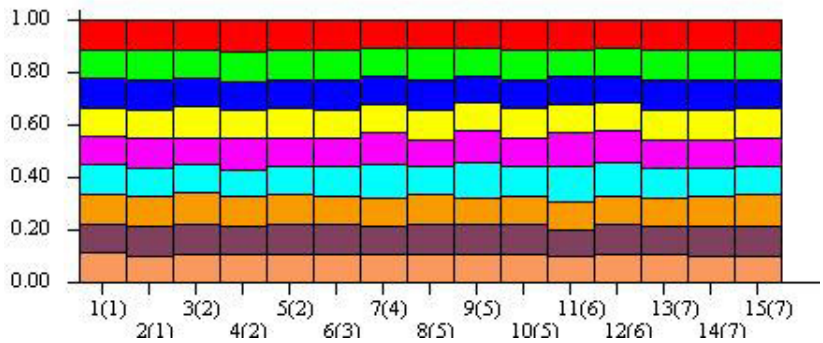


**Figure 9**: Lack of population structure in the species as indicated; assuming nine populations based on STRUCTURE analysis.

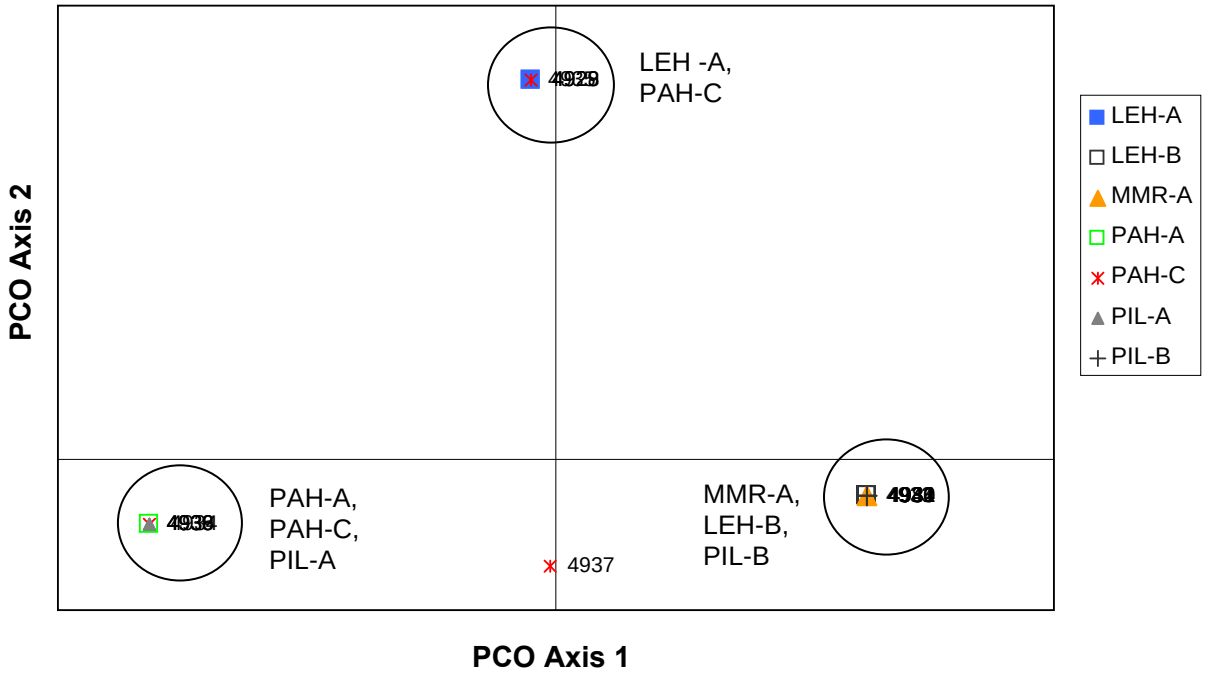


**Figure 10**: Principal Coordinate Analysis of microsatellite data for individuals from seven *Schiedea obovata* localities. The overlapping populations have been outlined.

## Discussion

For many species at risk of extinction, such as the *Schiedea* species found on U.S. Army lands, reintroductions may be needed to prevent extirpation. The consequences of mixing source populations will depend on a number of factors, including the degree of inter-population and intra-population genetic variation, and the extent of gene flow between individuals and populations. Reductions in genetic variability further limit a population's ability to withstand changes in the environment and stochastic events, such as habitat loss, fire, invasive species impacts, low population numbers (U.S. Army Garrison 2007, USFWS 2008), experienced by *Schiedea* species. Reintroduction activities should source populations in the vicinity of reintroduction sites, but potential source material can often be limited, and mixing of individuals from different populations may be necessary for the establishment of new populations to ensure

sufficient genetic variability. This microsatellite study of the three *Schiedea* species can provide insight into the current intra- and inter-population genetic variability, and assist with the selection of source plant material in future management activities.

All three of the *Schiedea* species exhibited relatively low levels of molecular variability, heterozygosity, and percentage polymorphism, which was dependent on breeding system and is indicative of low population sizes, as has been documented previously by Weller *et al.* (1996) using isozyme analysis. Microsatellite analysis showed the same trends in genetic diversity as isozyme analyses, but with higher estimated values, with the outcrossing species *S. nuttallii* having the highest percentage of polymorphic loci and mean heterozygosity of the three species (58.3 vs 22.2% and 0.24 vs 0.103, respectively for microsatellites vs allozymes), and the autogamous *S. obovata* (published as *Alsinodendron obovatum*) having the lowest values (3.57 vs 0% and 0.01 vs 0.004). *S. kaalae* demonstrated lower allozyme molecular variability than observed here for microsatellite analyses (48.7 vs 11.1% and 0.21 vs 0.041), but agrees more closely when only Waiʻanae individuals are considered (16.7% and 0.08).

***Schiedea kaalae***: Microsatellite analysis of the Koʻolau and Waiʻanae populations of *Schiedea kaalae* show that individuals from the two populations are genetically distinct, with the Koʻolau populations having a significantly higher heterozygosity and percent polymorphism than the Waiʻanae populations. Microsatellite analyses suggest differences between the northern and southern populations of *S. kaalae* in the Koʻolau Mountains, possibly reflecting differences in habitat adaptation. Keir and Weisenberger (2011) suggest that mixing of populations from the two mountain ranges would be beneficial, but given the higher genetic diversity within populations in Koʻolau Mountains and differences between the two mountains, only Koʻolau individuals should be planted in the Koʻolau Mountains, taking into account habitat differences between populations. However, the lower genetic diversity of the Waiʻanae populations indicates that future reintroductions of *S. kaalae* into the Waiʻanae Mountains would benefit from source material from both the Koʻolau and Waiʻanae populations.

***Schiedea nuttallii***: Microsatellite analysis of *S. nuttallii* indicated differences in genetic diversity between the three Wai‘anae populations. Low among population genetic variability and the low *Fst* of *S. nuttallii* indicates that gene flow is occurring within and between these populations, more so than for the other two *Schiedea* species. Keir and Weisenberger (2011) recommended that Kahanahā‘iki (MMR) populations not be introduced into Pahole (PAH) populations (i.e. preserve genetic lines), and this would be advised especially given the higher genetic diversity within the Pahole population as indicated by the microsatellite data presented here. Kahanahā‘iki, by contrast, exhibiting lower genetic variability could benefit from being augmented with Pahole individuals.

*Schiedea nuttallii* individuals from the PAH-B population have been noted to look different morphologically than other *Schiedea nuttallii* individuals from any of the other sites, having a viney growth habit and larger leaves (H.K. Kawelo, pers. comm. 2012). It has been hypothesized that this may be a hybrid between *S. nuttallii* and *S. pentandra*. The distribution of the two species appears to overlap, and both exhibit hermaphroditic breeding systems. While the PAH-B population did have higher levels of heterozygosity that other populations of *S. nuttallii*, and one individual (PCMB 5186) from the PAH-B population was somewhat separated from the majority of *S. nuttallii* individuals within the PCO analysis (Figure 6), the data presented here are not able to confirm whether the PAH-B population is true *S. nuttallii* or a hybrid without including *S. pentandra* in analyses.

***Schiedea obovata***: Microsatellite analysis of *Schiedea obovata* populations in the Wai‘anae Mountains reflected the facultative autogamous breeding system of this species. In selfing species with a long history of inbreeding, strongly deleterious recessive alleles may have been expressed and purged. The high level of homozygosity within these *S. obovata* populations coincides with high levels of selfing. Makaleha (LEH) populations showed evidence of environmental fitness differences and local adaptation to elevation and rainfall in this microsatellite study, as has been found also in pollination and common-garden studies (L. Weisenberger, pers. comm. 2012). The 2003 Makua Implementation plan indicated that plants of *S. obovata* from different stocks should not be mixed together in outplantings (U.S. Army Garrison 2003). However, Keir and Weisenberger (2011) recommended gene flow should be re-

established between all populations of *S. obovata* to benefit from heterosis, but that outplanting should take into account locality and elevation differences of the different founder populations. This would similarly be a management recommendation based on the microsatellite data presented here.

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## Acknowledgements

Many thanks to Lauren Weisenberger, U.S. Army Natural Resources for providing plant material for this study, Oahu Army Natural Resources Program for providing the maps, and Clifford Morden and Mitsuko Yorkston, Department of Botany, University of Hawaii for assistance with data analysis and interpretation.

**Appendix 1**: Specimens included in analyses. PCMB No. is the collection number of the tissues and DNA aliquots stored at the Bishop Museum. Specimens indicated by * were not used in final analyses.

| PCMB number. | Population | Plant number | Tag number; comments |
|---|---|---|---|
| ***Schiedea kaalae*** | | | |
| 4976 | AKA-A | 1 | |
| 5180 | AKA-A | 1 | 21581 |
| 4885 | EKA-A | 1 | |
| 4977 | EKA-A | 11 | |
| 4891 | EKA-A | 13 | 968 |
| 4890 | EKA-A | 13 | 980 |
| 4978 | EKA-A | 14 | |
| 4886 | EKA-A | 2 | 967 |
| 4887 | EKA-A | 2 | 976 |
| 4888 | EKA-A | 2 | 977 |
| 4889 | EKA-A | 2 | 979 |
| 5165 | EKA-A | 4 | 14503 |
| 5166 | EKA-A | 6 | 15660 |
| 5172 | EKA-A | 14 | 17710 |
| 5175 | EKA-A | 5 | 18678 |
| 5178 | EKA-A | 8 | 21409 |
| 5181 | EKA-A | 11 | 21586 |
| 5182 | EKA-A | 10 | 21601 |
| 5183 | EKA-A | 9 | 21602 |
| 4892 | EKA-B | 1 | 1253 |
| 4893 | EKA-B | 1 | 1302 |
| 4979 | EKA-B | 3 | |
| 5168 | EKA-B | 3 | 16080 |
| 4980 | EKA-C | 1 | |
| 5179 | EKA-C | 1 | 21578 |
| 4894 | EKA-D | 11 | |
| 4895 | HUL-A | 1 | 965 |
| 4981 | KAL-A | 1 | progeny |
| 4982 | KNA-A | 5 | |
| 4896 | KNA-A | 7 | 989 |
| 4897 | KNA-A | 9 | 1204 |
| 5167 | KNA-A | 15 | 15887 |
| 5171 | KNA-A | 10 | 17360 |
| 5173 | KNA-A | 11 | 18068 |
| 5196 | KNA-A | 3 | |
| 5197 | KNA-A | 4 | |
| 5198 | KNA-A | 5 | |
| 4983 | MAA-A | 3 | |
| 5176 | MAA-A | 3 | 20752 |
| 5184 | MAA-A | 1 | 21620 |
| 4899 | PAH-A | 1 | 1083 |
| 4898 | PAH-A | 1 | 1085 |
| 5174 | PAH-A | 1 | 18113 |

| PCMB number. | Population | Plant number | Tag number; comments |
|---|---|---|---|
| 4900 | PAH-B | 1 | 1004 |
| 4901 | PAH-B | 1 | 1304 |
| 5169 | PAH-B | 1 | 16275 |
| 4902 | PAL-A | 1 | 1260 |
| 4903 | PAL-A | 1 | 1289 |
| 4906 | PAP-A | 1 | 1589 |
| 4905 | PAP-A | 1 | 1624 |
| 4904 | PAP-A | 1 | 1627 |
| 4907 | PAP-A | 1 | 1628 |
| 5177 | PAP-A | 2 | 20774 |

| PCMB number. | Population | Plant number | Tag number; comments |
|---|---|---|---|
| ***Schiedea nuttalli*** | | | |
| 4908* | MMR-B | 1 | |
| 4909 | MMR-B | 3 | |
| 4910* | MMR-B | 5 | |
| 4911* | MMR-B | 7 | |
| 4912 | MMR-B | 11 | |
| 4913 | MMR-B | 16 | |
| 4914 | MMR-B | 17 | |
| 4915 | MMR-B | 25 | |
| 4916 | MMR-B | 31 | |
| 4917 | MMR-B | 39 | |
| 4918 | MMR-B | 54 | |
| 4919 | MMR-B | 66 | |
| 5185 | MMR-B | 28 | 11513 |
| 5187 | MMR-B | 46 | 16733 |
| 5188 | MMR-B | 65 | 18472 |
| 5189 | MMR-B | 37 | 18610 |
| 5191 | MMR-B | 61 | 21064 |
| 4920 | PAH-A | 1 | |
| 4921 | PAH-A | 4 | |
| 4922 | PAH-A | 5 | |
| 4923 | PAH-A | 7 | |
| 4924 | PAH-A | 8 | |
| 4925* | PAH-A | 10 | |
| 4926 | PAH-A | 12 | |
| 5190 | PAH-A | 6 | 19620 |
| 5192 | PAH-A | 14 | 21219 |
| 5193 | PAH-A | 16 | 21222 |
| 5194 | PAH-A | 3 | 21225 |
| 5195 | PAH-A | 19 | |
| 4927 | PAH-B | 1 | Reintro PAH-E 11 & 12 |
| 5186 | PAH-B | 1 | 11862 |

| PCMB number. | Population | Plant number | Tag number; comments |
|---|---|---|---|
| ***Schiedea obovata*** | | | |
| 4928 | LEH-A | 3 | GH 12826 |
| 4929 | LEH-A | 13 | GH 12825 |
| 4930 | LEH-B | 2 | GH 7499 |
| 4931 | LEH-B | 4 | GH 9638 |
| 4932 | LEH-B | 5 | GH 9640 |
| 4933 | MMR-A | 1 | GH 8806 |
| 4934 | PAH-A | 1 | GH 8374 |
| 4935 | PAH-C | 1 | GH 8839 |
| 4936 | PAH-C | 7 | GH 11305 |
| 4937 | PAH-C | 8 | GH 8882 |
| 4938 | PIL-A | 1 | GH 11261 |
| 4939 | PIL-A | 1 | GH 10994 |
| 4940 | PIL-B | 1 | GH 13971 |
| 4941 | PIL-B | 3 | GH 14331 |
| 4984 | PIL-B | 2 | |

Biol Invasions
DOI 10.1007/s10530-012-0280-3

ORIGINAL PAPER

# Large-scale rodent control reduces pre- and post-dispersal seed predation of the endangered Hawaiian lobeliad, *Cyanea superba* subsp. *superba* (Campanulaceae)

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Received: 17 October 2011 / Accepted: 5 July 2012


**Abstract** Large-scale rodent control can help to manage endangered species that are vulnerable to invasive rodent consumption. A 26 ha rodent snap-trap grid was installed in montane forest on Oahu Island, Hawaii, in order to protect endangered snails and plants. To assess the effectiveness of this trapping operation in reducing fruit consumption and seed predation of the endangered Hawaiian lobeliad, *Cyanea superba* subsp. *superba*, pre- and post-dispersal *C. superba* fruit consumption were monitored for 36 plants at the site with rodent control (Kahanahaiki) and 42 plants at an adjacent site without rodent control (Pahole). Over 47 % of all monitored fruit were eaten on the plants at Pahole compared to 4 % at Kahanahaiki. Images captured using motion-sensing cameras suggest that black rats (*Rattus rattus*) were the only pre-dispersal fruit consumers. To quantify post-dispersal fruit consumption, and to identify the culprit frugivore(s), mature fruit were placed in tracking tunnels positioned on the forest floor and checked daily. At Pahole, all of the fruit were consumed by rats compared to 29 % at Kahanahaiki. Lastly, to determine if rodents from the sites were predators or dispersers of *C. superba* seed, fruit were fed to captive black rats and house mice (*Mus musculus*). Black rats consumed entire fruit, killing all the seed, while mice did little damage to the fruit and seed. Therefore, large-scale rat trapping can directly benefit the reproduction of *C. superba* subsp. *superba*. Controlling black rats at restoration sites appears integral to the successful restoration of this endangered plant species.

**Keywords** Alien invasive species · Captive-feeding trials · Frugivory · *Mus musculus* · Plant recruitment · *Rattus rattus*

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## Introduction

Four rodents (black rats, *Rattus rattus*; Norway rats, *Rattus norvegicus*; Pacific rats, *Rattus exulans*, and

Published online: 25 July 2012

house mice, *Mus musculus*) are widespread invasive species that have been shown to negatively impact insular floras (Cuddihy and Stone 1990; Campbell and Atkinson 1999; Campbell and Atkinson 2002; Towns et al. 2006; Angel et al. 2009; Meyer and Butaud 2009; Auld et al. 2010). These rodents may have indirect impacts upon plants by modifying plant habitat and ecosystem functioning. For example, they may reduce native seed dispersal and pollination (Atkinson 1977; Atkinson 1985), or alter nutrient cycling and disturbance regimes associated with seabird nesting (Fukami et al. 2006; Mulder et al. 2009; Grant-Hoffman et al. 2010a, b). Rodents may also directly influence plants through the consumption of vegetative and reproductive parts (Sugihara 1997; McConkey et al. 2003; Salvande et al. 2006; Grant-Hoffman and Barboza 2010; Shiels 2011). As seed predators (see Grant-Hoffman and Barboza 2010 for a review), invasive rodents have been implicated in the breakdown of reproductive cycles of numerous island plant species (Campbell and Atkinson 2002; Meyer and Butaud 2009; Auld et al. 2010; Chimera and Drake 2011; Shiels and Drake 2011).

In Hawaii, the majority of studies concerning the effects of introduced rodents on the native flora have only recently been conducted (Athens et al. 2002; Pérez et al. 2008; Shiels 2010; Chimera and Drake 2011; Shiels and Drake 2011). Rodents were absent from Hawaii prior to the introduction of the Pacific rat by Polynesian settlers approximately 800 years ago (Wilmshurst et al. 2011). Athens et al. (2002) has suggested that Pacific rats were largely responsible for the decline of the native palms (*Pritchardia* spp.) that once dominated lowland forests on west Oahu. Three additional rodent species (Norway rat, black rat, and house mouse) were introduced by Europeans approximately 200 years ago (Atkinson 1977). Based on the results of contemporary studies, all four rodent species, and particularly black rats, probably have either directly or indirectly impacted the native Hawaiian flora (Cole et al. 2000; Shiels and Drake 2011). Today, Norway rats are most abundant in urban and agricultural lands on the main Hawaiian Islands and appear to be uncommon in native forest (Lindsey et al. 1999; Shiels 2010). Pacific rats are typically most common in lowland environments, although they have been recorded in montane rainforests up to 2,000 m (Sugihara 1997). House mice and black rats occupy most habitats from sea level to the alpine zones up to 3,000 m and are the most widespread of all introduced rodents in Hawaii (Tomich 1969; Shiels 2010).

In light of the nearly ubiquitous invasion of rodents on islands globally, rodent eradication has become a widely adopted strategy for the restoration of isolated islands (Towns and Broome 2003; Howald et al. 2007). However, when islands are either too large, or where rodent eradication is physically, socially or politically impractical, a targeted "Mainland Island" approach, first adopted in New Zealand (Saunders and Norton 2001), may limit rodent populations within areas surrounded by a matrix of habitat without rodent control. Such an approach may employ either the use of rodenticides and/or traps that must be regularly monitored (Saunders and Norton 2001).

In one of the first attempts to adopt a Mainland Island approach to rodent control in Hawaii, a 26 ha rodent trapping grid was established by the Oahu Army Natural Resources Program (OANRP) in montane forest on the island of Oahu, in May 2009. This ongoing trapping operation uses methods established by the New Zealand Department of Conservation (NZ DOC 2007; King et al. 2011). The trapping aims to reduce rodent (mainly rat) populations for the benefit of an endangered tree snail (*Achatinella mustelina*) and ten species of endangered plants.

One of these plant species is *Cyanea superba* subsp. *C. superba* (hereafter *C. superba*), a Hawaiian lobeliad historically recorded from mesic forest in the northern Waianae Mountains on Oahu (Wagner et al. 1999). The last wild plants of *C. superba* died in 2002. Seed previously collected from these remaining plants were germinated in nurseries and by mid-2011 over 800 *C. superba* had been outplanted across five restoration plantings in the Waianae Mountains. The decline of *C. superba* was attributed to habitat destruction, competition with invasive weeds, herbivory by introduced ungulates and slugs, and seed predation by introduced rodents (USFWS 1998; USFWS 2007; Joe and Daehler 2008). Casual observations indicated that introduced rodents (presumably rats) consumed significant quantities of *C. superba* fruit on the mature plants (USFWS 1998). However, whether these introduced rodents are predators or dispersers of the relatively small *C. superba* seed (<2 mm) remains unknown.

Our study had three aims: (1) to estimate the proportion of pre- and post-dispersal consumption of *C. superba* fruit by introduced rodents, (2) to

determine if the rodent species that consume fruit are seed predators or dispersers, and (3) to investigate the effectiveness of large-scale rodent trapping in reducing pre- and post-dispersal fruit and seed consumption of *C. superba*.

## Methods and materials

### Study site

The study was undertaken at two montane forest reserves located immediately adjacent to one another in the northern Waianae Mountain Range, Island of Oahu (21° 32′N, 158°11′W). Kahanahaiki Management Unit (36 ha) (hereafter Kahanahaiki) is managed by OANRP, while Pahole Natural Area Reserve (266 ha) (hereafter Pahole) is managed by the State of Hawaii Department of Land and Natural Resources. The two populations of *C. superba* monitored in this study were ca. 400 m apart over highly dissected terrain. Given their proximity, both sites likely share a similar altitude (500–660 m a.s.l.), monthly rainfall (50–170 mm; cited in Joe and Daehler 2008), and daily temperature range (16–24 °C; Shiels and Drake 2011). At both sites, vegetation communities were a mixture of native and introduced mesic forest species. The native canopy species included *Metrosideros polymorpha* and *Acacia koa*; however, introduced trees were the canopy dominants and included *Psidium cattleianum*, *Psidium guajava*, *Aleurites moluccana*, *Schinus terebinthifolius* and *Grevillea robusta*. The subcanopy was also a mix of native (e.g., *Diospyros hillebrandii*, *Planchonella sandwicensis*, *Pipturus albidus*, *Psydrax odorata*, *Hibiscus arnottianus*, *Pisonia umbellifera* and *Pisonia brunoniana*) and introduced species (*P. guajava*, *P. cattleianum*, *S. terebinthifolius*; Shiels 2010). Year-round fruit production occurs at the sites; the greatest numbers of fruit are produced between November and March, which overlaps with *C. superba* fruit production (A. Shiels, unpublished data). Through the use of fencing and subsequent trapping within the reserves, both sites have been free of introduced ungulates for the past 12 years.

Invasive rodents are common at Kahanahaiki and Pahole. A 26-month trap and release study of rodent densities and habitat use at Kahanahaiki, beginning in February 2007, revealed the presence of black and Pacific rats and house mice, but the absence of Norway rats (Shiels 2010). Black rats were the most common rodent (9.8 individuals/ha), followed by mice (5.1 individuals/ha) and Pacific rats were rare (0.2 individuals/ha; Shiels 2010). Given the proximity of Pahole and Kahanahaiki, the density of these rodents is likely to be similar at both sites.

### Study species

*Cyanea superba* is a single stemmed tree typically reaching 4–6 m (Wagner et al. 1999). The 0.5–1.0 m leaves are held in a rosette at the stem apex. Flowering is from September to mid-October (OANRP 2009) on racemes that hang up to 350 mm below the canopy of leaves (Wagner et al. 1999). The corolla is curved, white to cream in color, and 5.5–8.8 cm long (Wagner et al. 1999). The fruit are oval berries 25 mm long (±0.63 (SE), n = 31) and 21 mm wide (±0.54, n = 31) with a green-white exocarp and orange-red mesocarp containing ca. 130 seeds (±16.9, n = 31) (R. Pender, unpublished data). Each seed averages 1.86 mm long (±0.02, n = 20). Fruit mature between late November and early February (R. Pender, unpublished data).

### Rodent trapping at Kahanahaiki

Rodent trapping at Kahanahaiki commenced in May 2009 using 440 snap traps (Victor® model M326, Woodstream Corporation, Pennsylvania, USA) placed in individual 40 × 14 × 19 cm (l × w × h) wooden boxes with a single 4.5 × 4.5 cm entry hole nearest to the baited end of the snap trap (King et al. 2011). All trap-boxes were located along transects that collectively covered the 26 ha area. Trap spacing along the perimeter was 12.5 m (234 traps), and all interior transects had 25 m between each trap (206 traps). Each transect was approximately 50 m distant from the next closest transect. The traps were baited with either peanut butter or FeraFeed (a non-toxic feed paste containing a mixture of peanut butter and grains; Connovation Limited, Auckland, New Zealand), and half of a macadamia nut was also usually added to the bait. Traps were initially checked daily for 2 weeks, then every 2 weeks thereafter. Figure 1 summarizes the quantities of rats trapped each month between May 2009 and February 2010 (the period prior to and including the *C. superba* fruiting season monitored in the current study). A total of 576 rats and 274 mice were trapped at Kahanahaiki during this period.

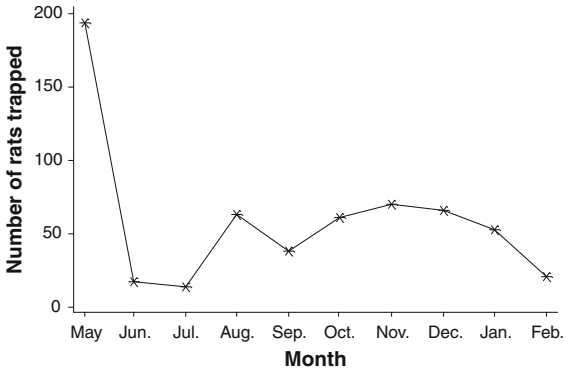


**Fig. 1** Number of monthly rat (*Rattus* spp.) captures from 440 snap-traps arranged in a 26 ha trapping grid at Kahanahaiki, Oahu, between May 2009 (start of trapping) and February 2010. The current study was undertaken during December 2009 and January 2010, which was the fruiting season for *C. superba*

Rodent activity at each site

To assess and compare rodent activity between Kahanahaiki and Pahole, seven plastic tracking tunnels (50 cm × 10 cm × 10 cm; Connovation Limited, Auckland, New Zealand) containing tracking cards that were not baited (The Black Trakka Gotcha Traps LTD, Warkworth, New Zealand) were placed at both sites for five consecutive nights, beginning on 15 December 2009. Each tunnel was placed within 2 m of the base of a fruiting *C. superba* tree. The minimum distance between any two stations was ca. 10 m. All tracking tunnels were checked every 24 h, and when footprints were present, the tracking card was removed and replaced with a new (untracked) card. The footprints on tracked cards were used to identify each animal species.

Pre-dispersal fruit consumption

To determine the level of pre-dispersal consumption of *C. superba* fruit, both sites were monitored every 2–3 days from the time fruit began to mature until the fruiting season ended (1 December 2009–28 January 2010). A total of 36 plants were monitored at the Kahanahaiki rodent control site and 42 plants were monitored at the Pahole non-treatment site. On the first monitoring visit, fruit in each infructescence were counted and the infructescence numbered using a tag attached to the peduncle. During each subsequent visit, the number of fruit on a given infructescence that had been partially or wholly consumed was recorded. The identities of the fruit-consuming animals were determined from the indentations in the fruit or pericarp (e.g., rodent chewing results in incisor marks distinct from bird or invertebrate indentations), as well as by photographs from the motion-sensing cameras (see below). Fruit that had been consumed were marked on their calyx with an ink pen to avoid mistakenly rerecording the consumption during later visits. In cases where infructescences aborted (i.e., no mature fruit formed) and fell, they were no longer monitored and were not included in the analysis. At the end of the fruiting season, total fruit consumption by rodents on each plant was determined by calculating the percentage of consumed fruit compared with those left undamaged from all infructescences on individual plants. Mean fruit consumption was then calculated for all plants at each site.

Motion-sensing cameras

Three infrared day/night still image cameras (Moultrie Game Spy D40, Moultrie Products, LLC, Alabama, USA) were used at each of the two sites to record animal visitation to ripe infructescences on *C. superba* plants during 16–28 December. The cameras were placed at an equal height to, and 1–2 m from, fruiting infructescences by securing them to introduced trees or 2.5 m long stakes. The cameras were moved every 3–4 days to randomly selected plants at each site. Color, still frame photos, were stored on solid disk (SD) cards and later copied onto a computer for viewing. The SD cards were removed and replaced each time the camera was moved. Each photo was viewed and all animals in the photos were identified; the activity (e.g., on the vegetative portion, on the infructescence, or eating fruit) of each animal was also noted. To avoid overestimating visits by individual vertebrate species, a 15 min interval (indicated by time stamps on photos) was required if consecutive visits were to be recorded as discrete visitation events.

Post-dispersal fruit consumption

To assess whether rats and mice consume *C. superba* fruit that fall to the ground (i.e., post-dispersal consumption) seven tracking tunnels were placed under fruiting *C. superba* trees at both sites (using the same methods, timing, and spacing, described for the

rodent activity assessment, above). Tracking cards were baited with ripe *C. superba* fruit. All tracking tunnels were checked every 24 h, and when footprints were present, the tracking card was removed and replaced with a new (untracked) card. The footprints on tracked cards were used to identify each animal species. The number of fruit that were consumed was recorded. A consumed fruit included those partially or wholly consumed or otherwise missing from the tracking tunnel; therefore, the amount of the exocarp, mesocarp, or seed consumed from each individual fruit was not quantified. Fruit were replaced if moldy or if any portion was consumed; otherwise fruit were not replaced during the 5-night study.

### Captive-feeding trials

Three male and three female adult black rats were captured from forest adjacent to Kahanahaiki and Pahole in December 2007 and taken to the University of Hawaii Lyon Arboretum Rodent Housing Facility. Each rat was held in an individual 38 cm × 22 cm × 18 cm metal-mesh (8 mm) cage. Rats were allowed to acclimate for at least 2 weeks before beginning the feeding trial, during which time the rats were fed mixed seed (e.g., corn, sunflower, wheat, barley, oats, sorghum) and occasionally wedges of fruit (tangerine). Rats were checked daily to ensure there was ample food and fresh water, and to clean urine/fecal trays.

On 13 January 2008, a single ripe fruit of *C. superba*, was placed in each rat's cage. After 48 h of exposure, fruit were visually inspected to estimate the proportion of the pericarp (fruit material) and seed mass remaining. Because seed of *C. superba* are small (ca. 1.86 mm length at longest axis), it was necessary to collect the droppings from each rat and microscopically inspect them for intact seed. Seed with at least half of their original mass remaining were extracted from droppings and sown onto agar Petri dishes to compare germination success with unconsumed (intact) *C. superba* seed (n = 3 agar Petri dishes with five unconsumed seeds sown on each; Shiels 2011). All fruit and seed for the captive-feeding trials were collected from unmonitored plants at Kahanahaiki. All Petri dishes were placed on a laboratory bench-top (23 °C ambient temperature) at the University of Hawaii where germination of sown seed was assessed weekly for a 10 week period.

In December 2009, two house mice were caught at Ka Iwi Shoreline in southeastern Oahu and held in captivity in a similar fashion as the rats. Each mouse was offered a fresh *C. superba* fruit, and after 24 h the fruit and mouse droppings were inspected using the same methodology as used for black rats. The shorter (24 h) time period for the trials with mice relative to black rats was used for two reasons: (1) minimal food was consumed during the first 24 h, and (2) house mice have higher metabolic rates when compared to rats (MacAvoy et al. 2006).

### Data analysis

Percentages of pre-dispersal fruit consumption at both sites were arcsin square-root transformed and tested for equal variances using a Levene's test. Upon verification of parametric assumptions, a two sample *t* test was used to compare fruit consumption between sites (n = 36 for Kahanahaiki, n = 42 for Pahole). For both the unbaited tracking tunnels that were used to assess rodent activity, and those used for assessing post-dispersal fruit consumption, we used Fisher's exact tests to compare 1) rat, and 2) mice activity in tunnels (n = 7 tunnels per site in both cases) between Kahanahaiki and Pahole. Although fruit and tracking cards were checked daily, statistical analyses were based on whether or not the tracking tunnel had been visited (for unbaited tunnels), or whether or not the fruit was consumed (for post-dispersal fruit consumption), at any point during the 5 day period. All analyses were completed in R (version 2.12.0, R Development Core Team 2010), and all means are presented ±1 SE.

## Results

### Fruit production

The 36 plants monitored at Kahanahaiki collectively produced 192 infructescences, with a mean of five per plant (±0.42). The mean number of fruit produced per plant was 85 (±9.74), with 16 fruit (±0.43) produced per infructescence. In total, 3,062 fruit were monitored at Kahanahaiki across all plants. At Pahole, the 42 plants collectively produced 194 infructescences, with a mean of four per plant (±0.38). The mean number of fruit produced per plant at Pahole was 60 (±6.77) with

13 fruit (±0.39) produced per infructescence. In total, 2,426 fruit were monitored across all plants at Pahole.

Rodent activity at the study sites

The incidence of rat activity around the *C. superba* trees (measured using unbaited tracking tunnels; n = 7 per site) was significantly less at Kahanahaiki than at Pahole ($df = 1$, $P = 0.005$). By contrast, mouse activity was similar between the two sites ($df = 1$, $P = 0.286$).

Pre-dispersal fruit consumption

At Pahole, without rodent control, 41 of the 42 plants had some fruit consumed by rodents. By contrast, at Kahanahaiki where rodents were controlled, 14 of the 36 plants had some fruit consumed by rodents. Almost half of the fruit on all monitored Pahole plants were consumed whereas at Kahanahaiki mean consumption of fruit by rodents was <5 % (t = 10.68, $df = 76$, $P < 0.0001$; Fig. 2). At both sites, consumption rates of *C. superba* fruit were highest around the middle of the fruiting season (Fig. 3).

Motion-sensing cameras and evidence of fruit consumption by animals

Nine plants were monitored with motion sensing cameras for a total of 28 camera nights at Pahole and 12 plants for a total of 39 camera nights at Kahanahaiki. Only one avian frugivore, a single Japanese white-eye (*Zosterops japonicus*), was photographed during daylight hours perching on a *C. superba* stem, but not interacting with the fruit. Black rats were the only animals photographed interacting with *C. superba* fruit (Fig. 4) and these were the likely culprits of all fruit consumption. All black rat visitations were at night. Eighteen photographs of individual visits by black rats to three plants were obtained at Pahole compared to seven photographed visits by black rats to three plants at Kahanahaiki. There was no evidence (e.g., absence of bird bill marks) that any other vertebrates interacted with the fruit.

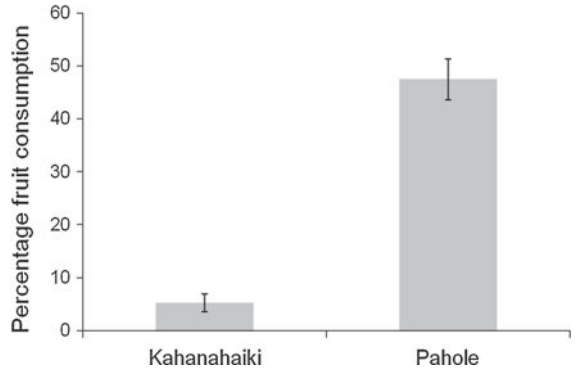


**Fig. 2** Mean (±SE) percentage pre-dispersal consumption of *C. superba* fruit at Kahanahaiki (n = 36 plants) (rodent control) compared to Pahole (n = 42 plants) (no rodent control) recorded throughout the fruiting season

Post-dispersal fruit consumption

Based on footprints, rats and mice visited *C. superba* fruit in the tracking tunnels on the forest floor at both sites. In several cases, rats and mice visited the same tunnel as evidenced by rat and mouse tracks on the same tracking card (71 and 14 % of cards at Pahole and Kahanahaiki, respectively). Rat consumption of *C. superba* fruit from the tracking tunnels was significantly higher at Pahole (100 % of fruit) compared to Kahanahaiki (29 % of fruit) after 5 days ($df = 1$, $P = 0.021$; Fig. 5). When rat tracks were observed on tracking cards (100 % at Pahole; 14 % at Kahanahaiki), the fruit was typically consumed entirely or otherwise missing. Where only mouse prints were recorded on tracking cards (43 % at Pahole; 71 % at Kahanahaiki), the fruit always remained in the tunnel and had little (<10 %) fruit consumption, which was largely limited to nibbling on the exocarp. There was no significant difference in mouse consumption of *C. superba* fruit between Pahole and Kahanahaiki ($df = 1$, $P = 0.559$; Fig. 5).

Captive feeding trials

After 48 h of exposure of *C. superba* fruit to black rats in captivity, all six rats had eaten all of the seed and mesocarp. Five of the six rats consumed the entire fruit, and the single rat that did not consume all of the fruit had just 15 % of the fruit exocarp remaining in its cage. Seed coats and very small (<1 mm) fragments of seed were recovered from each rat's droppings. None of the seed fragments that were extracted from rat droppings germinated when sowed, yet control seed (those sowed without passing through rats) readily (86.7 ± 6.7 %) germinated. Therefore, black rats destroyed all of the seed that they consumed in the captive feeding trials.

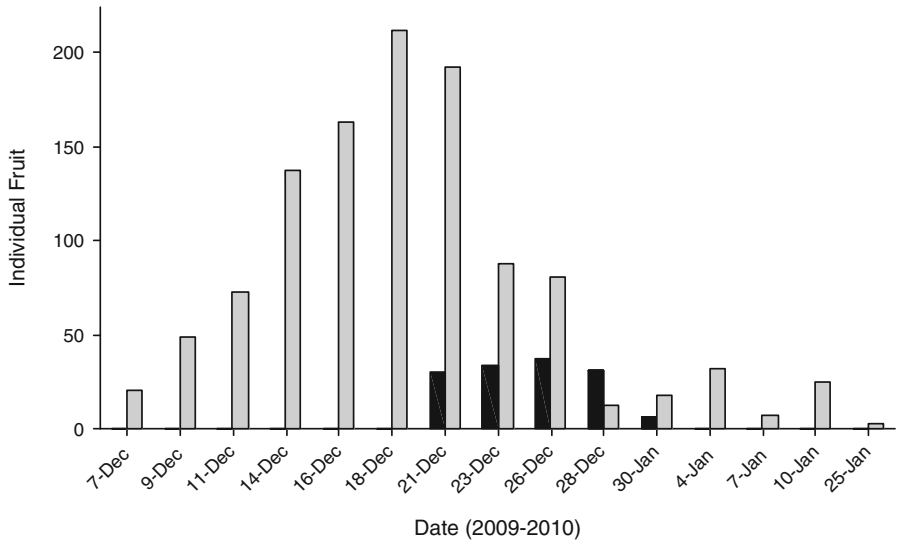


**Fig. 3** Total pre-dispersal consumption of individual *C. superba* fruit recorded during each field visit to Pahole (*gray bars*) and Kahanahaiki (*black bars*) during the study period (December 2009–January 2010)


**Fig. 4** Black rat interaction with *C. superba* fruit. *Photograph A*: A black rat feeding on the fruit of *C. superba* on a plant at Pahole. The image was captured using a motion-sensing camera. *Photograph B*: Black rat damage to a *C. superba* fruit placed in a tracking tunnel at Pahole. Note the tooth marks on the exocarp and total removal of the mesocarp of the fruit. Part of the exocarp and the calyx (held by fingers) remain

When captive mice were offered *C. superba* fruit and assessed after 24 h, there was very little consumption of the pericarp (97.5 % ± 0.5 fruit remained in each cage) and seed (98.0 % ± 1.0 seed remained in each cage). There were no obvious fragments or intact seed in the mice droppings, indicating that the few seed that may have been consumed by mice were likely killed upon consumption.

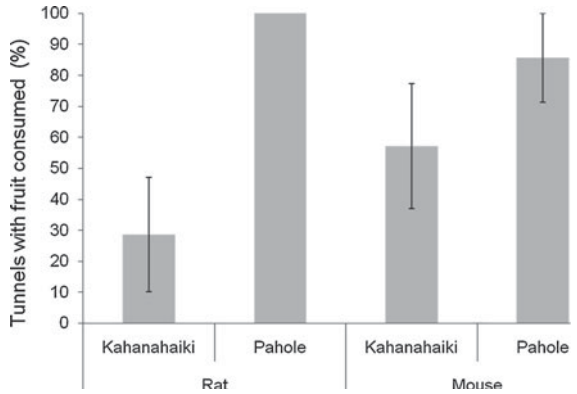


**Fig. 5** Mean (±SE) percentage of tracking tunnels containing *C. superba* fruit that were consumed by rats or mice at Kahanahaiki and Pahole

## Discussion

Results from pre- and post-dispersal fruit consumption combined with evidence from photographs and captive feeding trials suggest that invasive black rats are significant frugivores and seed predators of *C. superba*. First, black rats ate the fruit and destroyed all of the *C. superba* seed offered to them in captivity, suggesting that they destroy the seed that they consume in the field. Second, the considerable difference in both pre- and post-dispersal fruit consumption between Pahole and Kahanahaiki suggests that: (1) black rats are the major frugivores and seed predators where they freely interact with *C. superba*, and (2) large-scale rodent trapping significantly reduces pre- and post-dispersal fruit consumption and seed predation by rats at Kahanahaiki.

Black rats consumed almost half of all ripe *C. superba* fruit on the plants at Pahole. By contrast, trapping of rats at Kahanahaiki significantly reduced the pre-dispersal fruit consumption at Kahanahaiki (4 %). Black rats are arboreal and feed in trees and on the ground (Delgado Garcia 2002; Auld et al. 2010; Shiels and Drake 2011). Shiels (2010) found that black rats spend 64 % of their time above ground at Kahanahaiki. This allows them to freely access ripe fruit before they are dispersed. However, owing to the difficulty of quantifying fruit removal in plant canopies, few comparative studies have assessed levels of pre-dispersal fruit consumption by invasive rats. Meyer and Butaud (2009) found that rats (presumably black rats) consumed and destroyed the seed in 99 % of the fruit crop in trees of the Polynesian sandalwood (*Santalum insulare*) in Tahiti. Similarly, Delgado Garcia (2002) found that invasive black rats consumed 58 % of the fruit of *Viburnum tinus* in the Canary Islands. These findings, and those of the current study, suggest that invasive black rats may be significant, yet underappreciated, pre-dispersal seed predators in the habitats that they have invaded.

The post-dispersal consumption of *C. superba* fruit showed a similar trend to that of pre-dispersal consumption, with all fruit consumed at Pahole compared with 29 % at Kahanahaiki. The amount of post-dispersal fruit consumption recorded for *C. superba* was more pronounced than most other studies of native plants on Pacific islands. For example, Auld et al. (2010) found that up to 54 and 94 % of fruits of the palm species, *Hedyscepe canterburyana* and *Lepidorrhachis mooreana*, respectively, were removed by black rats in a study conducted on Lord Howe Island. Rodent baiting significantly lowered fruit removal for both palm species. In a 2.5-year-study conducted at Kahanahaiki, Shiels and Drake (2011) placed fruit of 12 woody plant species on the ground in a series of vertebrate exclusion treatments. Six of the 12 species had the majority (>50 %) of their fruit removed in treatments that were accessible to rats, and motion-sensing cameras also recorded only black rats removing fruit. Additional recent studies demonstrating post-dispersal fruit removal by invasive rodents have been conducted elsewhere in Hawaii (Chimera and Drake 2011) and in New Zealand (Moles and Drake 1999; Grant-Hoffman et al. 2010a).

The high rate of post-dispersal fruit consumption recorded in our study may partly owe to experimental design. First, due to the limited availability of undamaged fruit at Pahole, our study used a relatively small sample size (n = 7 tracking tunnels at each site), with tunnel nights undertaken during the peak period of pre-dispersal fruit consumption (Fig. 3). Second, tracking tunnels were placed in close proximity to one another at each site, which potentially allowed for a small number of rats to circulate among the tunnels. Further, we placed ripe fruit in the tracking tunnels; however, the majority of fruit that fall after natural abscission from the parent plant are already in an advanced stage of decomposition (R. Pender, per. obs.). Our study did not assess whether black rats

consume decomposing fruit. For these reasons, we may have slightly overestimated the rate of fruit consumption by rats under the parent plants.

Because of the difficulties in determining seed fate (e.g., if a seed consumed by an animal survives consumption), there have been few studies that have been able to determine if seeds removed by invasive rats are depredated (but see Williams et al. 2000; Pérez et al. 2008; Shiels and Drake 2011). The results from our laboratory feeding trials imply that black rats destroy all the seed in the *C. superba* fruit that they consume. Similarly, >80 % of the seeds from two native Hawaiian palms (*Pritchardia* spp.), which are ca. 6–10 times larger in seed length (>1,000 times larger in seed mass) than *C. superba*, were consumed and destroyed by captive black rats (Pérez et al. 2008). Williams et al. (2000) found that black rats in New Zealand destroyed seed larger than ca. 2.4 mm. However, a recent study by Shiels (2011) using captive black rats from Oahu that were fed the fruit of 25 different plant species, found that seed ≤1.5 mm survived gut passage but those seed ≥2.1 mm were destroyed. The seed of *C. superba* average 1.86 mm and were destroyed when ingested by black rats. The slightly smaller seed sizes that are destroyed by black rats in Hawaii (i.e., 1.86 mm and larger; Shiels 2011; this study) compared to New Zealand (>2.4 mm; Williams et al. 2000) may be explained by the larger average body sizes of black rats in New Zealand relative to those on Oahu (Shiels 2011).

Based on the results from tracking tunnels containing *C. superba* fruit, and the fruit offered in laboratory feeding trials, mice do not appear to be important seed predators of *C. superba*. Seed of a variety of species are commonly consumed by the house mouse, yet fleshy fruit is a small part (ca. 10 %) of mice diets in Hawaii (Cole et al. 2000; Shiels 2010) and other islands that they have invaded (Ruscoe and Murphy 2005; Angel et al. 2009). Additionally, it is unlikely that Pacific rats substantially affect *C. superba* fruit and seed destruction at our study sites because their densities were low (i.e., <1 indiv./ha; Shiels 2010) and there was no evidence that they visited *C. superba* fruit in trees or in the tracking tunnels.

Our photographic evidence revealed that only black rats consumed fruit on the *C. superba* plants. Despite the presence of introduced avian frugivores at both sites, we found no evidence that birds visited ripe fruit on the plants. Several introduced passerines, including white-rumped shama (*Copsychus malabaricus*), Japanese white eye, red-billed leiothrix (*Leiothrix lutea*), red-whiskered bulbul (*Pycnonotus jocosus*), and red-vented bulbul (*Pycnonotus cafer*) are common at both study sites and are known to eat fruit of other native plant species (Foster and Robinson 2007; Chimera and Drake 2010; R. Pender, pers. obs.). Given the small populations of *C. superba*, resident bird species may favor more common fruit sources. Although our post-dispersal experiment excluded birds from interacting with *C. superba* fruit, it is possible that frugivorous passerines or the introduced galliform, Erckel's francolin (*Francolinus erckelii*), may consume fruit on the ground after they have fallen from the plant. Based on a past diet study of Erckel's francolin at Kahanahaiki (A. Shiels, unpublished data), and additional passerines in Hawaiian forests (Foster and Robinson 2007), it is highly likely that *C. superba* seed would be passed intact (i.e., dispersed) by birds if they ate the fruit.

Because we demonstrate that black rats destroy seed and potentially influence the recruitment of *C. superba* seedlings, we strongly support continued rat control at *C. superba* restoration sites during the fruiting season. To further our understanding of this rat-plant interaction, as well as increase the efficiency of rat control in *C. superba* restoration plantings, we recommend surveys at each of the current restoration sites to quantify animal fruit consumption, seed predation, and seedling recruitment. This information could also be used to compare large-scale rodent control sites, such as Kahanahaiki, to small-scale localized rodent control sites to help identify the minimum amount of rodent control effort required during the fruiting season to prevent rats from negatively affecting the regeneration of this species.

**Acknowledgments** We thank the Oahu Army Natural Resources Program (OANRP) for funding and logistical support of this project—we are especially grateful for the many staff members that helped with the intensive and on-going rodent trapping at Kahanahaiki. We thank both OANRP and the Pahole Natural Area Reserve managers (State of Hawaii) for land access, and Don Drake, Kapua Kawelo, Matthew Keir, Clifford Morden, Julia Rowe, Lauren Weisenberger, and two anonymous reviewers for their helpful comments on an earlier draft of this manuscript. RJP and ABS wish to thank the Pacific Cooperative Studies Unit and Clifford Morden for providing logistical support. RJP gratefully acknowledges the financial support provided by Fulbright New Zealand and the John R. Templin Scholarship. This research was approved by the University of Hawaii Animal Use and Care Committee.

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# Nike/Pahole Nursery Snail Invasion Detection

1) Approximately 80 plastic containers (length 13 cm, width 10 cm, height 5 cm) will be put into the ground surrounding the nursery, approximately 5 meters out from the nursery and positioned 1 meter apart (Figure 2) by OANRP personnel.
2) Approximately 120 plastic containers (length 13 cm, width 10 cm, height 5 cm) will be put into the ground surrounding the nursery, approximately 5 meters out from the nursery and positioned 1 meter apart (Figure 2) by OANRP personnel.
3) Each container will have a hole cut out of its bottom, approximately 6 x 4 cm to permit drainage. Each container will contain a piece of lettuce (food) and a piece of cardboard (shelter), each approximately 4 x 4 cm.
4) Containers will be monitored by OANRP personnel every 3-4 days for any snails or slugs. Each container should be searched for at least 30 seconds, to ensure finding very small snails/slugs. On each occasion the lettuce and cardboard will be dampened as needed. Replace lettuce also as appropriate (if it has dried out or become rotten).
5) Collect any snails/slugs found for confirmation of identification by UH personnel, as necessary.
6) Monitor for 1 month.


Figure 2: Approximate placement of potted lettuce plants around the Nike/Pahole nursery. Map provided by Lauren Weisenberger.

# Final Report: Assessment of the current distribution and abundance of *Oxychilus alliarius* on Oahu, Hawaii



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# Annual Report for University of Hawaii Tree Snail Conservation Lab, to the Oahu Army Natural Resources Program:

## *Captive propagation of endangered tree snails and ongoing threat assessment of Jackson's chameleons, as well as other invasive species on Oahu*

**Date:** November 2012
**Address:** 337 Henke Hall
**Telephone:** (808) 956-6176
**Project Name:** Captive Propagation of Endangered Tree Snails,
Threat Assessment of Invasive Jackson's Chameleons on Oahu
**Location:** UH Manoa, Center for Conservation Research & Training
**Principal Investigator:** Brenden Holland (bholland@hawaii.edu)

### Current status of captive endangered tree snail populations:

We currently are caring for 759 Hawaiian tree snails, 699 of which are members of the endangered genus *Achatinella*, from Oahu. For summaries of all captive species of tree snails, please see Tables at the end of this report. At current tree snail population levels, we are operating 5 environmental chambers, and we culture 40 potato dextrose agar plates of tree fungus per 2-week cage changing cycle.

The primary ongoing function of this lab, coordinated and partially funded through Oahu Natural Resources Program (OANRP) is captive propagation of endangered Hawaiian tree snails, carried out by my staff of research technicians and students. Numbers of snails in several cages have dwindled in recent years such that there is only a single individual of the following species: *Achatinella apexfulva, A. sowerbyana, Partulina perdix,* and *P. proxima*. However certain other taxa continue to reproduce and persist relatively well in captivity, in spite of periods of elevated mortality due to undetermined causes. One of our priorities for improving health, reproduction and longevity of captive tree snails is improvement of diet. We will be applying for multi-year extramural funding to pursue this line of research in the near future. Tree snail captive propagation is summarized in the series of Tables A–C, at the end of this document.

A highlight of this funding cycle was the release of several hundred *Achatinella mustelina* into the tree snail exclosure at Puu Hapapa in the Waianae Mountains. Through this collaboration with OANRP biologists, between February and May, 2010, 202 *Achatinella mustelina* tree snails were collected and placed in the Hawaiian Tree Snail Conservation Lab (HTSCL), at the University of Hawaii (UH) in order to protect them from predation occurring at the Puu Hapapa site. This action was undertaken by the OANRP with approval of the U.S. Fish and Wildlife Service. The release followed guidelines agreed upon via a series of multi-agency meetings as detailed in the Reintroduction and Translocation Plan, December 2011. As part of this effort, tissue samples were collected from live snails at three separate locations by Vince Costello, OANRP and Brenden Holland, UH. Snails from across the site were genotyped and determined to be a single genetically homogenous population. The selected reintroduction site is protected within the ungulate free Kaluaa and Waieli management fence (fences completed and ungulate free since 2010) (see November 2010 Status Report For the Makua and Oahu Implementation Plans). In addition, we refined our release protocol in terms of first and second release as follows. During the evening and the morning following the first release, we noticed that many of the snails remained in the cages overnight. Upon examination of the cages we realized that although leaves and small branches had been placed in the release baskets, in most instances the branch and leaf material was not in contact with the tree from which the basket was hung, and the snails therefore had no way to exit the basket without contacting the screen material. We adjusted or added leaves such that snails crawling on the material could directly access either the trunk or even better, leaves of the tree. During the second release, this method was carefully adhered to and we realized the importance of this method since the snails departed from the baskets far more effectively.

Following the release of 340 individuals of *Achatinella mustelina* from the lab, several dozen more individuals from surrounding populations outside of the security fence structure have also been brought in. The main release events occurred in February 8 and February 21, 2012. This effort was the culmination of several years of planning and collaborative work among the OANRP, USFWS and the HTSCL.

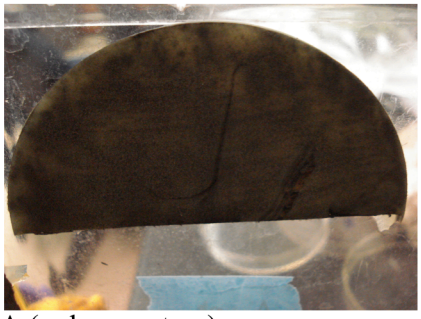
In this report we also describe results of work aimed at understanding the distribution, feeding ecology and movements of the invasive Jackson's chameleons (*Trioceros jacksonii xantholophus*) in Hawaii. Goals of this project include: 1) to estimate the amount of time required by Jackson's chameleons to digest *Achatinella mustelina* shells under different feeding conditions (completed and described previously) and 2) to assess their habitat utilization and daily movements using active radio transmitters, in different types of forest.

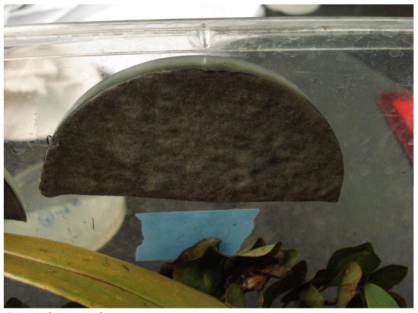
In addition we have summarized preliminary feeding trials and gut content analyses (Tables 4 & 5) of invasive herpetofauna from Oahu, and tested xylene paint on shells (Figure 7).

**Laboratory Culture and DNA Sequencing of New Species of Tree Fungus**

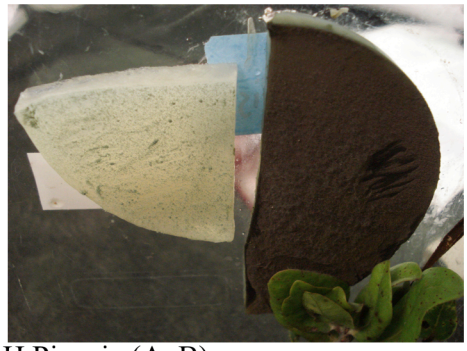
We have begun to make progress in the culture of additional tree fungus species, as well as molecular systematics of these additional species. We have extracted DNA, PCR amplified and sequenced a fragment of the Internal Transcribed Spacer (ITS) gene from eight species of fungus. However, studies are ongoing, results are not yet available. The eight species shown below have been cultured and sequenced. Preliminary data collected will be used to apply for additional, non-OANRP funding for this project.

# Fungus feeding trials


A (unknown tree)

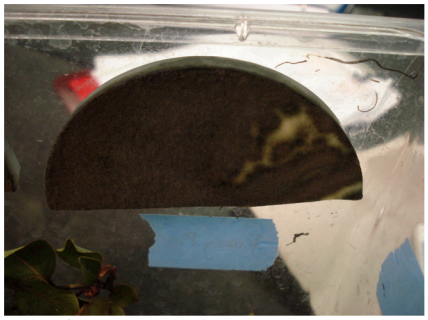

G Pisonia


D Pisonia


H Pisonia (A, B)


I'e I'e


K Ohia


F (unknown tree)

**Jackson's Chameleons: Egg predation lab study**

To follow up on one of our concerns, namely that Jackson's chameleons might prey upon eggs, particularly those of native birds, we conducted a series of trials with captive chameleons and eggs of three different species, including (from smallest to largest) those of *Euglandina rosea*, brown anole (*Anolis sagrei*), and commercially available quail eggs. We used eggs of various sizes of invasive taxa to serve as surrogates for native bird eggs. We also used a bird nest, most likely that of a Japanese white-eye (*Zosterops japonicus*), and presented the eggs, several at a time, to starved adult Jackson's chameleons (SVL range: 10 -13 cm), in turn. Under laboratory conditions, none of the eggs were consumed.

Continuing with the chameleon work, we now have good data on how long tree snail shell digestion takes, but we would like to gain some understanding of how far chameleons tend to move. This will further enhance our understanding of the potential impacts and threats posed by chameleon. In summary, we have found that otherwise starving Jackson's chameleons can completely digest an *Achatinella mustelina* shell in 8 days (12.5% of shell mass per day). However, well-fed individuals can pass a shell within 3 days. Our field studies with radio transmitters have also been concluded, showing that the home ranges of the 5 Jackson's chameleons at Tantalus did not overlap, and they covered the longest distances (averaging 19.5 m per day) during the first three days, while their movements decreased considerably after that, and followed a more or less circular pattern, allowing them to remain within a relatively small area for transmitter battery duration of more than three months. Second and third chameleon releases are also summarized in the following sections.

**Jackson's Chameleons: Field study**

Field studies focusing on understanding habitat utilization in invasive Jackson's chameleons (*Trioceros jacksonii xantholophus*) on Oahu, was initiated in June 2011 with the first release of individuals with radio-transmitters near the Tantalus summit, we conducted and concluded two additional releases at two different sites on Waahila Ridge: 1) Waahila "low" and 2) Waahila "high". Data collected during these additional field trials provides comparative information on habitat usage, including home range size, home range overlap, distance traveled from release point, and daily distance covered under different pre-selected environmental conditions.

The objective of this study was to assess and compare habitat unitization by Jackson's chameleons in suitable and non-suitable habitats in order to gain knowledge regarding their ecology to help develop management and control strategies for this invasive predator in Hawaii.

**Methods:**

**Habitat Utilization and Home Range Estimate:** The release sites were chosen based on perceived suitability of habitat for Jackson's chameleons based on presence of established populations of invasive chameleons and habitat and climatic conditions as described below (Figure 1):

1. **Tantalus** Suitable habitat. Established reproductive populations of chameleons are present in this area. Chameleons of all size classes have been documented in this area for several decades. Water (for precipitation comparison, see Figure 2) and food are abundant. Elevation was 1,430 ft (436 m) ambient temperatures, and complex canopy cover are presumably suitable.

2. **Waahila Ridge High** Unsuitable, chameleon populations are not established here. Elevation (1,230 ft, 375m) is slightly lower than Tantalus, this area is characterized by low diversity canopy cover, and intermediate rainfall levels (Figure 2), possibly rendering this site suboptimal.

3. **Waahila Ridge Low** Unsuitable. Chameleon populations are not present. This low elevation (190 ft, 58 m) release site has the highest temperatures, lowest canopy cover, lowest canopy and botanical diversity and lowest rainfall of all sites (Figure 2). This is a grassy exposed dry ridge with sparse low density trees and very little shade.

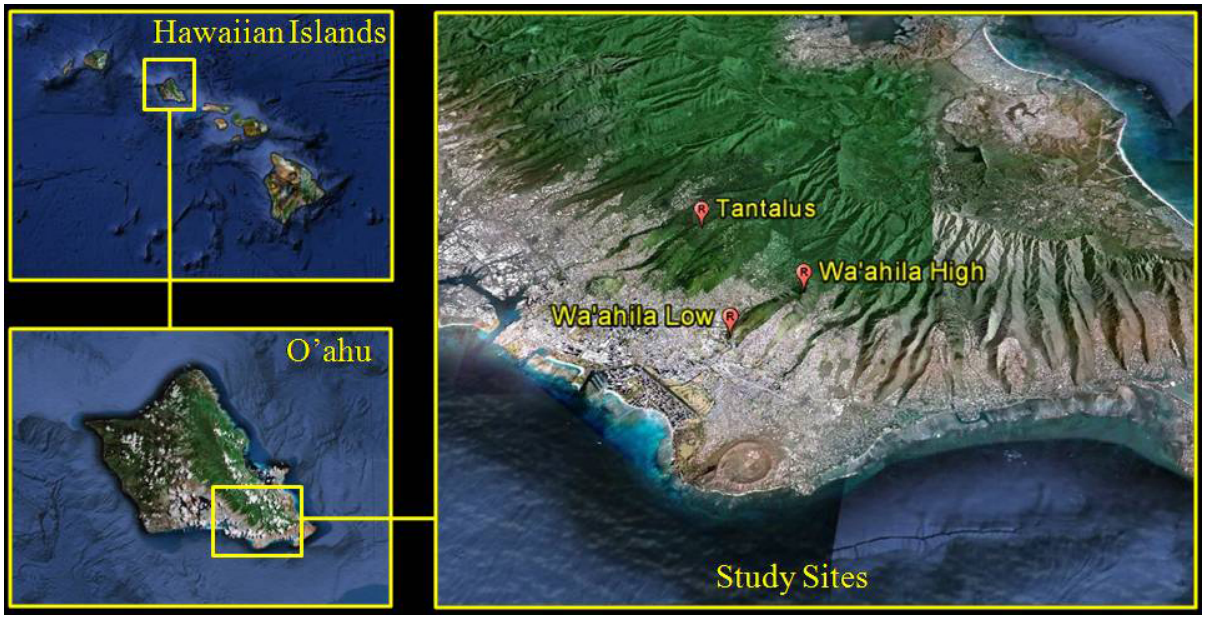



**Figure 1.** Maps showing the location of the three preselected release sites. Five Jackson's chameleons were released at Tantalus (suitable habitat), another five were at Waahila Low (non-suitable habitat), and four at Waahila High (potentially suitable habitat).

We selected Site 1 (Tantalus area) as a sort of "control habitat".

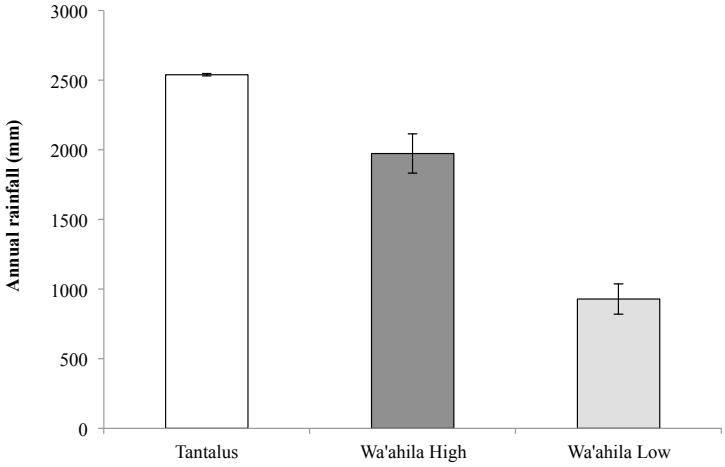



**Figure 2.** Mean annual rainfall for the three release sites.

The initial site was selected to help us determine how Jackson's chameleons move around in suitable areas, where populations have been established for many years. Site 2 (Waahila High) was selected to assess behavior of Jackson's chameleons in an area of perhaps intermediate suitability habitat, and since this area is adjacent to a public park with a well-used, popular hiking trail with picnic tables and recreational facilities, this site was selected to simulate a high potential release site. We used Site 3 (Waahila Low) in order to test behavior following release into an unsuitable habitat, which allowed us to assess their capacity to move, and potentially colonize more suitable upland areas. This is the model that we are testing as we assume historical release of pet chameleons in various areas both in Honolulu as well as outside of town, in parks and road side areas, has led to multiple range expansion events and played an important role in current distribution of Jackson's chameleons.

**Figure 3.** Adult male Jackson's chameleon fitted with a R1640 two-stage radio transmitter. Photo was taken during release at Tantalus.

**Release sites:** Five chameleons were released on June 23, 2011 at Tantalus, another five individuals were released at Waahila Low, on the trail just above the Dole Street bridge, on April 16, 2012, and five more were released at Waahila High, above Waahila Ridge State Recreation Area on May 9, 2012. Each chameleon was fitted with an ATS (Advance Telemetry Systems) R1640 two-stage radio transmitter using 5-minute epoxy adhesive. Transmitter weight was 2 g (less than 6% of chameleon weight) (Figure 3). An ATS R410 Scanning Telemetry Receiver, tuned to 148-152 MHz, was used to track signal of active transmitters. An ATS 13860 3-element folding Yagi antenna was used in conjunction with the receiver, attached via a 5-foot RG58 coaxial cable.

All capture, handling, attachment and removal of transmitters, and euthanasia was done in accordance with protocols of the University of Hawaii Institutional Animal Care and Use Committee (IACUC). In the first release, we tracked chameleons for ~3 months at Tantalus (see the 2011 Tree Snail Conservation Lab Annual Report), but tracked chameleons for 21 days at each of the other release sites (Site 2-Waahila Low and Site 3-Waahila High). In order to develop and use comparable datasets, we will present results based on 21 days of movement (following release) per location. We felt comfortable in shortening release times for Sites 2 and 3 for the following reasons, 1) this approach maximizes value of research done by recapture of tagged animals after 21 days, then releasing same individuals in different habitat, 2) if behavior of an individual varies at different sites, we are confident that variation is due to site characteristics rather than individual, 3) Tantalus trial showed that lizards moved longest distances during first few days, then seemed to settle into a repetitive pattern, retracing areas previously encountered.

**Analysis:** The software Google Earth Pro was used to measure (per individual, per site): 1) maximum straight-line distance traveled from release site, 2) daily distance covered per individual, and 3) home range area established, 4) degree to which home ranges overlap, if any. Daily distances covered by each chameleon were added to calculate the total distance covered. Google Earth Pro was also used to measure the percentage of home range overlapping within sites. A Generalized Additive Model (GAM) (non-linear regression) was used to determine the daily pattern of distance covered by chameleons over each trial period. When GAM results indicated a linear relationship (e.g., given by a non-significant *p*-value), a linear Regression Analysis was applied. One-way ANOVA testing was used to compare home ranges, maximum distance from release, and total distance covered by chameleons, among sites. The percentage of home range overlap was compared among sites using a non-parametric Kruskal-Wallis test because the assumption of homogeneity of variances was not met.

**Results:** The following results are summarized in Tables 1 - 3: 1) cumulative distance traveled from release site, 2) daily distance covered (from previous day), 3) mean distance covered from release site, 4) home range area, and 5) home range overlap, per individual, per site.

This study used three different preselected habitats that vary in fundamental ecosystem characteristics including canopy structure, rainfall (Figure 2), presence of established conspecific populations. The goal here was to evaluate the manner in which Jackson's chameleons establish and disperse within home ranges and the degree to which home ranges overlap. In order to statistically quantify the relationship between distance covered and time, we applied, where

appropriate either the Generalized Additive Model (GAM) or Linear Regression. Statistical analyses revealed substantially different patterns among sites summarized as follows:

1) **Site 1** Tantalus, suitable habitat – this is an area known for Jackson's chameleons, this is a shady tropical rainforest, with 25 meter high, diverse canopy as well as heavy, complex understory. However, forest in this area largely consists of introduced plants and trees, and few if any native invertebrate prey species. Individuals tracked here showed a non-linear pattern that consisted of initial relatively long travel distances following release. For the first three days chameleons moved in nearly straight lines with a mean distance of 17.2 m, and mean distance on the third day of 19.5 m, a period which we are calling the "exploratory phase". This pattern was followed by a dramatic decrease in distance covered per day. Following the exploratory phase, the average daily distance traveled was 6.9 m, and by day 21 the average distance covered was only 5.4 m per day. After the initial three days of exploratory phase movement away from release point, chameleons tended to move in circles, backtracking within each established home range (GAM: $r^2$= 85%, deviance: 40.9, smooths: 3, p = 0.02; Figure 4a).

2) **Site 2** Individuals released at Waahila Low, the hot exposed habitat just above the road, steadily *increased* daily distances covered, in a linear fashion, from day one until the end of the study (Figure 4b) at day 21 (Linear Regression: $F_{1,9}$: 6.7, r = 0.48, $p < 0.05$). However, movement was not in a consistent direction here, for example chameleons did not move upslope towards higher elevation and cooler temperatures, as had been widely suspected for some time. There was no net elevation gain for any tagged animals relative to the release point.

3) **Site 3** Chameleons released at this site (Waahila High) showed a non-linear pattern, initially similar to that showed by chameleons released at Tantalus site. For the first several days the tagged animals moved relatively large distances in an exploratory phase, which as at Site 1,

tapered off after about a week. But at this site dispersal increased once again about two weeks into the trial. This increase in distance traveled was in contrast the to Tantalus pattern, where following the exploratory phase, daily distances dropped down low and remained low (GAM: $r^2$: 65.8%, deviance: 79.9, smooths: 3, $p = 0.037$; Figure 4c).

Overlap in chameleon home ranges also varied significantly among sites (Kruskal-Wallis: $H_{2,13} = 6.68$, $p < 0.05$) (Figure 5). The home ranges of individuals released at Tantalus and at Waahila High showed significantly less overlap in area relative to ranges at Waahila Low (Post-Kruskal-Wallis, $p < 0.05$). At Tantalus, where home range overlap was the lowest among all sites, male chameleons did not overlap home ranges with any other male counterpart, and only slightly with females. In fact, most of the home range overlap at this site was among females (Figure 5). Home range overlap was the highest at Waahila Low, and both male and female chameleons shared home ranges with conspecifics of both sexes. An intermediate situation was observed at Waahila High (Figure 5); however, no significant differences were detected in home range overlap between Site 3 and Site 1 (Tantalus) (Post-Kruskal-Wallis, $p > 0.05$).

The ANOVA results indicated that there were no significant differences in home ranges, maximum distance reached from release, and total distance covered by Jackson's chameleons among sites (ANOVA, $p > 0.05$). The lack of statistical significance was due to high variability within sites (see Tables 1, 2 and 3). However, our data strongly suggest that, on average, individuals released at Waahila Low (Site 2) had the largest home ranges, traveled the longest distances from release, and covered the longest total distances. By contrast individuals released at Tantalus (Site 1) showed the opposite trend, with the smallest home ranges and the shortest total distances covered overall. Individuals released at Waahila High (Site 3) generally showed

intermediate values for these parameters, with the exception of maximum distance reached from release, which was the shortest for this site.

**Discussion:** Part of the motivation for this study was to understand dispersal behavior of chameleons released as a result of the legal pet trade. Chameleons are a popular pet locally, and are available and inexpensive, statewide. However keeping pet chameleons healthy is challenging for non-specialists. Although chameleons will consume nearly any species that moves and that they are able to swallow, their optimal long-term feeding strategy is to diversify prey, which is challenging to mimic in captivity. Once captive chameleons cease eating commercially available food, pet owners frequently release them. Therefore we strongly suspect that numerous new range expansions have historically been caused by pet releases. One management-based interest is to determine whether established populations occurring at mid- and upper elevation sites might have arisen due to migration of such released animals, rather than human transport to upslope sites. In other words, we seek to address the long-standing question: do chameleons released into low elevation unsuitable habitat move to suitable habitat upslope? Findings of this study suggest that migratory behavior of invasive Jackson's chameleons is strongly habitat-dependent. However, our sample size did not provide sufficient statistical power to definitively understand detailed interplay of dispersal with additional variables such as animal age, gender, reproductive status, population density, seasons, etc.

Of the 15 individuals tagged and released in three different preselected sites, clear differences in daily movement patterns and home range overlap among the sites were evident. In suitable habitat, such as Tantalus, chameleons covered the longest distances during the first three days following release, but dispersal distances steadily decreased for the ensuing seven days.

Thereafter, distance traveled remained low and relatively constant for the remainder of the trial (Figure 4a). In addition, Tantalus chameleons exhibited low home range overlap (Figures 5 and 6a). Chameleons are known to be highly visual, social and territorial animals, in that their behavior is strongly influenced by the presence of other individuals, particularly as adults. Establishment of well-defined non-overlapping home ranges at Tantalus is therefore likely due to 1) resource availability (water/prey) but also 2) presence and visibility of conspecific adults.

The second release occurred at Waahila Low, or Site 2 (Figure 1). We selected this site due to the lack of established chameleon populations in the area and lower precipitation (Figure 2), suggesting unsuitable conditions for long-term survival. Chameleons released at Waahila Low showed the opposite trend to that seen at Site 1. At Site 2 we saw a steady increase of their daily distances covered over time (Figure 4b), possibly due to lack of available resources. Although chameleons at this site covered the longest daily distances (see Tables 1, 2, and 3), they also had the largest home range overlap (Figures 5 and 6b,), suggesting the possibility that social interaction may not take precedence when resources are limited.

At Site 3, Waahila High, the first two weeks of data showed a similar pattern to that at Tantalus. However, after the second week at Waahila High, behavior diverged, as daily distances once again increased (Figure 4c). This behavior may be the result of relatively low resource availability at Waahila High compared with Tantalus. Therefore, it is likely that Waahila High is not suitable habitat, at least during this particular season. Chameleons may not be able to remain for extended periods due to potentially insufficient resources, forcing them to move in search of better conditions. At this site, chameleon movement reached a low point in around day 8 (similar time frame to that at Tantalus), but remained for only about one week, at which point they began

to move once again. This site also showed an intermediate value of home range overlap (Figure 5, Figure 6c, and Table 3).

The following patterns were observed: 1) individuals released in non-suitable habitat had larger home ranges, reached longer distances from release, and covered longer cumulative distances than those released in suitable areas, 2) the smallest chameleons had the largest home ranges and covered the longest distances, suggesting a potential developmental impact on behavior. However, based on our small sample size, this result, though intriguing, is only preliminary. Therefore this particular aspect, age structure and dispersal distance warrants further investigation. From a conservation perspective, it is important to determine how these invasive reptiles utilize habitat when varied environmental conditions are encountered. This study reveals a number of interesting patterns including the effect of environmental heterogeneity on home range size, and provides new perspectives on behavior of this important and ecologically damaging species.

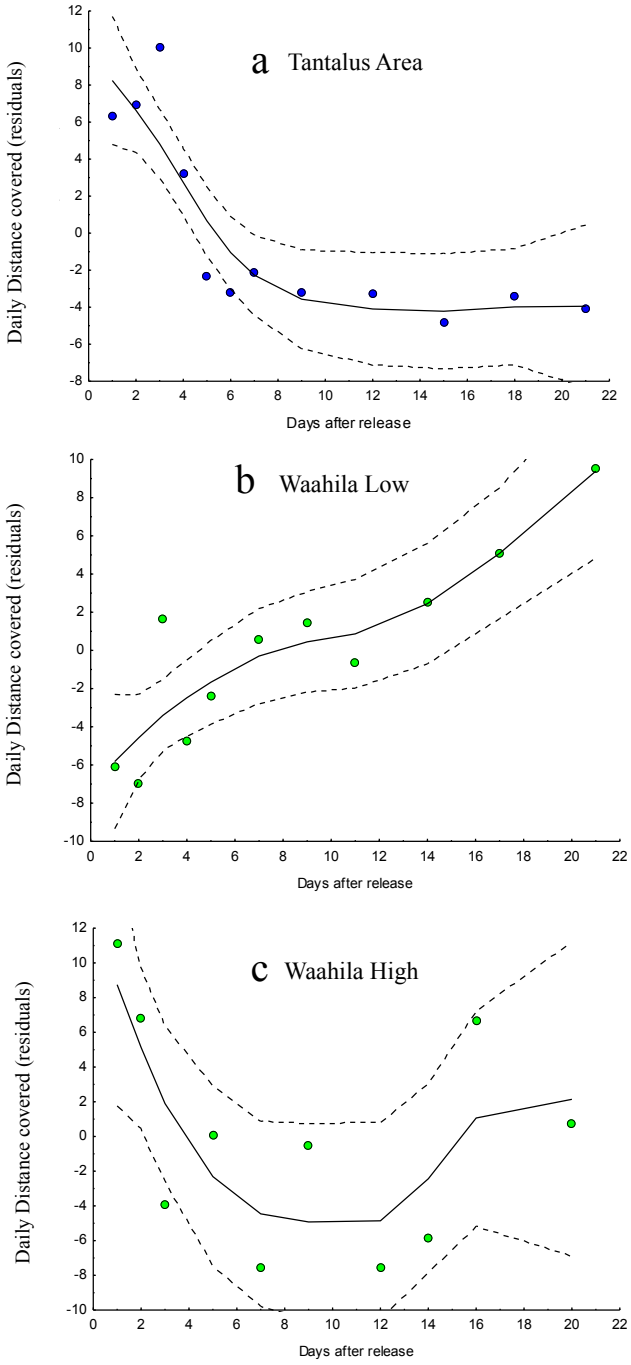



**Figure 4**. Daily distance covered over time by Jackson chameleons at the three study sites. Trends (solid lines) were determined by non-linear Generalized Additive Models (a, c) and by linear regression (b). Each dot represents the mean distance traveled per day by all chameleons within a site. Dashed lines represent 95% confidence levels.

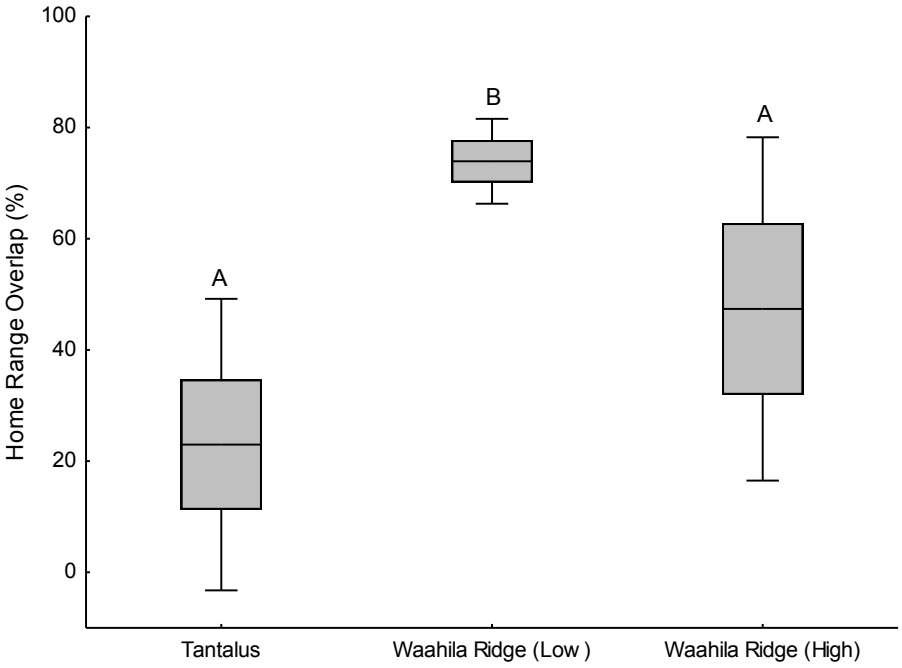



**Figure 5**. Box-plots showing home range overlap (%) in Jackson's chameleons at the three study sites. Box: SE, Whisker: SD. Line in box represents the mean home range overlap per site. Different letters indicate significant differences tested by Kruskal-Wallis test at $\alpha = 0.05$.

| | | Distance covered (m) by: | | | | | |
|---|---|---|---|---|---|---|---|
| Site | Day | Male 1 | Male 2 | Male 3 | Female 1 | Female 2 | **Site Average** |
| Tantalus | 1 | 10.3 | 7.4 | 23.8 | 7.6 | 29.9 | **15.8** |
| Tantalus | 2 | 10.7 | 13.6 | 23.6 | 15.5 | 18.8 | **16.4** |
| Tantalus | 3 | 12.0 | 15.0 | 27.6 | 26.1 | 16.9 | **19.5** |
| Tantalus | 4 | 15.5 | 4.7 | 31.0 | 8.1 | 4.2 | **12.7** |
| Tantalus | 5 | 6.9 | 3.4 | 10.9 | 10.2 | 4.4 | **7.2** |
| Tantalus | 6 | 7.5 | 5.0 | 4.3 | 7.8 | 6.9 | **6.3** |
| Tantalus | 7 | 11.6 | 4.8 | 9.8 | 4.4 | 6.1 | **7.3** |
| Tantalus | 9 | 3.0 | 8.1 | 8.4 | 6.9 | 5.2 | **6.3** |
| Tantalus | 12 | 5.2 | 3.2 | 8.5 | 6.0 | 8.4 | **6.3** |
| Tantalus | 15 | 5.6 | 3.8 | 5.8 | 4.8 | 3.3 | **4.7** |
| Tantalus | 18 | 5.7 | 4.3 | 7.8 | 6.2 | 6.4 | **6.1** |
| Tantalus | 21 | 4.2 | 4.9 | 9.0 | 3.4 | 5.4 | **5.4** |
| | | | | | | | |
| **Max dist from release (m)** | | **44.3** | **34.8** | **104.6** | **47.4** | **30.9** | **52.4** |
| **Total dist covered from release (m)** | | **98.2** | **78.2** | **170.2** | **107.0** | **115.9** | **113.9** |
| **Home range area ($m^2$)** | | **347.5** | **209.4** | **1088.0** | **210.9** | **341.2** | **439.4** |
| **Home range overlap (%)** | | **0.0** | **27.8** | **0.1** | **63.9** | **23.1** | **23.0** |

**Table 1**. Parameters of habitat utilization in Jackson's chameleons obtained from the Tantalus site on Oahu (Hawaii).

| | | Distance covered (m) by: | | | | | |
|---|---|---|---|---|---|---|---|
| Site | Day | Female 1 | Female 2 | Female 3 | Male 1 | Male 2 | **Site Average** |
| Wa'ahila (Low) | 1 | 15.5 | 12.6 | 6.0 | 11.9 | 27.6 | **14.7** |
| Wa'ahila (Low) | 2 | 4.2 | 6.4 | 3.2 | 10.7 | 36.6 | **12.2** |
| Wa'ahila (Low) | 3 | 8.9 | 10.9 | 19.4 | 13.1 | 13.5 | **13.2** |
| Wa'ahila (Low) | 4 | 5.7 | 7.0 | 5.7 | 21.5 | 7.4 | **9.5** |
| Wa'ahila (Low) | 5 | 10.7 | 11.6 | 9.4 | 11.1 | 0.0 | **8.5** |
| Wa'ahila (Low) | 7 | 12.0 | 15.4 | 13.3 | 8.7 | 29.4 | **15.8** |
| Wa'ahila (Low) | 9 | 16.4 | 7.7 | 13.1 | 27.4 | 76.7 | **28.2** |
| Wa'ahila (Low) | 11 | 9.0 | 4.5 | 6.8 | 29.4 | 47.4 | **19.4** |
| Wa'ahila (Low) | 14 | 21.5 | 14.1 | 10.1 | 27.5 | 29.3 | **20.5** |
| Wa'ahila (Low) | 17 | 12.0 | 9.9 | 12.3 | 12.9 | 0.0 | **9.4** |
| Wa'ahila (Low) | 21 | 18.8 | 9.2 | 17.2 | 18.7 | 132.3 | **39.2** |
| | | | | | | | |
| **Max dist from release (m)** | | **55.4** | **24.8** | **41.1** | **55.5** | **152.6** | **65.9** |
| **Total dist covered (m)** | | **134.6** | **109.3** | **116.5** | **192.8** | **400.2** | **190.7** |
| **Home range area (m2)** | | **558.6** | **205.0** | **414.0** | **547.3** | **6950.2** | **1735.0** |
| **Home range overlap (%)** | | **69.7** | **100.0** | **79.2** | **87.2** | **5.5** | **68.3** |

**Table 2**. Parameters of habitat utilization in Jackson's chameleons obtained from the Waahila Low site on Oahu (Hawaii).

| | | Distance (m) covered by | | | | |
|---|---|---|---|---|---|---|
| Site | Day | Female 1 | Female 2 | Female 3 | Male 1 | Site Average |
| Wa‘ahila (High) | 1 | 17.5 | 34.0 | 17.5 | 34.0 | 25.8 |
| Wa‘ahila (High) | 2 | 30.7 | 20.9 | 13.4 | 20.9 | 21.5 |
| Wa‘ahila (High) | 3 | 4.0 | 17.4 | 4.2 | 17.4 | 10.7 |
| Wa‘ahila (High) | 5 | 0.0 | 18.4 | 22.3 | 18.4 | 14.8 |
| Wa‘ahila (High) | 7 | 0.0 | 15.6 | 0.0 | 13.0 | 7.1 |
| Wa‘ahila (High) | 9 | 19.5 | 19.6 | 7.0 | 10.5 | 14.1 |
| Wa‘ahila (High) | 12 | 5.1 | 10.4 | 4.5 | 8.5 | 7.1 |
| Wa‘ahila (High) | 14 | 13.8 | 4.6 | 10.2 | 6.6 | 8.8 |
| Wa‘ahila (High) | 16 | 29.8 | 16.8 | 16.8 | 22.1 | 21.4 |
| Wa‘ahila (High) | 21 | 29.7 | 12.6 | 10.0 | 9.5 | 15.4 |

| | | | | | |
|---|---|---|---|---|---|
| **Max dist from release (m)** | **45.0** | **41.2** | **21.7** | **44.7** | **38.2** |
| **Total dist covered (m)** | **150.1** | **170.2** | **105.8** | **160.8** | **146.7** |
| **Home range area (m2)** | **1500.4** | **130.6** | **329.9** | **359.8** | **580.2** |
| **Home range overlap (%)** | **17.5** | **24.7** | **68.0** | **79.4** | **47.4** |

**Table 3**. Parameters of habitat utilization in Jackson’s chameleons obtained from the Tantalus area on Oahu (Hawaii).

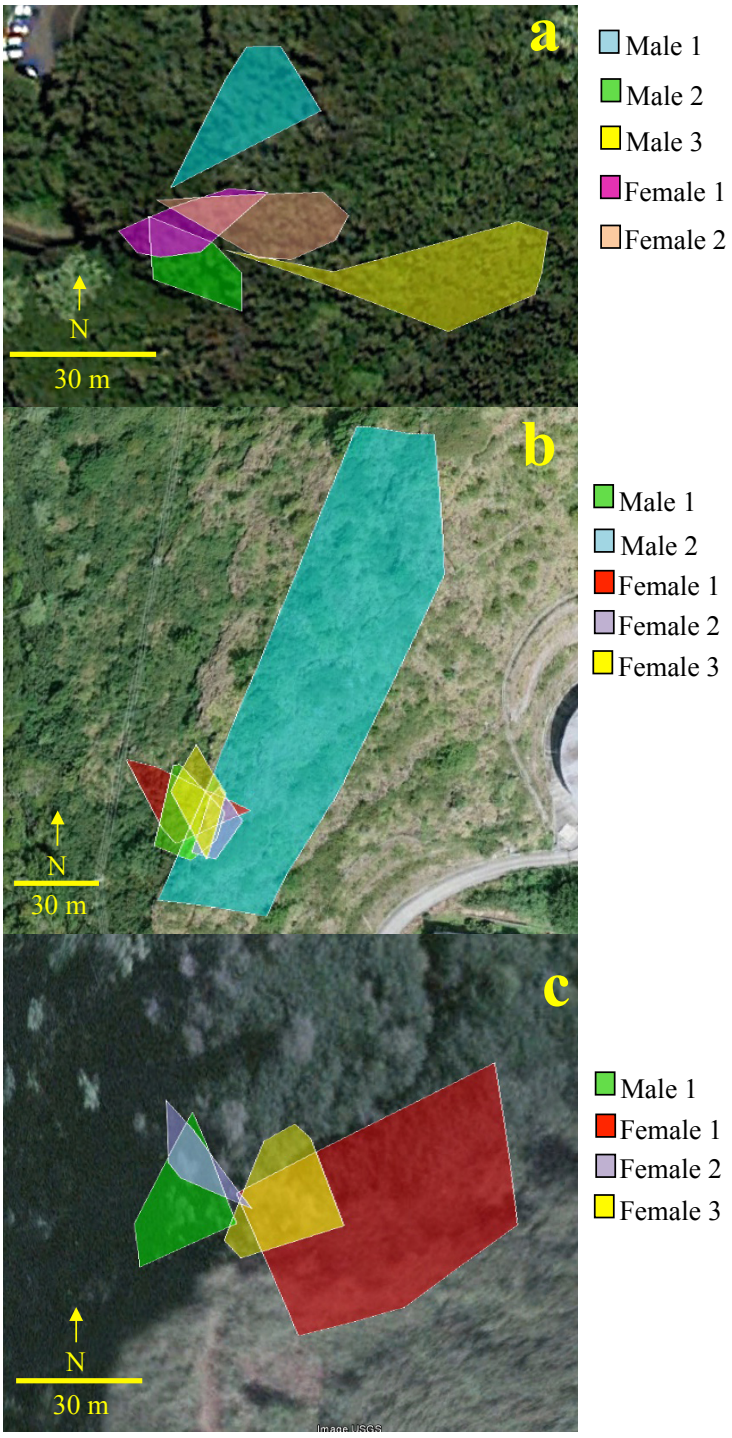



**Figure 6**. Home range overlap patterns in Jackson's chameleons at three different sites, (a): Tantalus, suitable habitat, (b): Waahila Low, unsuitable habitat, and (c): Waahila High intermediate suitability habitat. Polygons represent home ranges (i.e., area covered in 21 days), and different colors represent different individuals. Note that in figure labeled b, Male 2 covered the largest area of any individual in the study, and this was a subadult. However, home range of Male 2 did not show a net increase in elevation relative to release site. In c, we ultimately only collected data for 4 individuals, as one chameleon was lost during the trial. In spite of the presence of signage requesting the public not to interfere with the study animals, we assume a hiker picked up this individual.

**Pilot study: Dietary Analysis of the Metallic Skink (*Lampropholis delicata*)**

*Summary:* During tree snail field surveys and counts in the Waianae Mountains from Fall 2011 to Summer of 2012, a number of specimens of the invasive metallic skink, *Lampropholis delicata*, were found inside of the snail exclosure at Pahole as well as outside of the snail exclosure at Puu Hapapa. Although this invasive reptile species has been observed in both Koolau and Waianae mountain ranges up to about 800 m in elevation, and has been known for decades to be sharing habitats with native invertebrates and plants, their potential predatory impact on native fauna has not as yet been determined. Based on recent revelations by UH and OANRP biologists that invasive Jackson's chameleons are feeding on native invertebrates, we have proposed to evaluate feeding in other invasive predators in Hawaii. Our group has so far received two small grants to conduct preliminary surveys and trials in order to determine whether further work should be focused on some of these taxa, and if so, which ones. Therefore, since this skink is common in native habitat, and feeding behavior is unknown, preliminary gut content analysis and feeding trials were performed using adult skinks from both sites in order to assess threat status and prey preference.

*Gut content analysis:* Specimens of *Lampropholis delicata* were collected by hand from inside the Pahole (n=23) and outside of the Puu Hapapa snail exclosures (n=8). All individuals were brought to the Hawaiian Tree Snail Lab and placed in a -20$^{o}$ C freezer overnight to euthanize. Lizards were dissected, sexed, and measured (snout-vent and tail length). Both stomach and intestines were removed and contents were examined using a dissecting microscope. Invertebrates found were all arthropods, and were initially identified to order and preserved in 95% ethanol to be further analyzed by entomologists. Preliminary results are summarized in Table 4.

*Feeding trials:* Six live skinks were collected from inside the Pahole snail exclosure and were used in feeding studies conducted during Fall 2012.

Each trial started by placing individuals in separate containers (20x15x15 cm), which were dark and kept warm by a *uv* heat lamp. All lizards were starved 72 hours before the feeding

experiment. Feeding trials consisted of providing each individual lizard three live snails and recording observations for 8 minutes.

For Trials 1 and 2, adult Tornatellidinae were used. However, lizards showed no interest in feeding on these snails, and juvenile *Bradybaena similaris,* newborn *Achatina fulica*, and an adult *Polygyra cereolus*, were used in Trial 3.

Each individual inspected each snail with interest and each skink attempted to consume *Achatina* by biting, while however only one skink attempted to consume *Bradybaena*. After Trial 3, based on the observation that the shell of the snail was too hard for the skinks to crush, 6 juvenile *Achatina* were crushed and offered to each skink one at a time. All skinks (6/6) consumed the crushed *Achatina fulica*. To assure that this was not due to primarily starvation, the offer was repeated after 24 hours, and again, 6/6 skinks consumed the offered crushed *Achatina*.

*Future studies:* Since the preliminary observations indicate that the shell of *Achatina* may be too hard or thick for the skinks to crush by biting, future feeding trials will be carried out using non-native snails with thinner shells, such as *Succinea tenella*. In addition, we are interested in conducting a set of laboratory experiments to determine digestion time of shell and other prey items (i.e., insects) by skinks, and condition of those items in the gut over time.

*Other research:* Additional species of reptiles and amphibians have been observed at mid- and upper elevations in and near native snail habitat, including: the wrinkled frog (*Rana rugosa*), American bullfrog (*Lithobates catesbiana*), the mourning gecko (*Lepidodactylus lugubris*), the stump-toed gecko (*Gehyra mutilata*), and the Indo-Pacific gecko (*Hemidactylus garnotii*). Preliminary gut contents of individuals of each of these species have been analyzed as well and results are summarized in Table 5.

| | Relative abundance (%) | |
|---|---|---|
| **Order** | **Pahole** | **Puu Hapapa** |
| Arachnia | 13.48 | 31.25 |
| Coleoptera | 2.61 | 12.5 |
| Diptera | 6.95 | 0 |
| Isopoda | 0.43 | 0 |
| Orthoptera | 25 | 25 |
| Lepidoptera | 1.74 | 0 |
| Unidentified | 35.65 | 31.25 |

**Table 4**. Summary of gut content analysis for *Lampropholis delicata* captured near Pahole (n=23) and Puu Hapapa (n=8) snail exclosures. Gut contents are presented by taxonomic order according to relative % abundance. No snails were detected. We will further identify these samples to determine the ratio of endemic/non-native taxa.

| | Relative abundance (%) | | | | |
|---|---|---|---|---|---|
| **Order** | ***R. rugosa*** **Wrinkled Frog** | ***L. catesbiana*** **Bullfrog** | ***G. mutilata*** **Gecko** | ***H. garnotii*** **Indo-Pac Gecko** | ***L. lugubris*** **Mourning Gecko** |
| Lepidoptera | 0 | 0 | 0 | 1.67 | 0 |
| Dermaptera | 0 | 0 | 0 | 6.67 | 0 |
| Diptera | 0 | 0 | 0 | 16.67 | 0 |
| Arachnia | 0 | 0 | 0 | 13.33 | 0 |
| Coleoptera | 0 | 0 | 0 | 21.67 | 0 |
| Plant material | 20 | 50 | 0 | 40 | 0 |
| Unidentified | 80 | 50 | 0 | 0 | 0 |

**Table 5**. Summary of preliminary gut content analysis for *Rana rugosa* (n=3), *Lithobates catesbiana* (n=1), *Gehyra mutilata* (n=1), *Hemidactylus garnotii* (n=3), and *Lepidodactylus lugubris* (n=1) captured in native snail habitat. *R. rugosa* and *L. catesbiana* were captured at Poamoho in the Koolaus, and the three gecko species from outside the Pahole snail exclosure. Two gecko species, *G. mutilata* and *L. lugubris*, had empty stomachs, so diet could not be determined. Gut contents are presented by taxonomic order according to relative % abundance.

**Figure 7**. Xylene paint environmental test. In order to experimentally determine durability of paint pen on *Achatinella mustelina* shells we paint dotted 10 shells on June 27, 2012, then placed shells in a screen cage in an environmental chamber. This photo was taken after 4 months of exposure to chamber conditions including 3 minutes of sprinkler spray every 8 hours. Paint is still bright and intact.

**Snail Summary Table A.** Captive Propagation Data for Koolau *Achatinella* 2007-2012

| | August 2007 | August 2008 | August 2009 | August 2010 | August 2011 | August 2012 |
|---|---|---|---|---|---|---|
| **Species** | **Juv/Sub/Adu Total** | **Juv/Sub/Adu Total** | **Juv/Sub/Adu Total** | **Juv/Sub/Adu Total** | **Juv/Sub/Adu Total** | **Juv/Sub/Adu Total** |
| *A. lila* | 215/246/8 470 | 151/372/21 544 | 175/363/118 656 | 129/287/0 416 | 212/102/141 455 | 243/72/116 431 |
| *A. sowerbyana* | 4/14/3 21 | 8/14/3 25 | 7/13/5 25 | 2/10/4 16 | 2/5/2 9 | 0/0/1 1 |
| *A. livida* | 50/66/6 122 | 28/75/5 108 | 17/51/17 85 | 2/44/8 54 | 14/29/19 62 | 20/3/15 38 |
| *A. byronii* | 5/14/9 28 | 6/17/7 30 | -- | -- | -- | -- |
| *A. apexfulva* | 3/4/1 8 | 2/0/0 2 | 0/2/0 2 | 0/2/0 2 | 0/1/0 1 | 0/0/1 1 |
| *A. bulimoides* | 21/4/9 34 | 24/15/4 43 | 18/22/3 43 | 4/19/9 32 | 1/5/1 7 | 2/0/7 9 |
| *A. fulgens* | - | - | 3/24/1 28 | 2/8/4 15 | 0/6/6 12 | 1/0/7 8 |
| *A. decipiens* | - | - | 3/17/5 25 | 1/5/0 6 | 0/3/1 4 | 0/1/1 2 |
| *A. fuscobasis* | - | - | 69/66/210 345 | 29/63/57 149 | 18/73/47 138 | 78/35/59 172 |

**Snail Summary Table B.** Captive Propagation for *Achatinella mustelina* by ESU.

| Population | ESU | Date | # juv | # sub | # adult | # Individuals |
|---|---|---|---|---|---|---|
| Peacock Flats | A | 1995 | 0 | 0 | 6 | **6** |
| | | 2003 | -- | -- | -- | **21** |
| | | 4/2004 | 8 | 11 | 4 | **23** |
| | | 9/2005 | 3 | 15 | 2 | **20** |
| | | 8/2006 | 1 | 12 | 3 | **16** |
| | | 7/2007 | 0 | 9 | 2 | **11** |
| | | 8/2008 | 0 | 3 | 3 | **6** |
| | | 8/2009 | 0 | 2 | 0 | **2** |
| | | 8/2010 | 0 | 0 | 2 | **2** |
| | | 9/2011 | 0 | 0 | 2 | **2** |
| | | 9/2012 | 2 | 0 | 2 | **4** |
| ʻŌhikilolo – Makai | B1 | 2003 | 0 | 0 | 10 | **10** |
| | | 4/2004 | 27 | 0 | 4 | **31** |
| | | 9/2005 | 15 | 8 | 0 | **23** |
| | | 8/2006 | 3 | 9 | 0 | **12** |
| | | 7/2007 | 1 | 9 | 1 | **11** |
| | | 8/2008 | 0 | 9 | 0 | **9** |
| | | 8/2009 | 0 | 8 | 0 | **8** |
| | | 8/2010 | 0 | 6 | 1 | **7** |
| | | 9/2011 | 0 | 2 | 1 | **3** |
| | | 9/2012 | 0 | 1 | 1 | **2** |
| ʻŌhikilolo – Mauka | B1 | 2003 | 0 | 0 | 8 | **8** |
| | | 4/2004 | 20 | 5 | 0 | **25** |
| | | 9/2005 | 18 | 7 | 0 | **25** |
| | | 8/2006 | 0 | 21 | 2 | **23** |
| | | 7/2007 | 0 | 12 | 1 | **13** |
| | | 8/2008 | 0 | 11 | 1 | **12** |
| | | 8/2009 | 0 | 10 | 0 | **10** |
| | | 8/2010 | 0 | 4 | 0 | **4** |
| | | 9/2011 | 0 | 3 | 0 | **3** |
| | | 9/2012 | 0 | 0 | 2 | **2** |
| Kaʻala S-ridge | B2 | 2003 | 0 | 0 | 10 | **10** |
| | | 4/2004 | 23 | 0 | 6 | **29** |
| | | 9/2005 | 19 | 5 | 0 | **24** |
| | | 8/2006 | 4 | 11 | 0 | **15** |
| | | 7/2007 | 0 | 4 | 1 | **5** |
| | | 8/2008 | 0 | 3 | 1 | **4** |
| | | 8/2009 | 0 | 2 | 1 | **3** |
| | | 8/2010 | 0 | 1 | 0 | **1** |
| | | 9/2011 | 0 | 1 | 0 | **1** |
| | | 9/2012 | 0 | 0 | 1 | **1** |

| | | | | | | |
|---|---|---|---|---|---|---|
| Alaiheihe Gulch | C | 2003 | 0 | 0 | 10 | **10** |
| | | 4/2004 | 14 | 4 | 4 | **22** |
| | | 9/2005 | 17 | 5 | 0 | **22** |
| | | 8/2006 | 2 | 20 | 0 | **22** |
| | | 7/2007 | 2 | 21 | 0 | **23** |
| | | 8/2008 | 1 | 20 | 0 | **21** |
| | | 8/2009 | 0 | 17 | 0 | **17** |
| | | 8/2010 | 0 | 0 | 11 | **11** |
| | | 9/2011 | 1 | 4 | 4 | **9** |
| | | 9/2012 | 0 | 0 | 0 | **0** |
| Palikea Gulch | C | 2003 | 0 | 0 | 10 | **10** |
| | | 4/2004 | 20 | 1 | 8 | **29** |
| | | 9/2005 | 22 | 3 | 2 | **27** |
| | | 8/2006 | 12 | 13 | 0 | **25** |
| | | 7/2007 | 0 | 22 | 2 | **24** |
| | | 8/2008 | 0 | 20 | 1 | **21** |
| | | 8/2009 | 0 | 17 | 1 | **18** |
| | | 8/2010 | 0 | 8 | 1 | **9** |
| | | 8/2011 | 0 | 5 | 1 | **6** |
| | | 9/2012 | 0 | 4 | 3 | **7** |

| | | | | | | |
|---|---|---|---|---|---|---|
| Schofield Barracks West Range | C | 2003 | 0 | 0 | 10 | **10** |
| | | 4/2004 | 15 | 1 | 9 | **25** |
| | | 9/2005 | 27 | 1 | 2 | **30** |
| | | 8/2006 | 8 | 22 | 0 | **30** |
| | | 7/2007 | 2 | 28 | 0 | **30** |
| | | 8/2008 | 0 | 26 | 1 | **27** |
| | | 8/2009 | 0 | 23 | 1 | **24** |
| | | 8/2010 | 0 | 17 | 2 | **19** |
| | | 9/2011 | 0 | 10 | 1 | **11** |
| | | 9/2012 | 1 | 0 | 10 | **11** |
| 10,000 snails | D1 | 2001 | 0 | 0 | 9 | **9** |
| | | 2003 | -- | -- | -- | **29** |
| | | 4/2004 | 8 | 22 | 0 | **30** |
| | | 9/2005 | 3 | 24 | 3 | **30** |
| | | 8/2006 | 1 | 24 | 3 | **28** |
| | | 7/2007 | 7 | 14 | 4 | **25** |
| | | 8/2008 | 8 | 13 | 0 | **21** |
| | | 8/2009 | 9 | 2 | 0 | **11** |
| | | 8/2010 | 0 | 8 | 2 | **10** |
| | | 9/2011 | 3 | 5 | 2 | **9** |
| | | 9/2012 | 4 | 2 | 2 | **8** |

| | | | | | | |
|---|---|---|---|---|---|---|
| Schofield South Range | D1 | 2003 | 0 | 0 | 10 | **10** |
| | | 4/2004 | 18 | 7 | 3 | **28** |
| | | 9/2005 | 24 | 2 | 0 | **26** |
| | | 8/2006 | 11 | 12 | 0 | **23** |
| | | 7/2007 | 0 | 21 | 0 | **21** |
| | | 8/2008 | 0 | 15 | 3 | **18** |
| | | 8/2009 | 0 | 11 | 2 | **13** |
| | | 8/2010 | 0 | 7 | 4 | **11** |
| | | 9/2011 | 0 | 1 | 9 | **10** |
| | | 9/2012 | 0 | 2 | 7 | **9** |
| Mākaha | D2 | 2003 | 0 | 0 | 10 | **10** |
| | | 4/2004 | 16 | 0 | 8 | **24** |
| | | 9/2005 | 23 | 0 | 3 | **26** |
| | | 8/2006 | 10 | 14 | 0 | **24** |
| | | 7/2007 | 5 | 17 | 0 | **22** |
| | | 8/2008 | 0 | 20 | 0 | **20** |
| | | 8/2009 | 0 | 10 | 0 | **10** |
| | | 8/2010 | 0 | 2 | 6 | **8** |
| | | 9/2011 | 0 | 0 | 5 | **5** |
| | | 9/2012 | 0 | 1 | 2 | **3** |
| ʻĒkahanui - Honoʻuliʻuli | E | 2003 | 0 | 0 | 10 | **10** |
| | | 4/2004 | 24 | 2 | 3 | **29** |
| | | 9/2005 | 22 | 2 | 0 | **24** |
| | | 8/2006 | 7 | 9 | 0 | **16** |
| | | 7/2007 | 2 | 9 | 1 | **12** |
| | | 8/2008 | 0 | 8 | 0 | **8** |
| | | 8/2009 | 0 | 6 | 0 | **6** |
| | | 8/2010 | 0 | 0 | 5 | **5** |
| | | 9/2011 | 2 | 0 | 5 | **7** |
| | | 9/2012 | 8 | 0 | 4 | **12** |
| Palikea Lunch / former Pālehua | F | 1997 | 1 | 0 | 0 | **1** |
| | | 4/2004 | 4 | 0 | 4 | **8** |
| | | 9/2005 | 20 | 0 | 2 | **22** |
| | | 8/2006 | 5 | 14 | 0 | **19** |
| | | 7/2007 | 1 | 15 | 0 | **16** |
| | | 8/2008 | 0 | 13 | 0 | **13** |
| | | 8/2009 | 0 | 3 | 0 | **3** |
| | | 8/2010 | 0 | 3 | 0 | **3** |
| | | 9/2011 | 3 | 1 | 2 | **6** |
| | | 9/2012 | 1 | 3 | 0 | **4** |
| **TOTAL** | | 2003 | -- | -- | -- | **138** |
| **TOTAL** | | 4/2004 | -- | -- | -- | **303** |
| **TOTAL** | | 9/2005 | -- | -- | -- | **299** |
| **TOTAL** | | 8/2006 | -- | -- | -- | **255** |

| | | | | | | |
|---|---|---|---|---|---|---|
| **TOTAL** | | 7/2007 | **--** | **--** | **--** | **213** |
| **TOTAL** | | 8/2008 | **--** | **--** | **--** | **180** |
| **TOTAL** | | 8/2009 | **--** | **--** | **--** | **127** |
| **TOTAL** | | 8/2010 | **0** | **56** | **34** | **90** |
| **TOTAL** | | 9/2011 | **9** | **32** | **32** | **73** |
| **TOTAL** | | 9/2012 | **16** | **13** | **36** | **65** |

Juvenile <10 mm, Sub-adult >10 mm no thickened lip, Adult has thickened lip

# Alien snail control in nurseries

## Report to the
## Oahu Army Natural Resources Program
## (OANRP)

**Prepared by**

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**30 November 2012**

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# ASSESSMENT OF EFFECTS OF RODENT REMOVAL ON ARTHROPODS, AND DEVELOPMENT OF ARTHROPOD MONITORING PROTOCOLS, ON CONSERVATION LANDS UNDER US ARMY MANAGEMENT

November, 2012

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## INTRODUCTION

Arthropods constitute a majority of the biodiversity in most terrestrial ecosystems. In addition, these animals typically play important roles in ecosystem processes such as decomposition, soil turnover and pollination, and form critical links in food webs. In short, native insects and their allies are not only important entities to conserve in their own right, but they are also important for the functioning of native ecosystems. Conversely, invasive arthropod species not only threaten native arthropods, but can also disrupt and alter entire biological communities. Obtaining basic measures of the status and trends of arthropod diversity should therefore be a fundamental component of any natural area management program. Understanding how arthropods are affected by other invasive species is central to their management and conservation. Because of their many roles throughout the larger biological community, this understanding is likely to have implications for the conservation of other endemic taxa, from plants that rely on arthropods for pollination to birds that use arthropods as prey.

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 has implemented rat removal operations in three areas in the Waianae Mountains: Kahanahaiki, Palikea and Ekahanui. In conjunction with these efforts, I am 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.

## METHODS

Kahanahaiki site: Arthropod sampling at this site is more limited than at the Palikea site because of very short lead time prior to initiation of rodent trapping. Pre-removal sampling was conducted in Kahanahaiki in May 2009, and post-removal sampling has been conducted in December 2009, May 2010, December 2010, May 2011 and May 2012. Pahole NAR was selected for the untrapped control site, but because obtaining sampling permits took a little bit of time, the first sampling event did not occur until late June 2009, and subsequent summer sampling events were also offset from the Kahanahaiki sampling by about six weeks. Sampling at Pahole occurred in June 2009, December 2009, June 2010, December 2010, June 2011 and June 2012. At both sites, sampling included pitfall trapping and vegetation beating on four shrub/tree species (*Charpentiera tomentosa, Pisonia umbellifera, Pipturus albidus, Psidium cattleianum*). At each site, 16 pitfall traps were established, one every 25 m, along the central gulch. Eight individuals of each of the four tree species were randomly chosen in the same general area as the pitfall traps. During each sampling event, each tree received five beats with a stick over a 1x1m beating sheet, and all arthropods dislodged were collected.

Palikea site: Arthropod sampling at Palikea has been conducted seasonally, occurring every four months. Three sampling events were completed, in November 2009, March 2010 and July 2010, before intensive rat trapping began in October 2010. Six post-trapping sampling events have now been completed (March 2011, July 2011, November 2011, March 2012, July 2012, November 2012), representing two full years of post-trapping sampling. Sampling at Palikea occurs within a randomly chosen subset of the 5 by 10 m WCA vegetation plots, and includes pitfall trapping, leaf litter extraction, and timed vegetation sweeping at both day and night. Eighteen plots were chosen for arthropod sampling: 3-70, 3-90, 3-100, 3-110, 3-160, 3-170, 3-180, 3-190, 3-200; 4-100, 4-110, 4-140, 4-190, 4-200, 4-210, 4-240, 4-250, 4-260. An additional 18 plots were established at a nearby control site that is not undergoing intensive rodent management. Sampling at removal and control sites are conducted simultaneously. A sampling protocol was also established at each site to monitor *Rhyncogonus* beetles. *Rhyncogonus* is a genus of native weevils that are relatively large, rare and nocturnally active, and could therefore be predicted to be strongly impacted by invasive rodents. It also therefore serves as a good taxon with which to track potential recovery after rodent suppression. These beetles have not been easily captured with standardized sampling methods, so potential host plants at each site were selected for targeted monitoring. At both sites, 12 trees or shrubs of two species (*Antidesma platyphyllum* and *Kadua terminalis*) were initially selected during the daytime (when adults are not active) and tagged for monitoring; each selected tree had at least some feeding damage on the leaves that was consistent with the damage caused by *Rhyncogonus* beetles. Numbers of monitored

trees/shrubs were gradually increased with each monitoring event, until a total of 25 trees/shrubs were designated at each site by July 2011, including five *Psychotria* sp. individuals at each site. During each sampling event, each tagged plant was visited on one night, and lightly beat over a 1x1m beating sheet to dislodge any adult beetles.

## RESULTS TO DATE

### I. Potential effects of rodent trapping at Palikea

Sorting, identification and database entry is complete for all samples collected up through May/June 2011 at Kahanahaiki/Pahole and November 2011 at Palikea. Samples collected in 2012 continue to be processed. Because the November 2011 annual report described changes in arthropod abundances one and two years after trapping at the Kahanahaiki site, results reported here will focus on new findings for the Palikea site: arthropod abundance trends at the rodent removal site and control site from one year prior to trapping initiation to one year post-trapping.

#### A. Seasonal patterns in arthropod abundances

Abundances of arthropods as a whole, as well as for most ordinal groups, showed relatively pronounced seasonal fluctuations. This was true for both vegetation-associated communities (as estimated by day and night sweeping samples, combined) and ground-associated communities (pitfall and leaf litter samples, combined). Some representative trends are shown in figures 1-8. Abundances for most groups were highest in July or November of each year. Although seasonal abundance peaks did not always occur in the same month for each particular taxonomic group, November appeared to have slightly more peaks across groups as compared to July. Future sampling plans include reducing collection events to one per year to make longer-term monitoring more efficient. Choosing July versus November for the timing of this sampling will likely be decided by examination of trends during the full year of seasonal sampling in 2012 (already collected), as well trends in patterns of seasonal diversity.

Overall abundances, as well as seasonal fluctuations in abundances, tended to be quite similar between the removal and control site plots. For some taxa, differences between sites were more substantial, such as Hemiptera on vegetation (Fig. 5) and ground-active Araneae (Fig. 7). In general, however, the control site plots appear to be well suited for the purpose of applying seasonal and/or annual adjustments to measured changes in arthropod communities following rodent trapping at the removal site.

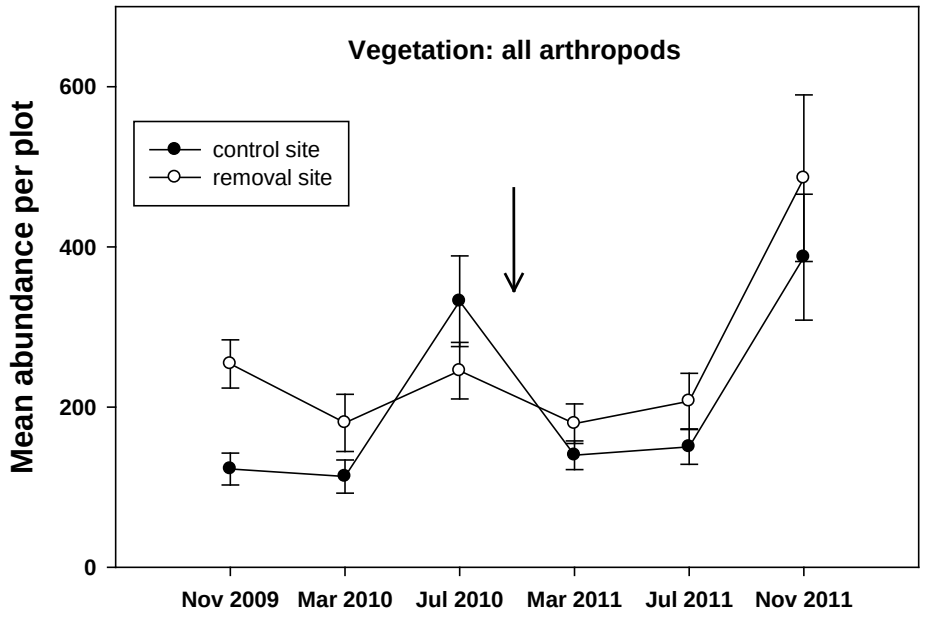


Figure 1. Seasonal trends in mean abundances (± SE) of all arthropods captured in vegetation (day and night sweeping) samples at Palikea over the first two years of the study. Data shown separately for rodent removal and control sites. Arrow indicates approximate timing of trapping initiation.

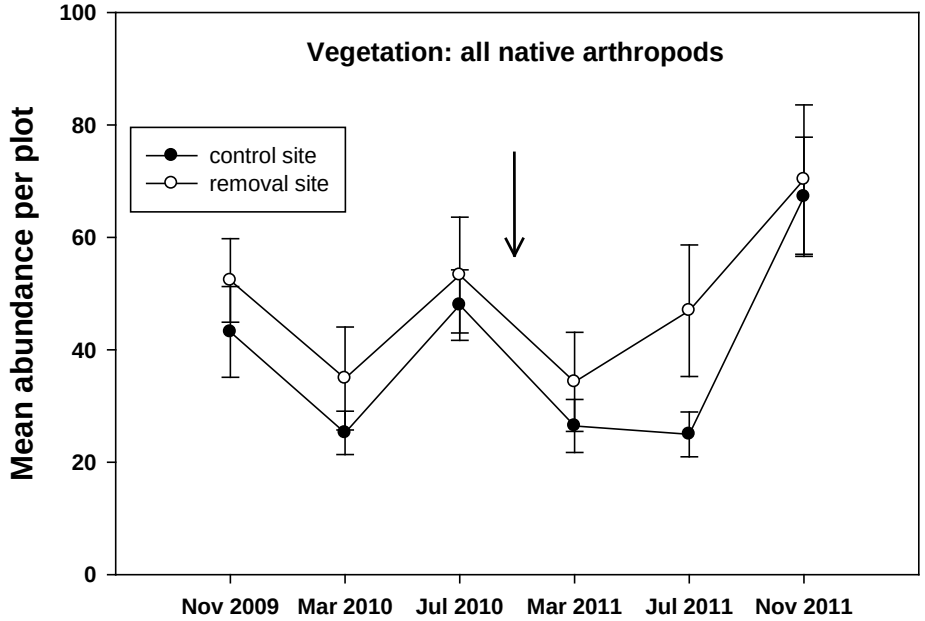


Figure 2. Seasonal trends in mean abundances (± SE) of all native arthropods captured in vegetation (day and night sweeping) samples at Palikea over the first two years of the study. Data shown separately for rodent removal and control sites. Arrow indicates approximate timing of trapping initiation.

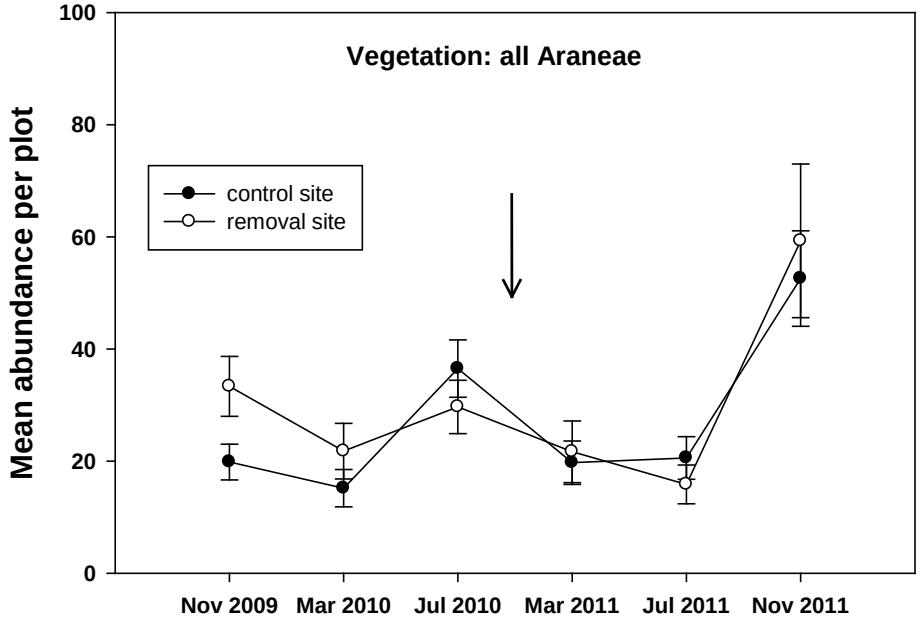


Figure 3. Seasonal trends in mean abundances (± SE) of all Araneae (spiders) captured in vegetation (day and night sweeping) samples at Palikea over the first two years of the study. Data shown separately for rodent removal and control sites. Arrow indicates approximate timing of trapping initiation.

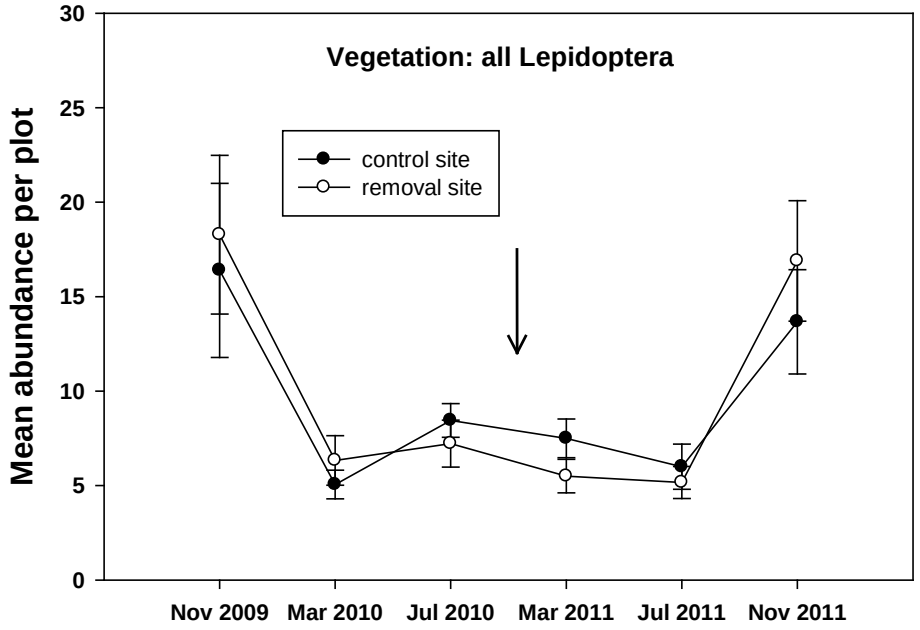


Figure 4. Seasonal trends in mean abundances (± SE) of all Lepidoptera (moths and butterflies) captured in vegetation (day and night sweeping) samples at Palikea over the first two years of the study. Data shown separately for rodent removal and control sites. Arrow indicates approximate timing of trapping initiation.

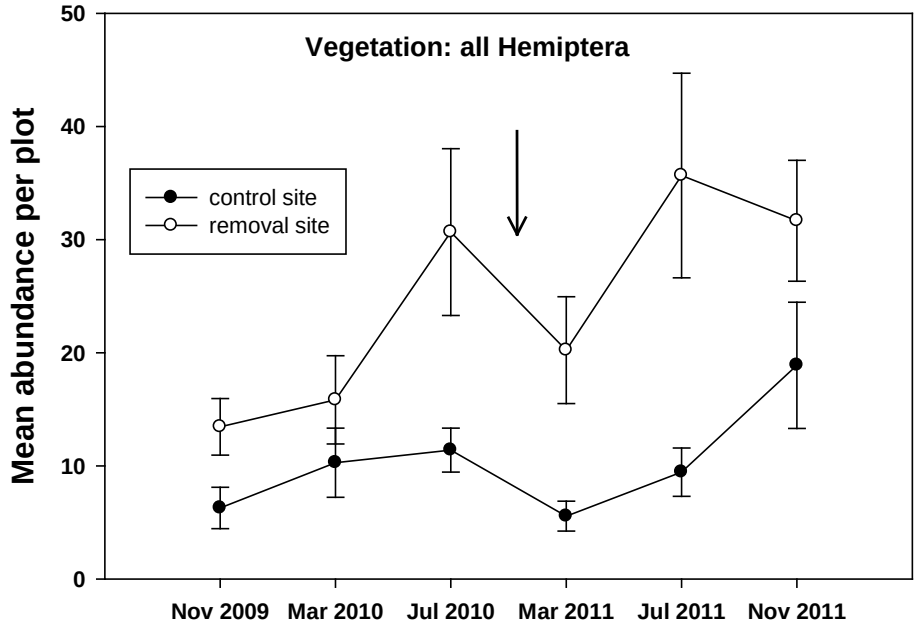


Figure 5. Seasonal trends in mean abundances (± SE) of all Hemiptera (true bugs) captured in vegetation (day and night sweeping) samples at Palikea over the first two years of the study. Data shown separately for rodent removal and control sites. Arrow indicates approximate timing of trapping initiation.

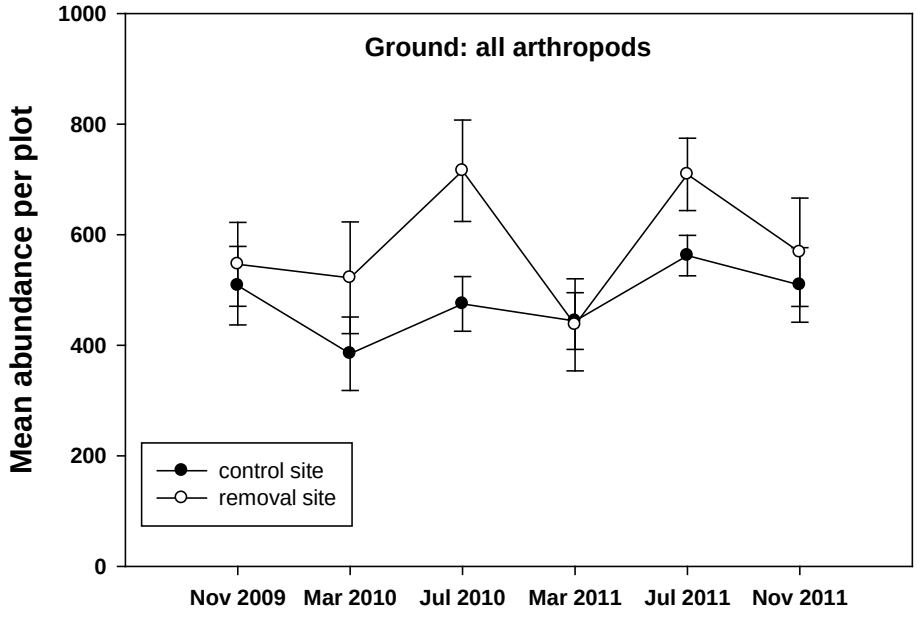


Figure 6. Seasonal trends in mean abundances (± SE) of all arthropods captured in ground (pitfall and leaf litter extraction) samples at Palikea over the first two years of the study. Data shown separately for rodent removal and control sites. Arrow indicates approximate timing of trapping initiation.

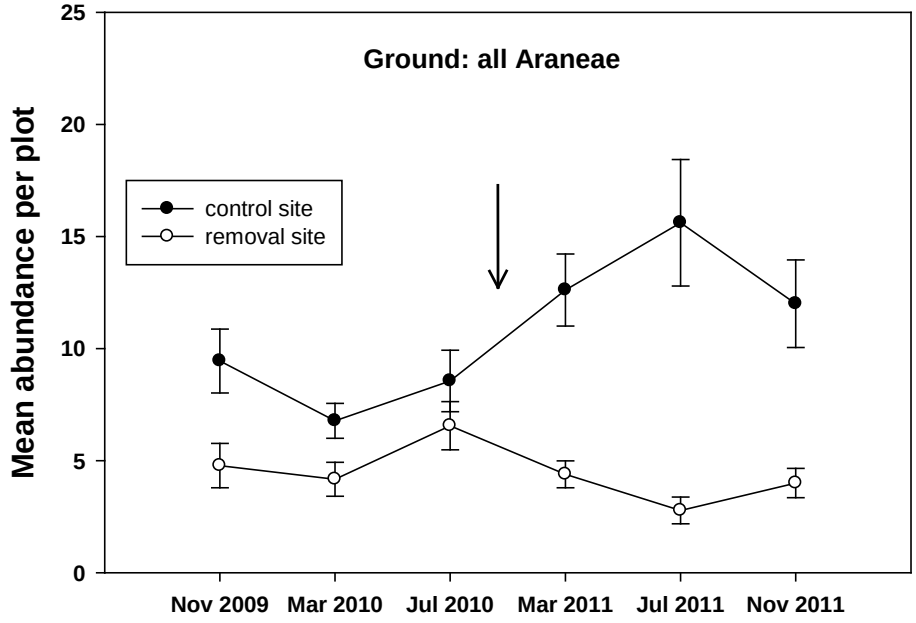


Figure 7. Seasonal trends in mean abundances (± SE) of all Araneae (spiders) captured in ground (pitfall and leaf litter extraction) samples at Palikea over the first two years of the study. Data shown separately for rodent removal and control sites. Arrow indicates approximate timing of trapping initiation.

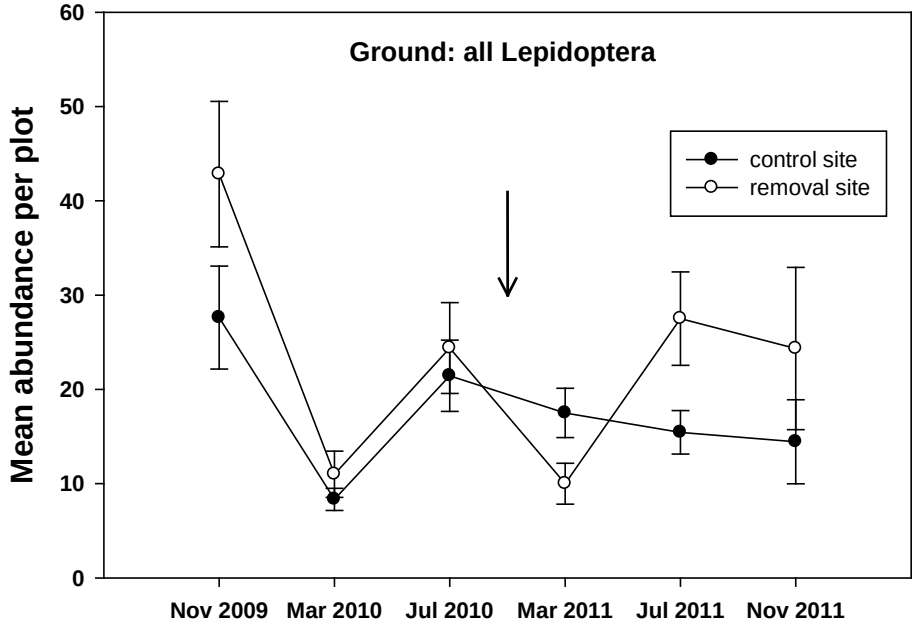


Figure 8. Seasonal trends in mean abundances (± SE) of all Lepidoptera (moths and butterflies) captured in ground (pitfall and leaf litter extraction) samples at Palikea over the first two years of the study. Data shown separately for rodent removal and control sites. Arrow indicates approximate timing of trapping initiation.

B. Relative changes in abundance following trapping

Changes in arthropod communities after rodent trapping began in October of 2010 would become apparent as divergences between trends at the removal and control sites for sampling events in 2011 (i.e., to the right of the arrow in Figures 1-8). This type of pattern is most easily seen for ground-based spiders (Fig. 7). In this case, spider abundances were lower at the removal site prior to trapping, and this difference became larger during the year after trapping began, indicating a relative decrease in spider abundances at the removal site after trapping.

I conducted a more direct assessment of relative changes in abundances over time for a range of taxonomic groups. Samples were pooled into two temporal periods for each site: the year pre-trapping and the first year post-trapping. Changes in abundances from before to after trapping were calculated for the matched sites, and then these changes were compared between sites to derive measures of the magnitude of relative abundance increases or decreases. Positive values indicate that the taxon increased more (or decreased less) at the removal site relative to the control site, while negative values indicate the opposite: the taxon decreased more (or increased less) at the removal site relative to the control site. A value of 0 indicates that the taxon fluctuated over the time period equally at both sites. The 18 sampling plots at each site were used as replicates, and mean relative changes for each taxon were compared to 0 with a one-sample t-test.

Relative changes in abundances of the major arthropod orders are presented in Figures 9 and 10 for communities on vegetation. Statistically significant mean relative increases in abundance at the removal site were found only for Orthoptera and Hemiptera, whereas significant relative decreases were found only for Psocoptera. For both Orthoptera and Hemiptera, relative increases were significant for all individuals as well as for native individuals only (Fig. 9). Other groups sometimes had large mean relative changes, but also had very high variances among replicate plots, and thus were not significantly different from 0.

Orthoptera at Palikea were comprised mainly of native (*Banza* spp.) and introduced katydids (family Tettigoniidae) and native crickets (?*Laupala* spp., family Gryllidae). Lower-level analysis indicated that all three groups showed trends of relative increases in abundances at the removal site after trapping, but that this change was significant only for the crickets, which dominated the overall pattern for Orthoptera (Fig. 11).

Hemiptera (true bugs) at Palikea are very diverse, represented by many species in 24 families. The significant relative increase in abundance of Hemiptera as a group on vegetation at the removal site, post-trapping, resulted predominantly from abundance increases in five families (Fig. 12): Delphacidae (plant hoppers), Lygaeidae (seed bugs), Nabidae (damsel bugs), Psyllidae (plant lice), and Derbidae (one introduced plant hopper species, *Cedusa* sp.).

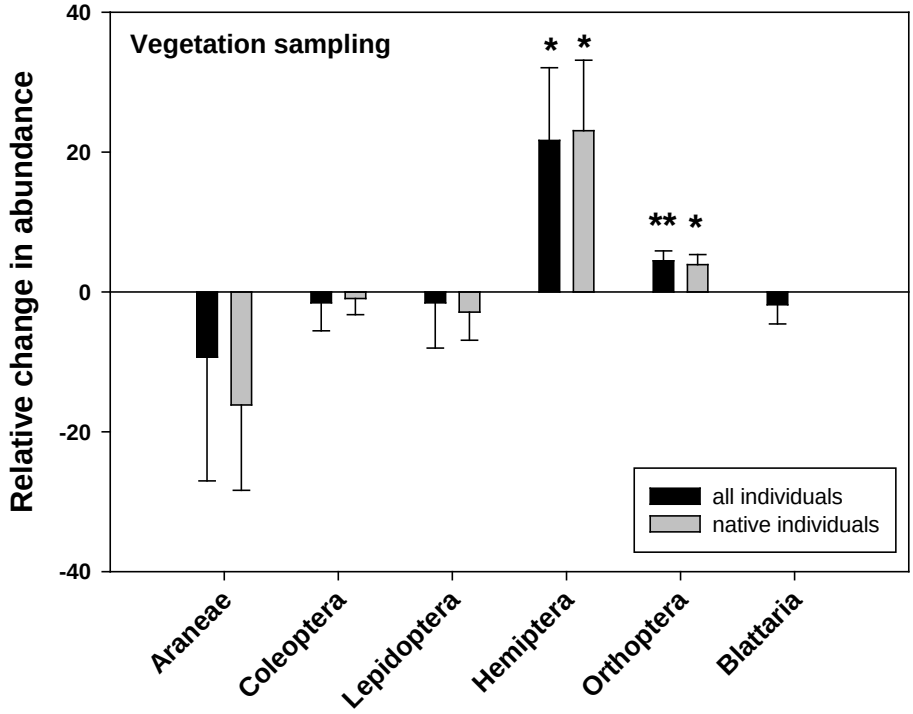


Figure 9. Mean changes in abundances (± SE), per sampling plot, of various taxonomic groups on vegetation (day and night sweeping) at the Palikea removal site relative to the control site, from the pre-trapping period to the first year post-trapping. Changes are shown for all individuals as well as for native individuals only for most groups. Positive values indicate increases at the removal site relative to the control site, while negative values indicate decreases at the removal site relative to the control site. Comparisons that are significantly different from zero are indicated with * for $p<0.05$ and ** for $p<0.01$.

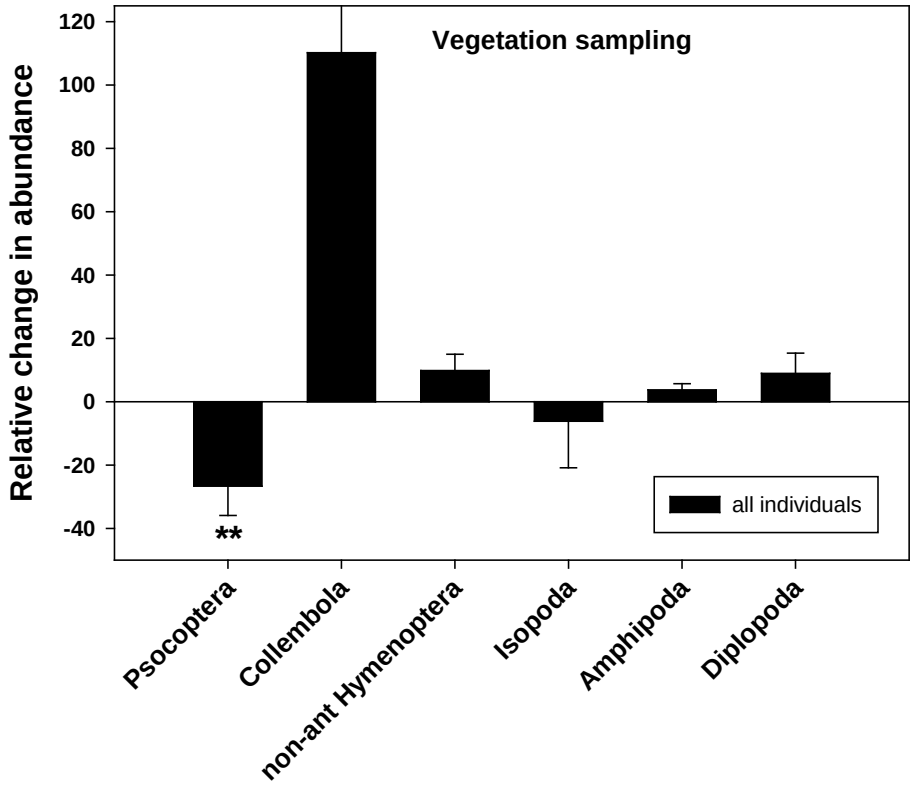


Figure 10. Mean changes in abundances (± SE), per sampling plot, of various taxonomic groups on vegetation (day and night sweeping) at the Palikea removal site relative to the control site, from the pre-trapping period to the first year post-trapping. Positive values indicate increases at the removal site relative to the control site, while negative values indicate decreases at the removal site relative to the control site. Comparisons that are significantly different from zero are indicated with * for $p<0.05$ and ** for $p<0.01$. The standard error bar for Collembola extends far beyond the scale shown on figure; the large mean change in Collembola abundances was not significantly different from 0 because of this high variance.

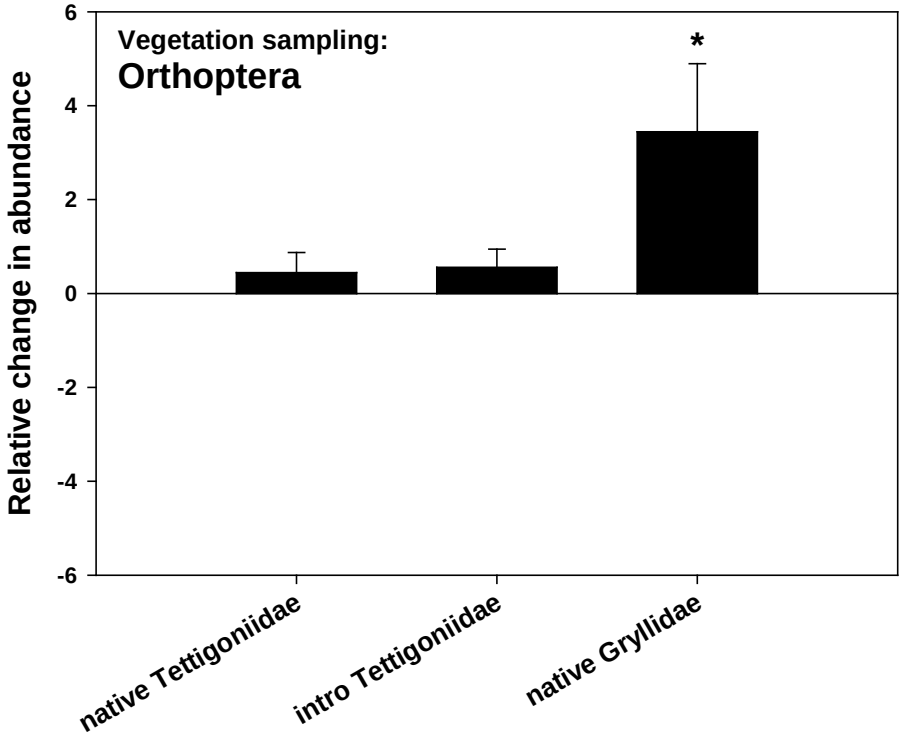


Figure 11. Mean changes in abundances (± SE), per sampling plot, of groups of Orthoptera on vegetation (day and night sweeping) at the Palikea removal site relative to the control site, from the pre-trapping period to the first year post-trapping. Positive values indicate increases at the removal site relative to the control site, while negative values indicate decreases at the removal site relative to the control site. Comparisons that are significantly different from zero are indicated with * for $p<0.05$ and ** for $p<0.01$. Native Tettigoniidae (katydids) were comprised of *Banza* spp., introduced Tettigoniidae were comprised of *Conocephalus saltator* and *Elimaea punctifera*, and native Gryllidae (crickets) were comprised of ?*Laupala* spp.

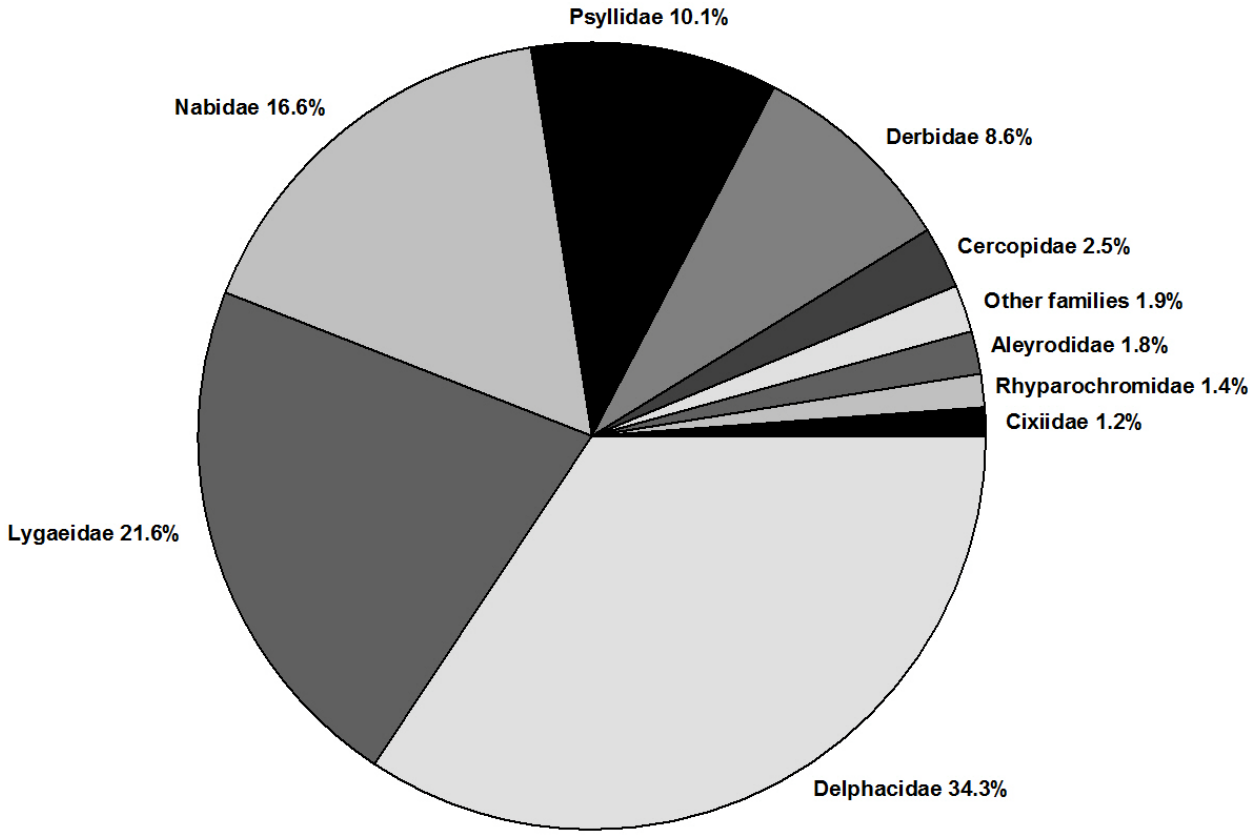


Figure 12. Proportional representation, by family, of the overall relative increase in Hemiptera abundances at the Palikea removal site after rodent trapping. Other families, each contributing to less than 1% of total relative increase at the removal site, include Coccidae, Cydnidae, Flatidae, Membracidae, Pentatomidae, and Saldidae. Families that declined in abundance at the removal site relative to the control site include Aphididae, Cicadellidae, Miridae, Pseudococcidae, Reduviidae, Rhopalidae, and Tingidae.

Relative changes in abundances of the major arthropod orders represented in ground-active communities are shown in Figures 13 and 14. Statistically significant mean relative increases in abundance at the removal site were found only for non-ant Hymenoptera (almost exclusively parasitic micro-Hymenoptera) and Diplopoda (millipedes), whereas significant relative decreases were found only for Araneae (spiders). Native Araneae showed a small but statistically non-significant trend of relative increases in abundances at the removal site. However, these make up a small fraction of the overall ground-active spider community, which is dominated by individuals of unidentified linyphiid species of unknown provenance. Other groups sometimes had large mean relative changes, but also had very high variances among replicate plots, and thus were not significantly different from 0.

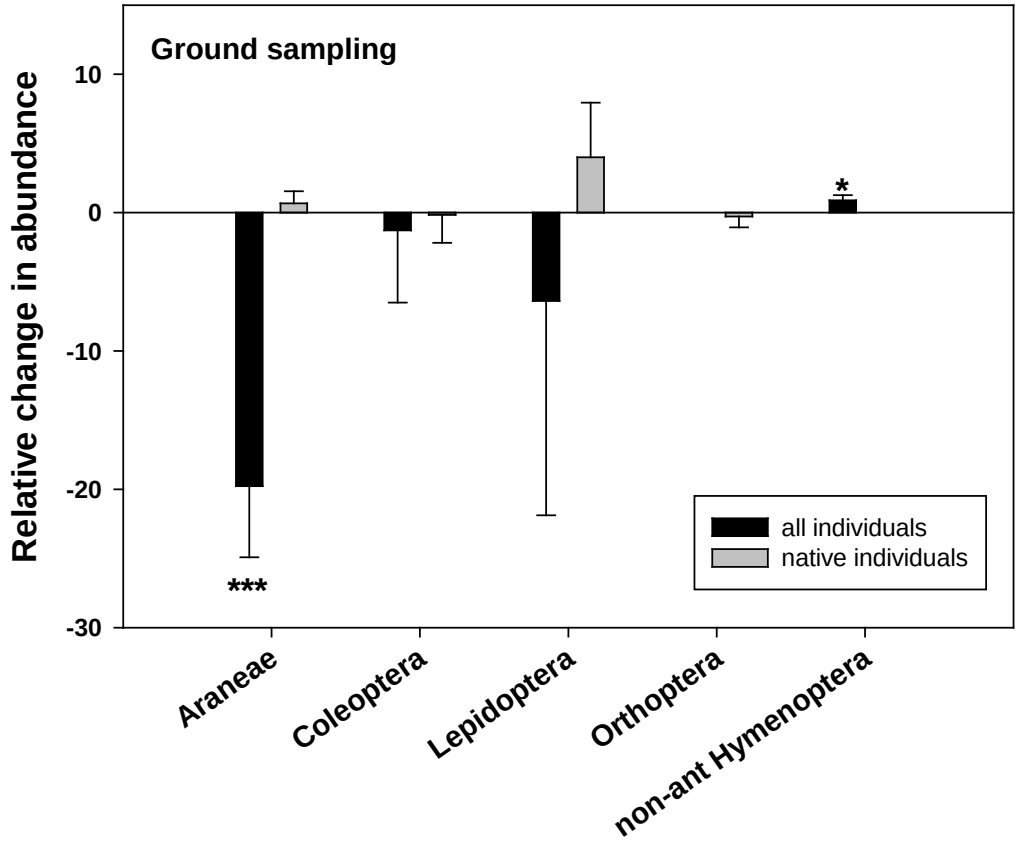


Figure 13. Mean changes in abundances (± SE), per sampling plot, of various taxonomic groups active on the ground (pitfall and litter extraction samples) at the Palikea removal site relative to the control site, from the pre-trapping period to the first year post-trapping. Changes are shown for all individuals as well as for native individuals only for most groups. Positive values indicate increases at the removal site relative to the control site, while negative values indicate decreases at the removal site relative to the control site. Comparisons that are significantly different from zero are indicated with * for $p<0.05$, ** for $p<0.01$ and *** for $p<0.001$.

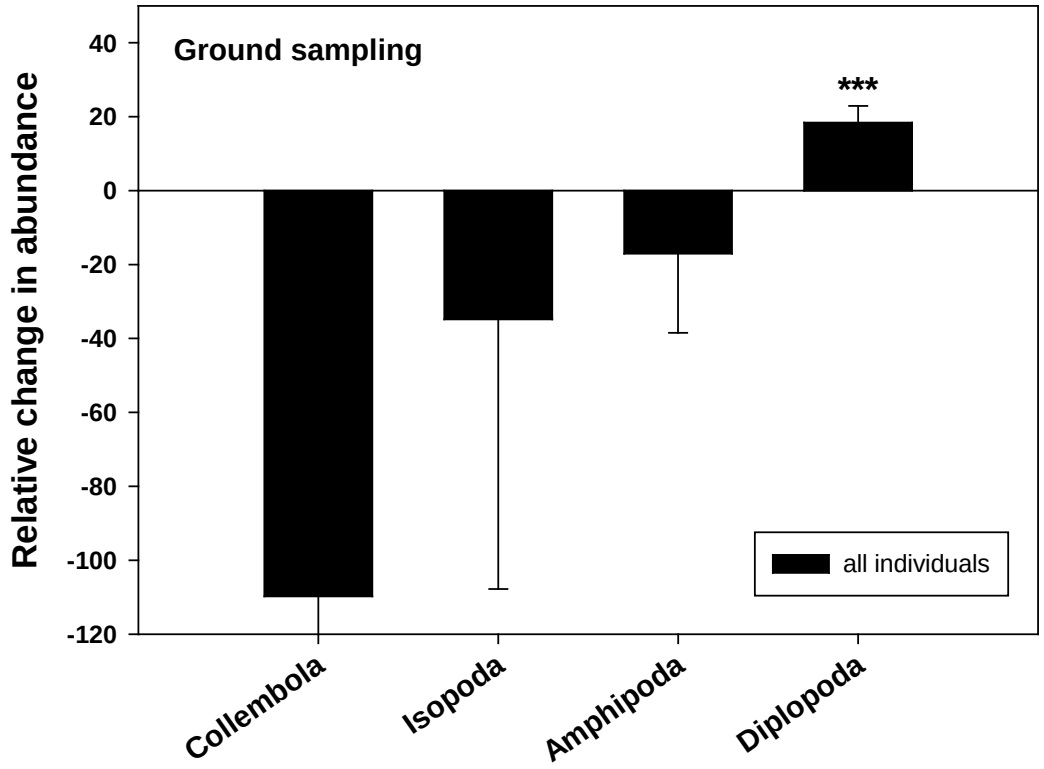


Figure 14. Mean changes in abundances (± SE), per sampling plot, of various taxonomic groups active on the ground (pitfall and litter extraction samples) at the Palikea removal site relative to the control site, from the pre-trapping period to the first year post-trapping. Positive values indicate increases at the removal site relative to the control site, while negative values indicate decreases at the removal site relative to the control site. Comparisons that are significantly different from zero are indicated with * for $p<0.05$, ** for $p<0.01$ and *** for $p<0.001$. The standard error bar for Collembola extends far beyond the scale shown on figure; the large mean change in Collembola abundances was not significantly different from 0 because of this high variance.

## C. Conclusions to date

Because I have assessed numerous population changes involving multiple taxa without applying adjustments for multiple statistical comparisons, caution needs to be used when concluding that population fluctuations are real as opposed to resulting from statistical sampling error (the chances of which increase as number of comparisons increase). Furthermore, because of the nature of the design of this study, in which the treatment (rodent suppression) is only replicated once in each study area, further caution needs to be used when inferring a causal relationship between rodent trapping and population trends among arthropods. For this reason, single statistically significant results that don't appear to fit a larger pattern should be regarded as questionable evidence of a treatment effect. On the other hand, patterns of similar results among related taxa, or results that appear to be consistent over multiple time periods, or between

sampling methods or study areas, are unlikely to be due to haphazard population fluctuations or random sampling error, and can be regarded as tentative evidence of a response to rodent trapping.

In general, there were relatively few statistically significant changes in abundances among the various arthropod groups at the Palikea removal site, after adjusting for changes at the control site, in the first year after rodent trapping began. In addition, there is relatively little agreement between the taxonomic trends seen in the first two years after trapping at Kahanahaiki Valley and those presented here for the first year post-trapping at Palikea. The estimated relative changes in abundances to date, for both study areas, are summarized in Table 1. Relative increases have been strongest and/or most consistent at Kahanahaiki for Araneae and Lepidoptera, but both of these groups failed to increase and instead showed tendencies to decrease after rodent trapping at Palikea. However, only one of these relative declines, among ground-active spiders, was statistically significant, and the (non-significant) decrease in Lepidoptera in ground samples at Palikea matched the significant decline in the same group at Kahanahaiki. The most consistent response between study areas has been significant declines in Psocoptera abundances on vegetation after trapping began.

The two groups that significantly increased in abundance after trapping at Palikea, Hemiptera and Orthoptera, have shown only inconsistent evidence for increase at Kahanahaiki, namely, crickets increased in abundance on the ground at Kahanahaiki after two years. However, recovery by Orthoptera fits well with predictions, as this group of relatively large-bodied insects represent common prey items in rodent diets (St Clair 2010), and one *Banza* leg was found in a black rat stomach trapped at Kahanahaiki (Shiels et al. in press). Increases in numbers of Hemiptera at Palikea, especially among small-bodied Delphacidae, Psyllidae and Lygaeidae, could represent a trophic cascade mediated by the apparent decline in predatory spiders, as rodents may be unlikely to prey heavily on these groups. Other Hemiptera, such as the Nabidae and larger lygaeid species, may be more common rodent prey items and could experience release from predation by both rodents and spiders. Hemiptera have not increased in abundance at Kahanahaiki, but this matches expections based on the apparent increase in spider numbers in that area.

Spiders make up a substantial portion of the arthropod communities in both study areas, and given their predatory roles are likely important mediators of arthropod food web dynamics. It is unclear why they have apparently increased after rodent trapping at Kahanahaiki but decreased (or shown trends in this direction) at Palikea. One potential explanation is a differential role of birds in the two study areas. Birds have been shown to strongly control spider populations in Hawaiian forests (Gruner 2004), and their top-down effects appear to be weaker on lower trophic levels, such as herbivorous insects. If predation pressure by birds is stronger at Palikea than at Kahanahaiki, especially after rodents are suppressed, the above pattern in spider abundances could emerge.

Analysis of changes in arthropod abundances after the second year of rodent trapping at Palikea, and the third year at Kahanahaiki, should help clarify potential patterns. In addition, dynamics in arthropod diversity have not yet been examined, and may shed additional light on changes in arthropod communities. I will be focusing on both of these questions in future work.

Table 1. Summary of mean (or median) relative changes in abundance estimated in the two study areas to date. Increases at the trapped sites relative to the control sites in each area that differ from 0 at p<0.05 highlighted in green and at 0.05<p<0.1 in light green. Decreases that differ from 0 at p<0.05highlighted in red and at 0.05<p<0.1 in pink.

| Taxon | Vegetation Sampling | | | Ground Sampling | | |
|---|---|---|---|---|---|---|
| | Kahanahaiki/Pahole | | Palikea | Kahanahaiki/Pahole | | Palikea |
| | 1 year | 2 years | 1 year | 1 year | 2 years | 1 year |
| | mean/med score | mean/med score | mean/med score | mean/med score | mean/med score | mean/med score |
| Araneae | 1.53 | 2.56 | -9.33 | 4.533 | 4.783 | -19.78 |
| native Araneae | 0.218 | 0.219 | -16.17 | 0.062 | 0.625 | 0.67 |
| Coleoptera | -1.28 | 2.09 | -1.56 | 0.75 | 7.15 | -1.28 |
| native Coleoptera | -0.344 | -0.719 | -0.94 | 0 | 0 | -0.17 |
| Lepidoptera | 0.812 | 1.125 | -1.56 | -1.875 | -0.062 | -6.39 |
| native Lepidoptera | 0.906 | 0.906 | -2.89 | | | 4 |
| Eupithecia | 0.563 | 0.563 | -0.06 | | | |
| Hyposmocoma | 0.344 | 0.344 | -2.78 | -0.462 | -0.15 | 3.5 |
| Orthoptera | 0.125 | 0.094 | 4.44 | | | |
| native Orthoptera | -0.062 | -0.031 | 3.89 | 0 | 2 | -0.28 |
| Blattodea | 0.062 | 0.25 | -1.83 | | | |
| Dermaptera | | | | 0.554 | -0.258 | -1.44 |
| native Dermaptera | | | | -0.2 | 0.05 | |
| Hemiptera | -3 | 2.5 | 21.67 | 1.821 | 1.071 | -1.39 |
| native Hemiptera | -3.25 | 2.5 | 23.06 | | | |
| Psocoptera | -6 | -1.5 | -26.67 | | | |
| Hymenoptera (all non-ant) | 0 | 0 | 9.83 | -0.062 | 0.062 | 0.89 |
| Formicidae | 0.5 | 1 | 2.83 | 0.5 | 0.5 | -0.11 |
| Diptera | | | | 4.25 | 1 | 14.78 |
| Collembola | 14.344 | 16.75 | 110.17 | -4.962 | 8.788 | -109.78 |
| Isopoda | 0 | 1 | -6.17 | 3.904 | 4.217 | -34.83 |
| Diplopoda | 0.188 | 0.062 | 8.94 | -2.483 | -0.921 | 18.39 |
| Amphipoda | | | 3.72 | -9.5 | 17 | -17.06 |
| All arthropods | 7.5 | 36.25 | 83.67 | -1.562 | 37.188 | -217.67 |
| All native arthropods | -2.5 | 5.5 | 8.72 | | | 2.67 |

## II. Inventory and biodiversity patterns

The standardized plus opportunistic sampling for this project has resulted in the collection, sorting, and databasing, to date, of over 220,000 arthropod specimens. All specimens in many taxonomic groups have been identified to species or morphospecies. So far, 300 arthropod species or morphospecies have been identified from Kahanahaiki and Pahole, and 417 species or morphospecies have been identified from Palikea. One interesting recent find was the collection of several individuals of a new, undescribed species of *Nysius* seedbug (family Lygaiedae), provisionally named *N. "kaala"* and previously only known from the Kaala summit area (J. Eiben pers. comm.). The collections at Palikea therefore substantially expand the known habitat area for this apparently rare species.

Previous work found a preliminary, but strong relationship between arthropod species richness and the richness of native plant species in the forest understory at Palikea. Recently OANRP staff quantified the plant community richness and cover at the Palikea control plots, which doubles the sample size for this type of analysis. Combined with the increased number of arthropod samples now fully processed at Palikea, this will allow robust examination of patterns between plant community structure, including degree of invasion by adventive plants, and arthropod community characteristics.

Similarly, prior work indicated a preliminary trend of lower overall abundances of arthropods on *Psidium cattleianum* relative to native tree species at Kahanahaiki and Pahole. This finding led to the hypothesis that strawberry guava could provide inferior foraging habitat for the endangered insectivorous elepaio. However, the arthropod data at the time were incomplete, missing several abundant taxonomic groups, and the interpretation regarding habitat quality for elepiao would be contingent on abundance patterns of arthropod groups that serve as the main prey items for elepaio. Over the past year, the question has been investigated further, resulting in two main findings. First, when all arthropod groups are included, *P. cattleianum* trees at Kahanahaiki and Pahole did not have significantly lower numbers of arthropods than three native tree species (Fig. 15). However, many of the arthropods in *P. cattleianum* samples were springtails (Collembola). Unpublished USGS data on the prey composition of 92 elepaio fecal pellets from Hakalau NFR, Hawaii Island, indicate that Collembola were completely absent from elepaio diets.

When the Kahanahaiki and Pahole arthropod samples were re-examined with a consideration of elepaio prey preference, a different picture emerged. Mean total abundances of arthropod prey items were significantly lower on *P. cattleianum* than on two of the three native tree species, regardless of whether prey item abundance was estimated by a) including only arthropod groups that comprised at least 5% of elepaio diet contents, or b) by weighting the abundances of each arthropod group by its proportional representation in the elepaio diet (Fig. 16). This pattern is compelling, and a next step is to examine whether these results are corroborated by patterns of arthropod abundances as they relate to levels of *Psidium* infestation in the Palikea vegetation plots. In addition, elepaio fecal samples from the Waianae mountains are now being collected by OANRP staff, and these samples will be dissected to identify local diet composition. These data, possibly combined with observations on elepaio foraging behavior, may provide an important insight into a possible link between plant community composition and elepaio habitat quality, as mediated by arthropod community composition.

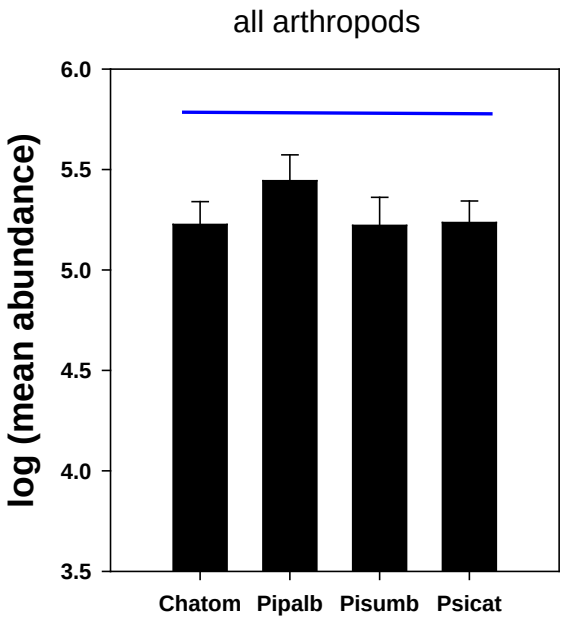


Figure 15. Mean total abundance (±SE) of all arthropods on four species of trees at Kahanahaiki and Pahole. Means are averages of all trees sampled at both sites (n=16 per species). Tree species connected by blue bar are not significantly different (p>0.05).

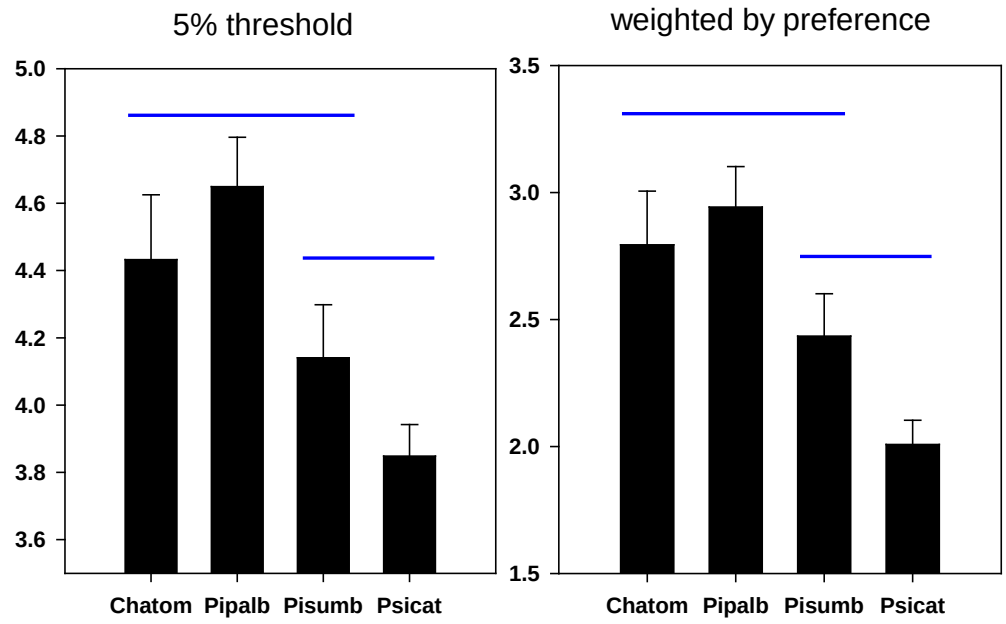


Figure 16. Mean total abundance (±SE) of all arthropods on four species of trees at Kahanahaiki and Pahole, when adjusted for elepaio diet composition (USGS unpub. data). Left panel shows mean total abundances of all arthropod groups that comprised at least 5% of elepaio prey items. Right panel shows mean total abundances of all arthropod groups, but with abundances of each group weighted by proportional composition in elepaio diets. Means are averages of all trees sampled at both sites (n=16 per species). Tree species connected by blue bars are not significantly different (p>0.05).

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Shiels, A.B., C.A. Flores, A. Khamsing, P.D. Krushelnycky, S.M. Mosher, and D.R. Drake. In press. Dietary niche differentiation among three species of invasive rodents (*Rattus rattus, R. exulans, Mus musculus*). Biological Invasions.

St Clair, J.J.H. 2010. The impacts of invasive rodents on island invertebrates. Biological Conservation, in press.

**APPENDIX 1-1**
**Environmental Outreach 2012**

**OUTREACH PHOTOS:**

Volunteers help to control the incipient moss, *Sphagnum palustre* along the Kaala boardwalk corridor.

Volunteers monitor *Carex wahuensis* and alahee (*Psydrax odorata*) in Pahipahialua.

Volunteer hauls wire mesh for the boardwalk improvement project at Kaala.

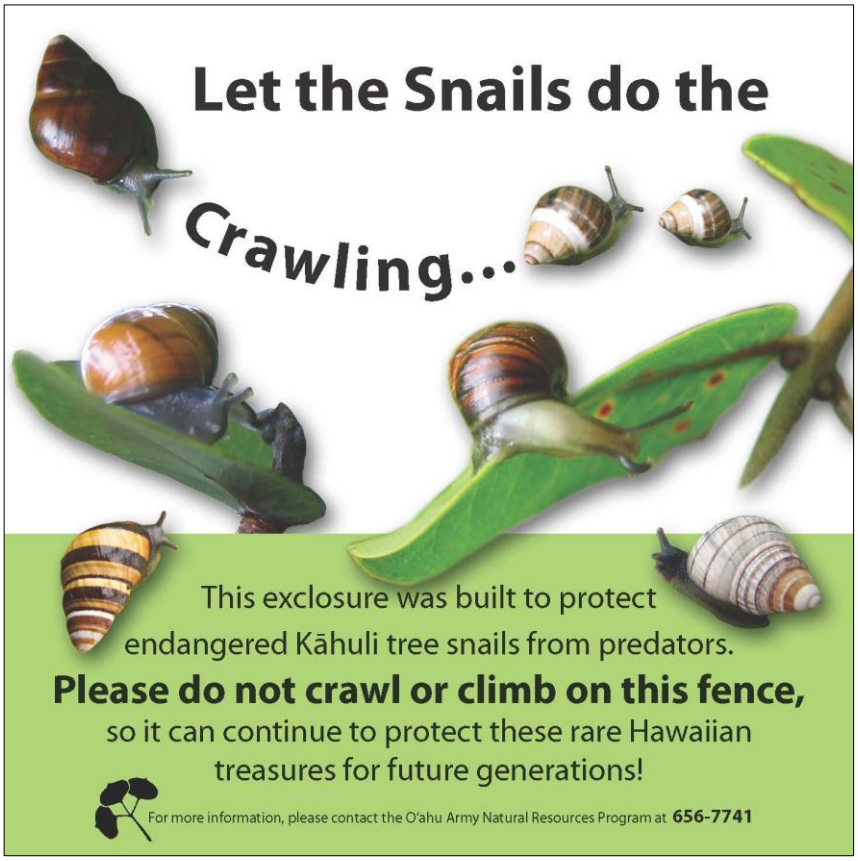
4th grade students at Hoala School plant koa (*Acacia koa*) in Kahanahaiki.


Kapua Kawelo, Federal Biologist, gives a briefing on natural resources in Makua at a public cultural access event. Natural resources signage (pictured) was developed for the Makua Interpretive Area for use at public cultural access events.

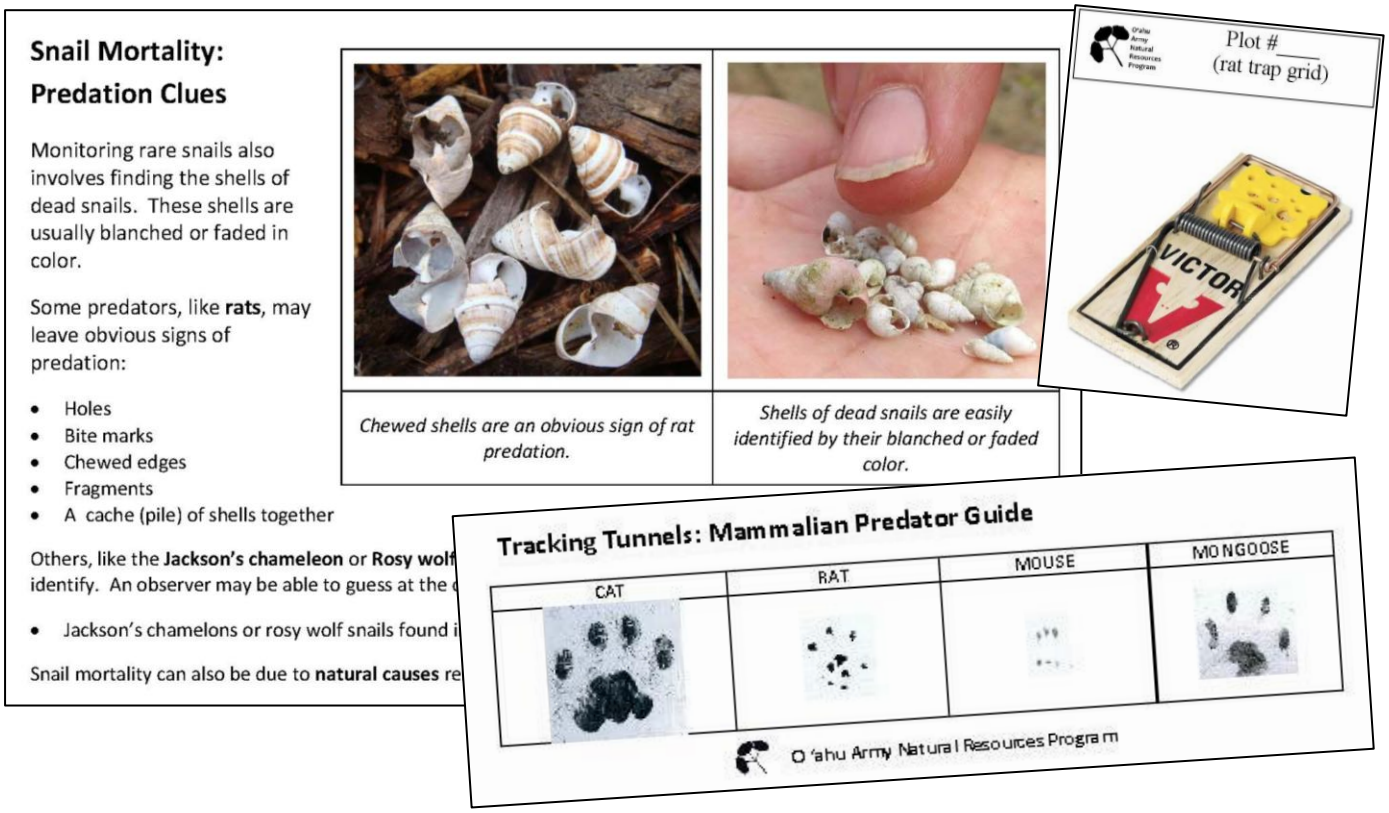
Natural Resources Field Crew Intern Aaron Osorio makes his way up the fencline in in Koloa.

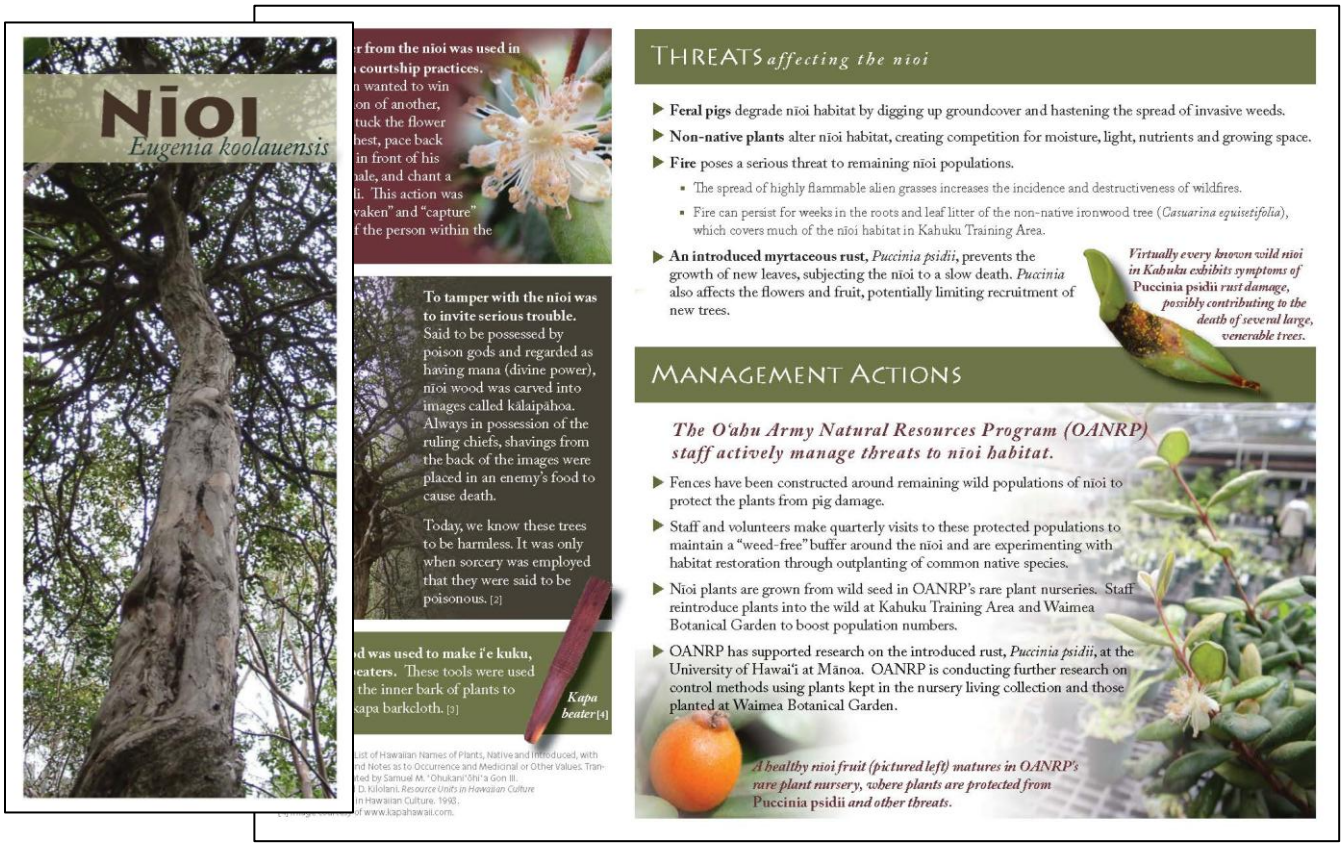

Orange team member Jenna Tomasa helps to make a kahuli button magnet at the OANRP display at Schofield Barracks Army Earth Day.

**EDUCATIONAL MATERIALS:**

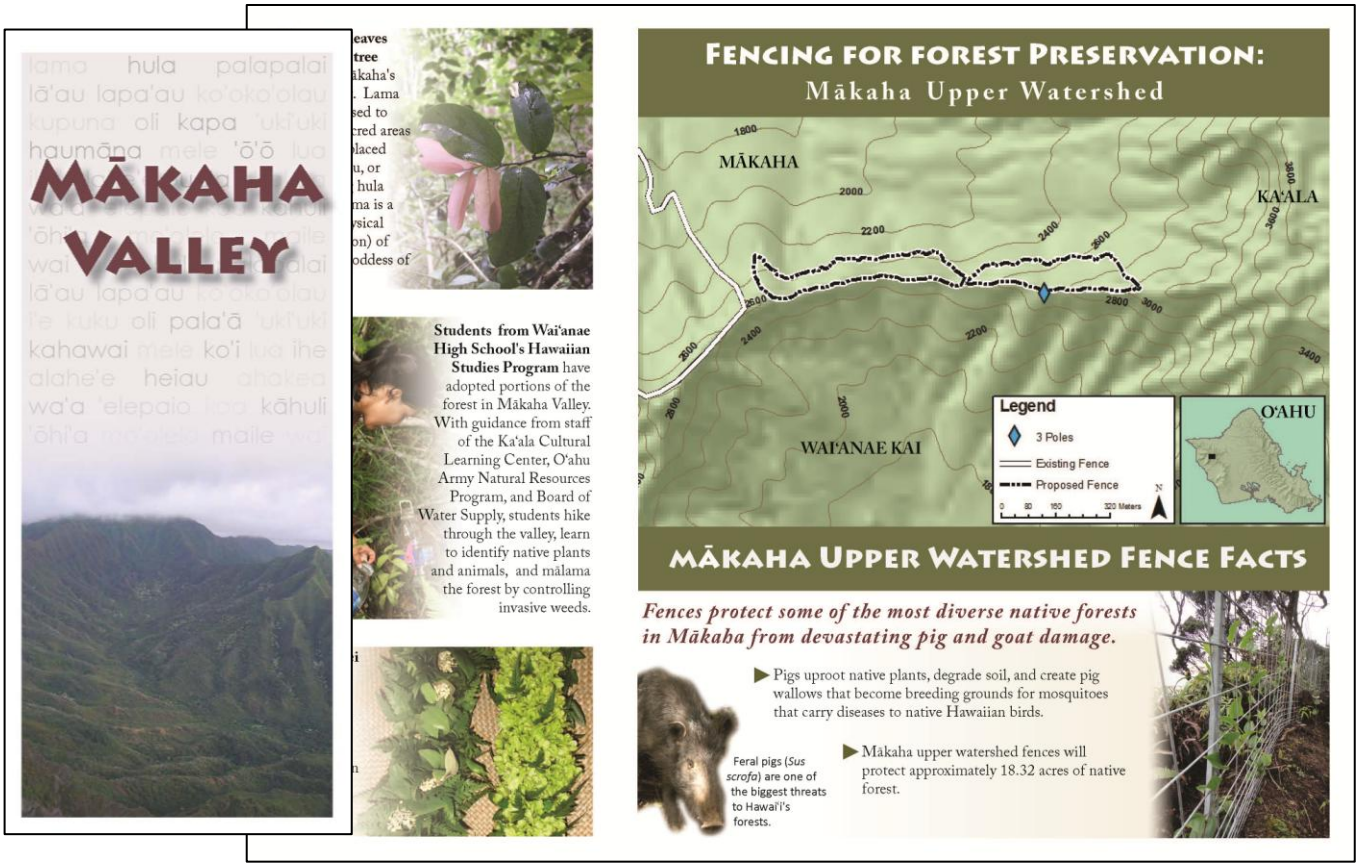



**Left:** Sign designed for kahuli (*Achatinella spp*.) predator barriers and displayed (**above**) at Puu Hapapa predator barrier. **Below:** Materials created for Hawaii Environmental Education Symposium monitoring activity.






**Above:** Tri-fold brochure highlighting nioi *(Eugenia koolauensis*) designed for Community Open House at Kahuku Training Area(KTA) and education of troops utilizing KTA. **Below:** Makaha Subunit II fencing project brochure.



**PUBLIC RELATIONS:**

HAWAI'I ARMY WEEKLY

PAU HANA

"When work is finished."

www.hawaiiarmyweekly.com FRIDAY, MARCH 2, 2012

# UPSCALE LIVING

## Slimy residents fill gated community

U.S. ARMY GARRISON-HAWAII PUBLIC AFFAIRS
News Release

SCHOFIELD BARRACKS — Army staff have welcomed the last incoming residents to a gated community high atop the Waianae Mountains.

Staff from Oahu Army Natural Resources Program, or OANRP, joined by the University of Hawaii's Rare Snail Conservation Laboratory and the U.S. Fish and Wildlife Service, or USFWS, flew the remaining half of more than 300 kahuli tree snails (Achatinella mustelina) to their new home in a one-of-a-kind snail enclosure, Feb. 21.

Previously, the snails had spent the last two years in a temporary home at the UH snail lab.

"It's very satisfying," said Vince Costello, OANRP rare snail conservation specialist. "We're bringing them back to either where they came from or where their ancestors came from."

Costello and group introduced the first half of the snail colony, Feb. 8, but waited to introduce the second half to make sure the snails were doing OK in their new habitat, which consists of an exclosure almost the size of a basketball court.

Army and industry professionals designed the exclosure to safeguard the kahuli from voracious predators that have pushed this tiny Hawaiian native to the brink of extinction.

Predators like the cannibal rosy wolf snail (Euglandina rosea), mice, rats and the Jackson's chameleon shouldn't be able to snack on the kahuli inside the exclosure, thanks to its 4-foot tall surrounding wall with multiple layers of built-in protection: a buried wall portion, curved fence hood, solid-wall construction, electric wiring and special sections of wire bristles that cannibal snails can't cross.

"I describe it as the management tool of the future," Costello said. "It's a unique project — one that's never been built before — and we hope we'll learn from it and be able to build others."

The Army started monitoring the kahuli in 1995 as part of its mission to support Soldier training through the management of threatened and endangered species.

As the years passed, Army biologists noted an increase in snail predators and a nearly 50-percent decrease in the Waianae Mountains kahuli population, spurring them to action.

"This area is exceptional in its (kahuli) richness, (but) also exceptional in its astronomical numbers of (rosy wolf snails). It deserves an exceptional response to preserve what snails remain," Costello wrote in his 2010 report detailing the situation.

The proposal to save the kahuli included temporarily relocating them to the care of the UH snail lab, with the intention of building the snails a home safe from predators. Today that vision is a reality with the help of conservation professionals from New Zealand and agencies like the USFWS.

"The service is excited about the completion of this snail exclosure because it provides a protected area where Oahu tree snails can once again thrive," said Joss Newton, leader of the Endangered Species Recovery Program for USFWS's Pacific Islands Fish and Wildlife Office.

"Currently 73 percent of these snail species are extinct and the remaining species are near extinction. To lose them, would be to lose a special piece of our local heritage."

The kahuli were an important part of native Hawaiian culture; prized for their beautiful shells, referenced in folklore and songs, and used in lei and other ornaments.

"This effort could be the difference between extinction and survival," Costello said.

He and other team members hope the exclosure will be a model for other agencies to use in the conservation battle.

In total, OANRP manages more than 100 threatened and endangered species on Oahu and the island of Hawaii. The team recently received an environmental award from the Secretary of the Army for its innovation and commitment to preserving Hawaii's natural resources.



Photos by Tech Sgt Michael R. Holzworth | U.S. Air Force

A Jackson chameleon is displayed after being removed from a Schofield Barracks training range, Feb. 8.



A helicopter performs a 500-pound sling load of endangered plants, Feb. 8, to be replanted on a mountain near Schofield Barracks.



Vince Costello, rare snail conservation specialist with U.S. Army Garrison -Hawaii's Oahu Army Natural Resources Program (OANRP), returns an endangered Hawaiian tree snail back into its natural environment, Feb. 8.

**Left:** Hawaii Army Weekly highlighted kahuli (*Achatinella mustelina*) in "Upscale living: Slimy residents fill gated community"

**Below:** OANRP is recognized for winning the 2012 Secretary of Defense Natural Resources Conservation Team Award on [www.army.mil](http://www.army.mil)

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## OANRP recognized for superior work

May 15, 2012

By U.S. Army Garrison-Hawaii Public Affairs

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WHEELER ARMY AIRFIELD, Hawaii -- The Army's Deputy Assistant Secretary of the Army for Environment, Safety and Occupational Health presented the Natural Resources Conservation Team Award for 2011 to the Oahu Army Natural Resources Program, or OANRP, and U.S. Army Garrison-Hawaii, here, May 5.

Related Links
Army natural resource efforts in Hawaii

In accepting the award from Hershell "Hew" Wolfe, Col. Douglas Mulbury, commander, USAG-HI, noted that the award recognizes the "phenomenal job" performed by the OANRP team.

"Recognition by the Secretary of the Army as having one of the finest natural resources programs in the Army is a public testament to the commitment, professionalism and dedication of the Natural Resources staff of USAG-HI," Mulbury said. "From my perspective, the OANRP's efforts allow us to train our Soldiers to prepare them for whatever mission our nation asks of our Soldiers."

The award, announced in January, is part of the annual Secretary of the Army Environmental Awards Program that recognizes and rewards excellence for the development, management and transferability of environmental programs that increase environmental

calabash | ENVIRONMENT

The kāhuli snail is slow to mature. It takes five years to reproduce and has only one to four live births a year.

# Hail Snails!

Sometimes, you build a jail to keep bad guys *out*.

BY SHEILA SARHANGI

WHEN THE WORLD IS CAVING in, build a stronger cave. That's essentially what happened in February, when 350 endangered O'ahu tree snails, known as kāhuli (*Achatinella mustelina*), were placed inside a state-of-the-art refuge in the Central Wai'anae Mountain Range. The exclosure, which some are playfully calling a "snail jail," is equipped with a fierce combination of safeguards to keep predators at bay. (Seriously, the measures make your brass deadbolt look pitiful.)

A few years ago, biologists at the O'ahu Army Natural Resources Program (OANRP) witnessed a frightening drop in the kāhuli population, a species found only along the ridgeline of the Wai'anae Mountains. In 2004, they counted 481 snails. Five years later, more than half were gone. The culprit? Researchers saw a spike in rosy wolf snails (*Euglandina rosea*)—a cannibalistic snail from Florida that sucks native snails out of their shells. "We know that if the rosy wolf snail continued, the area was going to be just another dot on the map where native snails used to be," says Vince Costello, rare snail conservation specialist with OANRP, a federally funded program that manages more than 100 native plant and animal species on the Big Island and O'ahu.

Hawai'i once had 750 species of native land snails. They were so commonly seen on trees, their nickname was "jewels of the forest." The snails also have a place in Hawaiian culture; they're mentioned in chants, songs and stories. Today, it's estimated that fewer than 10 percent of the species survive. A combination of factors caused their decline, including harvesting by shell collectors, the loss of native forests and the introduction of rats and Jackson chameleons.

In February 2010, through a partnership with the University of Hawai'i, U.S. Fish and Wildlife Service and OANRP, 202 kāhuli snails

Vince Costello spends hours every week protecting native kāhuli snails (at left) from predators.

## SNAIL LIFE

→ Kāhuli snails dine on fungus. They live most of their life on leaves, even preferring particular positions, such as in a little curl of a leaf, or sandwiched between two leaves for protection.

→ At night, kāhuli snails become active, even crusing from one tree to another, if the branches are connected.

→ All of O'ahu's

**41**

native snail species (Achitenella) are listed as endangered, though some haven't been seen for decades and are presumed extinct.



**Left:** Honolulu Magazine article on OANRP efforts to protect endangered kahuli (*Achatinella mustelina*) **Below:** Animal Planet's Jeff Corwin posted on Facebook about a blog highlighting OANRP kahuli protection efforts **Below, left:** Midweek call-out on kahuli conservation

**Jeff Corwin**

Great story covered by global citizen John Platt about the US Army protecting these very endangered Kahuli Tree snails in Hawaii. The Army has a long history of work to protect the kahuli tree snail and other wildlife. "The Army, as a federal agency, is required to protect threatened and endangered species found on its installations" says it all. Interesting use again of sniffer dogs btw who seem to be really playing a role in conservation. Enjoy and connect others.

**U.S. Army Protects Critically Endangered Hawaiian Snails from Invasive Predators | Extinction Countd**

blogs.scientificamerican.com

Three hundred critically endangered kahuli tree snails (Achatinella sowerbyana) have a new home this week: a basketball court–size, predator-proof enclosure built for them by the U.S. ...

Like · Comment · February 16 at 2:05am ·

Nidia C-f, Dulce Cielo Fons Melg, Hengameh Mesgarzadeh and 137 others like this.

New Schofield Barracks neighbors, **Achatinella mustelina**, are settling into their special gated community, safe from predators in the Waianae mountains – so don't go try to greet them. **Vince Costello** and the team from the award-winning Oahu Army Natural Resource Program escorted some 300 kahuli tree snails to the fancy, fenced and wired enclosure by helicopter last month. Vince, a rare-snail conservation specialist, explained to *Hawaii Army Weekly* that some 300 kahuli tree snails were brought back "to either where they came from or where their ancestors came from." Live long and prosper ...

EMP
Ecosystem Management Program Bulletin
Volume 54 November 2011-May 2012

# Slimy Residents Fill Gated Community

By Stefanie Gardin

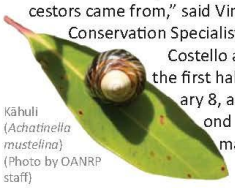
ARMY STAFF WELCOMED incoming residents to a gated community high atop the Waiʻanae Mountains this February.

The Oʻahu Army Natural Resources Program (OANRP) staff, joined by personnel from the University of Hawaiʻi's Tree Snail Conservation Laboratory (UH snail lab) and the U.S. Fish and Wildlife Service,

Juvenile kāhuli snails (*Achatinella mustelina*) climb their first tree! In 2010, their parents and 200 more kāhuli were rescued from predators and brought to the UH snail lab for safe keeping. Within the two years time it took to construct an exclosure in the wild, this group of snails grew to 342. This February, all were returned to their ancestral home. (Photo by OANRP staff)

flew the remaining half of more than 300 kāhuli tree snails (*Achatinella mustelina*) to their new home in a one-of-a-kind exclosure.

"It's very satisfying. We're bringing them back to either where they came from, or where their ancestors came from," said Vince Costello, Rare Snail Conservation Specialist with the OANRP.



Kāhuli (*Achatinella mustelina*) (Photo by OANRP staff)

Costello and the group introduced the first half of the snails on February 8, and introduced the second half on February 21, to make sure the snails were doing okay in their new habitat.

## Inside this issue:



EMP
Ecosystem Management Program Bulletin
Volume 55 Summer 2012

# Kahuku Huakaʻi: A Glimpse into the Past

By Kim Welch and Jaime Raduenzel

AS TWO TRUCKLOADS of eager volunteers approached the Army's Kahuku Training Area (KTA), all eyes were drawn to the latest construction projects in the area. Spinning wind turbines and a large building occupied the upper portion of our viewscape atop a 200-foot-tall coralline bluff, which resided below sea level at one point in time—many millenia before the ideas of alternative energy and construction were conceived. Like many of the low-lying areas on Oʻahu, the land at Kahuku has undergone numerous changes throughout its history, both natural and man-made.

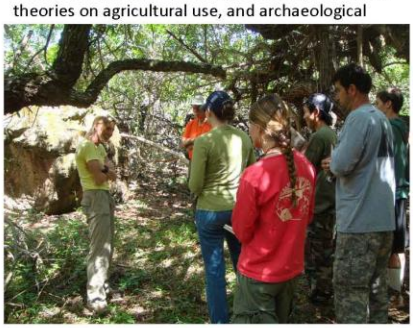
On this special Oʻahu Army Natural Resources Program (OANRP) volunteer service trip, many of Kahuku's less obvious manmade and natural changes were highlighted. Combining forces, outreach staff from both the OANRP and the Oʻahu Army Cultural Resources Program (OACRP) provided volunteers with background on several historic sites within KTA.

Some of the more obvious land-use changes were visible during the drive into the training area. Horses grazed on surrounding ranch land, energy-generating windmills towered above the hills to the east, and heavy equipment lined a nearby road construction project on the training range. While checking in at Range Control, volunteers oriented themselves on posted maps of the training range, tracing the planned driving route on the maze of unpaved access roads and motocross tracks that criss-cross KTA.

As the group drove away from Range Control and began heading further into KTA, OACRP's Outreach Specialist, Jaime Raduenzel, soon motioned to stop next to a guardrail.

"We're here," she stated. "Here" was a nondescript roadside stop sandwiched between a steep hill covered with invasive Christmasberry trees (*Schinus terebinthifolius*) and a gulch filled with koa haole trees (*Leucaena leucocephala*)—the landscape of Kahuku has been changed radically in the last few hundred years with the introduction and spread of invasive weed species.

The group gathered around Raduenzel as she shared some history of Kahuku, including information about the early deforestation of the area between 1810-1840 due to the sandalwood trade, theories on agricultural use, and archaeological



Jaime Raduenzel, Cultural Resources Outreach Specialist, (left) shares a story about the "Waikane Stone," said to exist in the Kahuku area. Could this large pohaku (pictured left) be the one referenced in moʻolelo? (Photo by OANRP staff)

## Inside this issue:



Cover pages from the 2012 Winter and Summer editions of the Ecosystem Management Program Bulletin. Full bulletins and previous volumes can be downloaded at http://manoa.hawaii.edu/hpicesu/dpw_emb.htm.


# Identification of invasive plant species on U.S. Army lands, Base Year October 2011 to July 2012

Hawaii Biological Survey

**Final Report** **October 2012**

**Cover image:**

Voucher collection of *Chromolaena odorata*. This specimen, deposited in Herbarium Pacificum, Bishop Museum, was collected in January 2011 from the Kahuku Training Area, O‘ahu, by the O‘ahu Army Natural Resources Program field crew, and represents the first documenatation of this highly invasive species in the state of Hawai‘i.

Photographed by C. Imada

# Identification of invasive plant species on U.S. Army lands, Base Year October 2011 to July 2012

Final report prepared for:

O‘ahu Army Natural Resources Program (OANRP)
Schofield Barracks, Hawai‘i 96857

Prepared by:

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Honolulu HI 96817, USA

October 2012

Contribution No. 2012-020 to the Hawaii Biological Survey

# Identification of invasive plant species on U.S. Army lands, Base Year October 2011 to July 2012

## Introduction

The goal of the U.S. Army's ecosystem management program is to conserve, protect, and enhance the natural and cultural resources of Hawai‘i and to comply with all applicable Federal and state laws and regulations while improving the Army's ability to conduct and maintain military readiness. In order to obtain this goal, a better understanding of the resources must be achieved to ensure that proper management measures and decisions are made. Introduced plant taxa threaten endangered species and native ecosystems by altering habitat and disrupting community structure. Weedy plant species outcompete native plants for light, space, and nutrients. As such, rapid identification of newly located and potentially invasive plant species is critical for their timely eradication on Army lands. The goal of this project is to accurately identify newly discovered invasive and potentially invasive plant species found on U.S. Army lands using the resources of the Bishop Museum's *Herbarium Pacificum* (BISH).

## Methods

During the period of 1 October 2011 to 31 July 2012, 57 plant specimens were collected from U.S. Army lands and taken to Bishop Museum for identification or confirmation. Specimens that were new state or island records, important distributional additions, or those extending the expressed range of morphological variation of a taxon were mounted and accessioned into Bishop Museum's *Herbarium Pacificum*. If needed, images of the specimens were submitted to taxonomic experts for identification. In general, specimens were discarded by Bishop Museum staff or affiliates if they were sterile and unidentifiable or were identifiable but added no significant new data to the collections.

## Results

Of the 57 plant specimens submitted to the Bishop Museum for identification, 46 were identified to the species level or lower, while 11 could only be identified to genus or family level, sometimes due to the sterile nature of the material (Table 1). Total staff time dedicated to species identification and processing of specimens was 21 hours by Clyde Imada; in addition, the O‘ahu Early Detection team (Danielle Frohlich, Alex Lau) spent 46 hours.

Of the collections made during this period, 1 naturalizing species had not previously been recorded in the Hawaiian Islands (New state record: *Albizia adianthifolia* (Schum.) W.Wight, Fabaceae); 5 species known to be naturalized on other islands were recorded for the first time on O‘ahu [New island records: *Urochloa decumbens* (Stapf) R.D.Webster (Syn. *Brachiaria decumbens* Stapf) (Poaceae), *Entolasia marginata* (R.Br.) Hughes (Poaceae), *Schizachyrium condensatum* (Kunth) Nees (Poaceae), *Sisyrinchium exile* E.P.Bicknell (Iridaceae), and *Juniperus bermudiana* L. (Cupressaceae)]; 1 species long cultivated in the State was noted as adventive on O‘ahu (*Pterocarpus indicus* Willd., Fabaceae); and one species recorded as naturalized on Maui was noted as adventive on O‘ahu *(Cryptomeria japonica* (L.f.) D.Don (Taxodiaceae).

The new O‘ahu island record for *Entolasia marginata* was published this year (Frohlich & Lau 2012); the remainder will be published in a future issue of the Bishop Museum Occasional Papers. In addition, 18 other vouchers collected by U.S. Army Natural Resources staff prior to October 2011 were published as newly naturalized or adventive this year in Bishop Museum’s *Records of the Hawaii Biological Survey for 2011; part II; Plants* (Frohlich & Lau 2012; Lau and Frohlich 2012).

| **Family** | **Scientific name** | **Record type** |
|---|---|---|
| Asteraceae | *Chromolaena odorata* (L.) R.M.King & H.Rob. | New state record |
| Bignoniaceae | *Pyrostegia venusta* (Ker Gawl.) Miers | New naturalized record |
| Blechnaceae | *Blechnum orientale* L. | New state record |
| Caryophyllaceae | *Petrorhagia velutina* (Guss.) P.W.Ball & Heywood | New island record |
| Crassulaceae | *Crassula multicava* Lem. | New island record |
| Cupressaceae | *Callitris columellaris* F.Muell. | New island record |
| Cupressaceae | *Callitris endlicheri* (Parl.) F.M.Bailey | New naturalized record |
| Cupressaceae | *Cupressus lusitanica* Mill. | New naturalized record |
| Fabaceae | *Albizia saponaria* (Lour.) Blume ex Miq. | New island record |
| Iridaceae | *Dietes iridioides* (L.) Sweet | New naturalized record |
| Liliaceae | *Dianella caerulea* Sims | New naturalized record |
| Orchidaceae | *Dendrobium mirbelianum* Gaudich. | New state record |
| Orchidaceae | *Epidendrum nocturnum* Jacq. | New state record |
| Orchidaceae | *Habenaria rodeiensis* Barb.Rodr. | New island record |
| Moraceae | *Ficus pumila* L. | New adventive |
| Podocarpaceae | *Podocarpus macrophyllus* (Thunb.) Sweet | New naturalized record |
| Pteridaceae | *Adiantum* ‘Edwinii’ | New island record |
| Scrophulariaceae | *Veronica serpyllifolia* L. | New island record |

*Dendrobium mirbelianum,* new state naturalized record from Waikane Trail, O‘ahu. Photo by O‘ahu Early Detection.

*Blechnum orientale,* new state naturalized record from Kahalu‘u, O‘ahu. Photo by O‘ahu Army Natural Resources Program.

**Management actions**

The rapid identification of unknown and potentially invasive species found on U.S. Army lands is critical for decision-making and management actions to quickly eliminate those introduced plant taxa that could irreparably damage native ecosystems. The significant number of new state and island records discovered in native ecosystems on Army lands is cause for concern, and demonstrates the importance of field surveys for introduced, potentially invasive species. Digital images of unidentified specimens captured at the time of collection, documenting characteristics of habit, flowers, and fruits, may further assist with the identification process. The followup dissemination of new naturalized records via Bishop Museum’s *Records of the Hawaii Biological Survey* allows for all those in the state involved in natural resource and weed management, landscaping, and nursery or botanical garden management to become quickly aware of the naturalization potential of plants growing on lands under their care.

**Acknowledgments**

The authors wish to thank the staff of *Herbarium Pacificum,* Bishop Museum, especially Napua Harbottle and Barbara Kennedy; Rachel Neville of the O‘ahu Invasive Species Committee; Michelle Mansker, Kapua Kawelo, and Jane Beachy of the O‘ahu Army Natural Resources Program, along with their hard-working staff; and taxonomists Melissa Luckow (Cornell University) and Mark Strong (Smithsonian Institution) for help with plant identifications.

**References**

Frohlich, D. and A. Lau. 2012. New plant records for the Hawaiian Islands 2010–2011. Bishop Mus. Occas Pap. 113: 27–54.

Lau, A. and D. Frohlich. 2012. New plant records from O‘ahu for 2009. Bishop Mus. Occas Pap. 113: 7–26.

**Table 1**: Collections made by U.S. Army personnel and identified by O'ahu Early Detection and Bishop Museum staff from 1 October 2011 to 31 July 2012. Unhighlighted taxa have been positively identified; taxa highlighted in yellow were not identifiable due largely to the material being sterile, and should be recollected with flowers and/or fruit and resubmitted for identification; taxa highlighted in green are tentatively identified, but require herbarium confirmation; and taxa in aqua were fertile but not identifiable, and their determination is still pending.

| US Army # | Date | Family | Taxon | Comments |
|---|---|---|---|---|
| 233 | 10/10/11 | Poaceae | *Entolasia marginata* (R.Br.) Hughes | kept; new island record |
| 234 | 10/10/11 | Araliaceae | *Schefflera* cf. *elegantissima* (Veitch ex Masters) Lowry & Frodin | |
| 235 | 10/13/11 | Orchidaceae | *Dendrobium* 'Jaquelyn Thomas' | |
| 236 | 10/19/11 | Poaceae | *Digitaria ciliaris* (Retz.) Koeler | ID uncertain; more field collections desirable |
| 237 | 10/20/11 | Grossulariaceae | *Brexia madagascariensis* (Lam.) Thouars ex Ker Gawl. | discarded; sterile, already documented |
| 238 | 11/21/11 | Poaceae | *Cenchrus setaceus* (Forssk.) Morrone (Syn. *Pennisetum setaceum* (Forssk.) Chiov.) | kept; documents distribution |
| 239 | 11/20?/11 | Orchidaceae | *Polystachya concreta* (Jacq.) Garay & Sweet | kept; documents distribution |
| 240 | 11/20/11 | Davalliaceae | *Davallia fejeensis* Hook. | discarded; already documented |
| 241 | 11/22/11 | Combretaceae | *Terminalia myriocarpa* Van Heurck & Müll.Arg. | discarded; already documented |
| 242 | 11/28/11 | Fabaceae | *Pterocarpus indicus* Willd. | kept; adventive |
| 243 | 11/28/11 | Verbenaceae | *Duranta erecta* L. | discarded; already documented |
| 244 | 11/28/11 | Fabaceae | *Erythrina poeppigiana* (Walp.) O.F.Cook | discarded; sterile |
| 245 | 11/28/11 | Fabaceae | *Albizia adianthifolia* (Schum.) W.Wight | kept; new state record |
| 246 | 11/29/11 | Annonaceae | *Artabotrys hexapetalus* (L.f.) Bhandari | photo only |
| 247 | 8/17/11 | Polygonaceae | *Rumex?* | photo only; sterile |
| 248 | 12/21/11 | Fabaceae | *Albizia adianthifolia* (Schum.) W.Wight | kept; provides additional fertile material |
| 249 | 12/21/11 | Fabaceae | *Senna spectabilis* (DC.) H.S.Irwin & Barneby | discarded; already documented as naturalized; this material cultivated |
| 250 | 1/4/12 | Cupressaceae | | |
| 251 | 1/4/12 | Cupressaceae | *Callitris endlicheri* (Parl.) F.M.Bailey | |
| 252 | 1/4/12 | Fabaceae | *Albizia* sp? | sterile, not kept; fertile collection needed |

| US Army # | Date | Family | Taxon | Comments |
|---|---|---|---|---|
| 253 | 1/12/12 | Fabaceae | *Senna spectabilis* (DC.) H.S.Irwin & Barneby | |
| 254 | 2/6/12 | Taxodiaceae | *Cryptomeria japonica* (L.f.) D.Don | kept; adventive or possibly naturalized |
| 255 | 2/6/12 | Fabaceae | *Albizia* sp? | discarded; sterile |
| 256 | 2/9/12 | Iridaceae | *Dietes iridioides* (L.) Sweet | discarded; sterile, need flowers to confirm |
| 257 | 2/14/12 | Poaceae | *Schizachyrium condensatum* (Kunth) Nees | kept; new island record |
| 258 | 2/14/12 | Basellaceae | *Anredera cordifolia* (Ten.) Steenis | discarded; already documented |
| 259 | 2/14/12 | Moraceae | *Ficus nota* (Blanco) Merr. | discarded; already documented |
| 260 | 2/14/12 | Asteraceae | *Heterotheca grandiflora* Nutt. | discarded; sterile |
| 261 | 2/14/12 | Combretaceae | cf. *Quisqualis indica* L. | discarded; sterile |
| 262 | 2/14/12 | Fabaceae | *Senna spectabilis* (DC.) H.S.Irwin & Barneby | discarded; already documented |
| 263 | 2/14/12 | Fabaceae | *Adenanthera* cf. *pavonina* L. | discarded; sterile |
| 264 | 2/14/12 | Fabaceae | *Peltophorum* cf. *pterocarpum* (DC.) K.Heyne | discarded; sterile |
| 265 | 2/22/12 | Poaceae | *Stenotaphrum* cf. *secundatum* (Walter) Kuntze | discarded; sterile |
| 266 | 2/22/12 | Poaceae | cf. *Agrostis* sp. | discarded; sterile |
| 267 | 2/22/12 | Poaceae | cf. *Digitaria* sp. | discarded; sterile |
| 268 | 2/27/12 | Poaceae | *Schizachyrium condensatum* (Kunth) Nees | kept; new island record |
| 269 | 1/6/08 | Orchidaceae | *Vanda tricolor* Lindl. var. *suavis* Veitch | kept |
| 270 | 3/12/12 | Combretaceae | *Terminalia myriocarpa* Van Heurck & Müll.Arg. | discarded; already documented |
| 271 | 2/22/12 | Brassicaceae | *Lepidium virginicum* L. | discarded; already documented |
| 272 | 3/15/12 | Poaceae | *Urochloa decumbens* (Stapf) R.D.Webster (Syn. *Brachiaria decumbens* Stapf) | kept; new island record |
| 273 | 3/15/12 | Poaceae | *Eragrostis elongata* (Willd.) J.Jacq. | kept; good material |
| 274 | 3/15/12 | Poaceae | *Eragrostis* sp. | discarded; same as #276 |
| 275 | 3/15/12 | Fabaceae | *Desmodium* sp. | discarded; sterile |
| 276 | 3/15/12 | Poaceae | *Eragrostis* sp. | kept for ID |
| 277 | 3/15/12 | Cyperaceae | *Rhynchospora* sp. | kept for ID |
| 278 | 3/15/12 | Cyperaceae | *Rhynchospora rugosa* (Vahl) Gale subsp. *lavarum* (Gaudich.) T.Koyama | kept; good material |
| 279 | 3/15/12 | Cyperaceae | *Rhynchospora rugosa* (Vahl) Gale subsp. *lavarum* (Gaudich.) T.Koyama | discarded; duplicate of #278 |

| US Army # | Date | Family | Taxon | Comments |
|---|---|---|---|---|
| 280 | 3/19/12 | Iridaceae | *Sisyrinchium exile* E.P.Bicknell | kept; new island record |
| 281 | 3/19/12 | Asteraceae | *Heterotheca grandiflora* Nutt. | discarded; already documented |
| 282 | 3/19/12 | Cyperaceae | *Rhynchospora caduca* Elliott | discarded; already documented |
| 283 | 3/29/12 | Fabaceae | ? | discarded; sterile |
| 284 | 4/3/12 | Viscaceae | *Korthalsella latissima* (Tiegh.) Danser | discarded; already documented |
| 285 | 4/12/12 | Poaceae | *Digitaria abyssinica* (Hochst. ex A.Rich.) Stapf | ID uncertain; need to recollect with underground parts |
| 286 | 6/4/12 | Poaceae | *Bromus catharticus* Vahl | discarded; already documented |
| 287 | 6/4/12 | Cupressaceae | *Juniperus bermudiana* L. | kept; new island record |
| 288 | 7/12/12 | Scrophulariaceae | *Lophospermum erubescens* D.Don | recollect if possible; range extension to Waianaes |
| 289 | 5/31/12 | Verbenaceae | *Tectona grandis* L.f. | discarded; already documented |

**College of Tropical Agriculture and Human Resources**
University of Hawai'i at Mānoa

**Weed Control**
**May 2012**
**WC-10**

# Practitioner's Guide for Effective Non-Restricted Herbicide Techniques to Control and Suppress Invasive Woody Species in Hawai'i

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This herbicide reference guide is intended for private or public non-commercial applicators conducting invasive weed management in the state of Hawai'i. It focuses on selective techniques to treat individual woody tree and shrub species with improved herbicide and species information. This bulletin complements CTAHR Extension Bulletin WC-4 *Woody Plant Control for the Home, Pasture, and Forest* (Motooka et al. 1999) and also builds on the *Summaries of Herbicide Trials for Pasture, Range, and Non-Cropland Weed Control* produced by Phil Motooka from 1998 to 2002 (WC 1, 5, 6, 7, and 9). Some of the herbicides previously shown to be effective are now restricted use, making these active ingredients a less practical management option. This bulletin only lists non-restricted herbicides registered in the State of Hawai'i as of 2012 and provides four basic tables for assisting with management decisions in (i) application techniques, (ii) active ingredient mode of action and use pattern, (iii) target species information, and (iv) maximum target treatment densities.

**Fig. 1. Herbicide injected into a stem cut that is just deep enough to expose the cambium.**

The application techniques presented in this publication are "tried and true" methods for individual plant treatment, including foliar, basal bark, cut stump, and injection. When performed correctly, these techniques are safe for the applicator and leave a very small footprint on the landscape. We only provide a brief description of the techniques here. To learn more, refer to *Herbicidal Weed Control Methods for Pastures and Natural Areas of Hawaii* (Motooka et al. 2002) and *Herbicide Application Techniques for Woody Plant Control* (Ferrell et al. 2006). Both documents are available on the Web. Practitioners are also encouraged to calibrate their application techniques with water before using an herbicide.

This bulletin makes reference to both chemical names (i.e., active ingredients) and the corresponding product trade names in an effort to promote a better association. Many commercial products have similar active ingredient compositions and should demonstrate equal performance in efficacy. However, different trade name products with the same active ingredient may not have

Published by the College of Tropical Agriculture and Human Resources (CTAHR) and issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, under the Director/Dean, Cooperative Extension Service/CTAHR, University of Hawai'i at Mānoa, Honolulu, Hawai'i 96822.

the same use patterns listed on the label. The practitioner has a legal obligation to be sure that their intended use pattern is approved on the product label they are using. **Always read and understand the label on the product container to determine if the intended herbicide application is approved and legal**. Every label gives a reminder of this enforcement standard in the form of a misuse statement: "*It is a violation of federal law to use this product in a manner inconsistent with its labeling*." This means that a pesticide user's action or inaction is a "misuse" of the pesticide if the label instructions and restrictions are not followed.

**Prohibited acts**, according to the Hawaii Pesticides Law – Chapter 149A of the Hawaii Revised Statutes:

- Any pesticide use **inconsistent** with its label
- Pesticide application **dosage**, **concentration**, or **frequency** that is **greater than** label specification
- Pesticide application to a crop, animal, or **site** that is **not specified** on the label
- Employing a **method of application** that is specifically **prohibited** on the label

**Table 1. Application techniques for individual treatment of woody tree and shrub weed species**

| Method | Definition | Herbicide Mix[a] | Calibration | Tools | Pro | Con |
|---|---|---|---|---|---|---|
| Foliar spray (F) | Water-diluted, low-concentration herbicide, high-volume application broadcast directed to leaf surfaces | Active ingredient <1%–10% v/v, surfactant adjuvant <2% v/v, water carrier >90% v/v | Flow rate (fl oz/sec), wand speed[b] (ft/s), spray swath (ft), target rate: 1–3 fl oz /10 ft2 | Hose sprayers or backpack hand-pump sprayer (4 gal), flat fan or solid-stream nozzle | Low concentration, affordable equipment, ability to treat large areas | Not practical on large trees, high water use, heavy payload, potential non-target drift injury, dead standing biomass |
| Basal bark (B) | Oil-diluted, high-concentration herbicide, high-volume application directed at the base of main stems | Active ingredient 10–50% v/v, penetrant oil adjuvant 50–90% v/v | Flow rate (fl oz/sec), stem circumference (in), target rate: 1–2 fl oz/stem | Squirt bottle or small hand-pump sprayer (1 gal), full cone or solid-stream nozzle | Easy application, no water consumption, no non-target injury | Less effective on large trees, dead standing biomass |
| Cut stump (C) | Oil-diluted or undiluted, high-concentration herbicide, high-volume application directed at the cambium of the cut stump surface | Active ingredient 10–100% v/v, penetrant oil adjuvant 0–90% v/v | Flow rate (fl oz/sec), stem circum. (in), target rate: 1–2 fl oz/stump | Chain saw, squirt bottle or small hand-pump sprayer (1 gal), full cone or solid-stream nozzle | Biomass reduced, no non-target injury | Most labor-intensive, physical injury hazard |
| Injection[c] (I) | Water-diluted, high-concentration herbicide, low-volume application directed into the cambium of main stems | Active ingredient 10-100% v/v, water carrier 0–90% v/v | Delivery volume (cc), stem circumference (in), target rate: < 1 fl oz/stem | Hatchet or machete, syringe (1–2 cc) | Effective on large trees, easy calibration, light payload, high use efficiency, simple application, no non-target injury | Custom precision equipment, dead standing biomass |

[a] v/v = volume product/volume total solution [b] Wand speed is how fast you sweep the nozzle, using a front-to-back or side-to-side arm motion. [c] Injection (I) also known as frill, girdle, or hack and squirt. In some cases oil-diluted formulations have been used with effective results.

**Table 2. Effective, non-restricted herbicides for woody arboreal and brush management in Hawai'i**

| Active Ingredient | Max Rate (lbs ae/acre)[a] | Max Conc. (v/v) | Site of Application[b] |
|---|---|---|---|
| **Triclopyr (TCP)** | **9** | **100** | **NC, F, RP, TO, AQ** |
| **Details**: Triclopyr is in the pyridine carboxylic acid family, with a synthetic auxin mode of action leading to abnormal growth, particularly at the apical points, and eventual death. It is a broadleafed and woody plant-selective herbicide with some sensitivity to warm-season grasses, including kikuyu grass (*Pennisetum clandestinum*). It is effective on many legume species. Registered commercial products are available in amine and ester formulations. Amine formulations are best for water-carrier applications (i.e., foliar and cut injection). Ester-based formulations are more compatible with oil carriers in basal bark and cut-surface applications. Drift injury from foliar applications may be more prevalent with the ester formulations due to the higher potential for volatilization. Registered products include Garlon® 3A (amine at 3 lbs ae/gal, EPA reg. no. 62719-37), Garlon® 4 Ultra (ester at 4 lbs ae/gal, EPA reg. no. 62719-527), Remedy® Ultra (ester at 4 lbs ae/gal, EPA reg. no. 62719-70, Renovate 3 (amine at 3 lbs ai/gal, EPA reg no. 62719-37-67690), Element 4 (ester at 4 lbs ae/gal, EPA reg. no. 62719-040). | | | |
| **Glyphosate (GLY)** | **10.6** | **100** | **NC, F, RP, TO, AQ** |
| **Details**: Glyphosate is a glycine amino acid analogue, interrupting EPSP synthase and inhibiting synthesis of aromatic amino acids (i.e., phenylalanine, tryptophan, and tyrosine), leading to a fairly rapid sequence of chlorosis, necrosis, and death. It is a broad-spectrum, non-selective herbicide that is effective on a wide range of species and is particularly effective on grasses. Drift injury to grasses and brush species is a common hazard of foliar over-application. Registered products include Roundup® Pro (3 lbs ae/gal, EPA reg. 524-475), Honcho® (3 lbs ae/gal, EPA reg. no. 524-445), Ranger® Pro (3 lbs ae/gal, EPA reg. no. 524-517), Rodeo (4 lb ae/gal, EPA reg. no. 62719-324), Accord XRT II (4 lb ae/gal, EPA reg. no. 62719-556). | | | |
| **Imazapyr (IMZ)** | **1.5** | **100** | **NC, F, RP, AQ** |
| **Details**: Imazapyr is in the imidazolinone family, interrupting acetolactate synthase and inhibiting branched chain amino acid production (i.e., valine, leucine, and isoleucine), leading to a slow development of necrosis and death. Another classic symptom includes massive proliferation of growing points immediately adjacent to the apical region. Similar to glyphosate, it is a broad-spectrum, non-selective herbicide that is particularly effective on grasses, though not on legumes. There is a strong potential for drift injury resulting from foliar over-application. Unlike GLY, IMZ can exhibit residual soil activity resulting in root uptake by neighboring plants and the suppression of seed bank germination. Aquatic applications can only be made by federal or State government entities or by applicators who are licensed or certified and are making applications under a program sponsored by federal or State government entities. Registered products include Stalker® (2 lbs ae/gal, EPA reg. no. 241-398), Arsenal® (2 lbs ae/gal, EPA reg. no. 241-346), Arsenal® AC (4 lbs ae/gal, EPA reg. no. 241-299), Arsenal® Powerline (2 lbs ae/gal, EPA reg. no. 241-431), Polaris® (2 lbs ae/gal, EPA reg. no. 228-534), Polaris® AC (4 lbs ae/gal, EPA reg. no. 228-570), Habitat® (2 lbs ae/gal, EPA reg. no. 241-426). | | | |
| **Aminopyralid (AMP)** | **0.110** | **10** | **NC, RP** |
| **Details**: Aminopyralid is in the pyridine carboxylic acid family with a synthetic auxin mode of action leading to abnormal growth, particularly at the apical points, and eventual death. It is a broadleaf-selective herbicide with no known efficacy on grasses but is highly effective on legume and aster species. Unlike TCP, AMP can exhibit residual soil activity resulting in root uptake by neighboring plants, and the suppression of seed bank germination. Registered products include Milestone® (2 lbs ae/gal, EPA reg. no. 62719-519). | | | |

[a] ae=acid equivalent, NC=non crop, F=Forestry, RP=Range and Pasture, TO=Turf and Ornamental, AQ=Aquatic

[b] All aquatic pesticide applications in the state of Hawai'i must submit for a notice of intent (NOI) and permit from the Department of Health under jurisdiction of the Clean Water Act.

**Table 3. Effective herbicides and application techniques for selected woody tree and shrub species**

| Name | Method[a] | Herbicide[b] | Concentration[c] | Rate[d] | Notes |
|---|---|---|---|---|---|
| Formosan koa *Acacia confusa* | F | TCP/AMP | 4/0.4% | 2 fl oz/10 ft² | (F) effective on saplings < 6 ft tall; do not exceed 0.11 lbs AMP/acre; GLY (C) does not mix well with oil adjuvant. |
| | B | TCP | 20% | 4 fl oz/10 ft² | |
| | C | GLY | 20% | 4 fl oz/10 ft² | |
| | I | AMP | 10% | 0.5 cc/2 in | |
| Black wattle *Acacia mearnsii* | B | TCP | 20% | 4 fl oz/10 ft² | Do not exceed 0.11 lbs AMP/acre; GLY (C) does not mix well with oil adjuvant. |
| | C | GLY | 20% | 4 fl oz/10 ft² | |
| | I | AMP | 10% | 0.5 cc/2 in | |
| Shoe button ardesia *Ardesia elliptica* | F | GLY | 4% | 2 fl oz/10 ft² | (F) effective on saplings < 6 ft tall. |
| | B | TCP | 20% | 4 fl oz/10 ft² | |
| Bamboo *Bambusa spp.* | F | GLY | 4% | 2 fl oz/10 ft² | Cut stand, treat 3-ft regrowth. |
| | F | IMZ | 0.5% | 2 fl oz/10 ft² | |
| Ironwood *Casuarina equisetifolia* | F | TCP | 4% | 2 fl oz/10 ft² | GLY (C) does not mix well with oil adjuvant. |
| | C | GLY | 100% | 4 fl oz/10 ft² | |
| Padang cassia *Cinnamomum burmannii* | I | TCP | 100% | 0.5 cc/4 in | Method (I) referenced in Motooka et al. 2003. |
| | I | IMZ | 100% | 0.5 cc/4 in | |
| Coffee *Coffea spp.* | F | GLY | 4% | 2 fl oz/10 ft² | (F) effective on saplings < 6 ft tall. |
| Eucalyptus *Eucalyptus spp.* | B | TCP | 20% | 4 fl oz/10 ft² | AMP (I) more effective than TCP. |
| Albizia *Falcataria moluccana* | B | TCP | 20% | 4 fl oz/10 ft² | |
| | C | TCP | 20% | 4 fl oz/10 ft² | |
| | I | TCP | 100% | 0.5 cc/4 in | |
| | I | AMP | 10% | 0.5 cc/2 in | |
| Tropical ash *Fraxinus uhdei* | B | TCP | 20% | 4 fl oz/10 ft² | GLY (C) does not mix well with oil adjuvant; TCP (I) was not effective. |
| | C | GLY | 20% | 4 fl oz/10 ft² | |
| | I | IMZ | 100% | 0.5 cc/4 in | |
| Silky oak *Grevillea robusta* | C | TCP | 20% | 4 fl oz/10 ft² | AMP (I) most effective. |
| | I | TCP | 100% | 0.5 cc/4 in | |
| | I | IMZ | 100% | 0.5 cc/4 in | |
| | I | AMP | 10% | 0.5 cc/2 in | |

[a] Methods (F), (B) and (C) are recommended based on the listed references. Method (I) recommendations are validated by field trials conducted by the authors of this document, unless otherwise indicated in the notes.
[b] For IMZ (B), use Stalker® (EPA reg. no. 241-398).
[c] Concentrations (% v/v) are estimated by the authors to correspond with rates listed in the next column. References may list higher or lower concentrations but do not list the rates of application. The user may adjust these concentrations as needed as long as the amount used does not exceed the recommendation of the label.
[d] The listed rates are for individual target treatments only and would GREATLY EXCEED THE MAXIMUM LABEL RATE with the corresponding concentration if broadcast-applied over the entire acre. THIS WOULD BE A VIOLATION OF THE LABEL. See Table 4 for estimated target treatment densities using these rates.

**Table 3, cont'd. Effective herbicides and application techniques for selected woody tree and shrub species**

| Name | Method[a] | Herbicide[b] | Concentration[c] | Rate[d] | Notes |
|---|---|---|---|---|---|
| Haole koa *Leucaena luecocephala* | F | TCP | 4% | 2 fl oz/10 ft$^2$ | (F) effective on saplings < 6 ft tall. |
| | B | TCP | 20% | 4 fl oz/10 ft$^2$ | |
| | C | TCP | 20% | 4 fl oz/10 ft$^2$ | |
| | I | AMP | 10% | 0.5 cc/2 in | |
| Miconia *Miconia calvescens* | F | TCP | 4% | 2 fl oz/10 ft$^2$ | (F) effective on saplings < 6 ft tall. |
| | B | TCP | 20% | 4 fl oz/10 ft$^2$ | |
| Faya tree *Morella faya* | C | TCP | 20% | 4 fl oz/10 ft$^2$ | GLY (C) does not mix well with oil adjuvant. |
| | C | GLY | 20% | 4 fl oz/10 ft$^2$ | |
| | C | IMZ | 20% | 4 fl oz/10 ft$^2$ | |
| Olive *Olea europaea* | F | TCP | 4% | 2 fl oz/10 ft$^2$ | |
| | C | TCP | 100% | 4 fl oz/10 ft$^2$ | |
| Strawberry guava *Psidium cattleianum* | F | TCP | 4% | 2 fl oz/10 ft$^2$ | (F) effective on saplings < 6 ft tall. |
| | B | TCP | 20% | 4 fl oz/10 ft$^2$ | |
| | C | TCP | 20% | 4 fl oz/10 ft$^2$ | |
| | I | TCP | 100% | 0.5 cc/4 in | |
| | I | AMP | 10% | 0.5 cc/2 in | |
| Poison devil's pepper *Rauvolfia vomitoria* | F | IMZ | 0.5% | 2 fl oz/10 ft$^2$ | (F) effective on saplings < 6 ft tall, IMZ (I) more effective than GLY |
| | I | GLY | 100% | 0.5 cc/4 in | |
| | I | IMZ | 100% | 0.5 cc/4 in | |
| Umbrella octopus tree *Schefflera actinifolia* | I | GLY | 100% | 0.5 cc/4 in | IMZ (I) most effective |
| | I | IMZ | 100% | 0.5 cc/4 in | |
| | I | AMP | 10% | 0.5 cc/2 in | |
| Christmas berry *Schinus terebinthifolius* | F | TCP | 4% | 2 fl oz/10 ft$^2$ | (F) effective on saplings < 6 ft tall. |
| | B | TCP/IMZ | 20/5% | 4 fl oz/10 ft$^2$ | |
| | C | TCP/IMZ | 20/5% | 4 fl oz/10 ft$^2$ | |
| | I | AMP | 10% | 0.5 cc/2 in | |
| African tulip tree *Spathodea campanulata* | B | TCP | 20% | 4 fl oz/10 ft$^2$ | GLY (C) does not mix well with oil adjuvant, TCP (I) was not effective. |
| | C | TCP | 20% | 4 fl oz/10 ft$^2$ | |
| | C | GLY | 20% | 4 fl oz/10 ft$^2$ | |
| | I | IMZ | 100% | 0.5 cc/4 in | |

[a] Methods (F), (B) and (C) are recommended based on the listed references. Method (I) recommendations are validated by field trials conducted by the authors of this document, unless otherwise indicated in the notes.
[b] For IMZ (B), use Stalker® (EPA reg. no. 241-398).
[c] Concentrations (% v/v) are estimated by the authors to correspond with rates listed in the next column. References may list higher or lower concentrations but do not list the rates of application. The user may adjust these concentrations as needed as long as the amount used does not exceed the recommendation of the label.
[d] The listed rates are for individual target treatments only and would GREATLY EXCEED THE MAXIMUM LABEL RATE with the corresponding concentration if broadcast-applied over the entire acre. THIS WOULD BE A VIOLATION OF THE LABEL. See Table 4 for estimated target treatment densities using these rates.

**Table 3, cont'd. Effective herbicides and application techniques for selected woody tree and shrub species**

| Name | Method[a] | Herbicide[b] | Concentration[c] | Rate[d] | Notes |
|---|---|---|---|---|---|
| Java plum *Syzigium cumini* | F | TCP | 4% | 2 fl oz/10 ft² | (F) effective on saplings < 6 ft tall; GLY (C) does not mix well with oil adjuvant. |
| | C | TCP | 20% | 4 fl oz/10 ft² | |
| | C | GLY | 20% | 4 fl oz/10 ft² | |
| | C | IMZ | 20% | 4 fl oz/10 ft² | |
| Rose apple *Syzigium jambos* | B | TCP | 20% | 4 fl oz/10 ft² | GLY (C) does not mix well with oil adjuvant. |
| | C | TCP | 20% | 4 fl oz/10 ft² | |
| | C | GLY | 20% | 4 fl oz/10 ft² | |
| Australian red cedar *Toona cilliata* | I | TCP | 100% | 0.5 cc/4 in | All effective at 100 days after treatment; most effective long-term TBD. |
| | I | IMZ | 100% | 0.5 cc/4 in | |
| | I | AMP | 10% | 0.5 cc/2 in | |
| Gunpowder tree *Trema orientalis* | B | TCP | 20% | 4 fl oz/10 ft² | Method (I) referenced in Motooka et al. 2003. |
| | C | TCP | 20% | 4 fl oz/10 ft² | |
| | C | GLY | 20% | 4 fl oz/10 ft² | |
| | I | TCP | 100% | 0.5 cc/4 in | |
| Gorse *Ulex europaeus* | F | TCP/AMP | 4/0.4% | 2 fl oz/10 ft² | Organo-silicone surfactant; do not exceed 0.11 lbs AMP/acre. |

[a] Methods (F), (B) and (C) are recommended based on the listed references. Method (I) recommendations are validated by field trials conducted by the authors of this document, unless otherwise indicated in the notes.
[b] For IMZ (B), use Stalker® (EPA reg. no. 241-398).
[c] Concentrations (% v/v) are estimated by the authors to correspond with rates listed in the next column. References may list higher or lower concentrations but do not list the rates of application. The user may adjust these concentrations as needed as long as the amount used does not exceed the recommendation of the label.
[d] The listed rates are for individual target treatments only and would GREATLY EXCEED THE MAXIMUM LABEL RATE with the corresponding concentration if broadcast-applied over the entire acre. THIS WOULD BE A VIOLATION OF THE LABEL. See Table 4 for estimated target treatment densities using these rates.

Electronic versions of all pesticide labels registered in Hawai'i may be searched on the CDMS Web site (www.cdms.net) or the Hawai'i Pesticide Information Retrieval System (HPIRS) (http://state.ceris.purdue.edu/doc/hi/statehi.html). These sites also include any Hawai'i Sec 24(c) Special Local Need (SLN) labels.

## Disclaimer

Mention of specific brand names of herbicides does not constitute endorsement of these brands or lack of endorsement of brands not listed on the part of the authors, CTAHR, or the University of Hawai'i. While the information offered here is up to date as of the publication of this bulletin, regulation of herbicide use is undergoing constant change. Always follow label instructions when using any herbicide.

**Table 4. Treated target densities (per acre) with the different methods at the maximum label rates[a] of the respective herbicides**

| (F) 2 fl oz/10 ft² at 4% | Foliar Canopy (ft²) | | | | | |
|---|---|---|---|---|---|---|
| | 10 | 50 | 100 | 200 | 300 | 400 |
| TCP | 3,600 | 720 | 360 | 180 | 120 | 90 |
| GLY | 4,240 | 848 | 424 | 212 | 141 | 106 |
| IMZ | 1,200 | 240 | 120 | 60 | 40 | 30 |
| AMP (0.4%) | 875 | 175 | 87 | 43 | 29 | 22 |
| **(B/C) 4 fl oz/10 ft² at 20%[b]** | **Basal Diameter (inches)** | | | | | |
| | 1 | 5 | 10 | 20 | 30 | 40 |
| TCP | 13,751 | 2,750 | 1,375 | 688 | 458 | 344 |
| GLY[c] | 16,196 | 3,239 | 1,620 | 810 | 540 | 405 |
| IMZ[d] | 4,584 | 917 | 458 | 229 | 153 | 115 |
| AMP (4%)[e] | 1,670 | 336 | 168 | 84 | 56 | 42 |
| **(I) 0.5 cc/4 in at 100%** | **Basal Diameter (inches)** | | | | | |
| | 1 | 5 | 10 | 20 | 30 | 40 |
| TCP | 21,689 | 4,338 | 2,169 | 1,084 | 723 | 542 |
| GLY | 25,545 | 5,109 | 2,554 | 1,277 | 851 | 639 |
| IMZ | 7,230 | 1,446 | 723 | 361 | 241 | 181 |
| AMP (0.5 cc/2 in at 10%) | 2,636 | 527 | 264 | 132 | 88 | 66 |

[a] Refer to the maximum label rates in Table 2.
[b] Assuming 12-inch swath around the circumference (circumference = diameter * π)
[c] Water-based salt formulations do not blend well with oil carriers and need to be agitated regularly.
[d] Stalker® recommended for better blending with oil carrier.
[e] A registered use pattern according to the Milestone® label; authors do not currently have efficacy data with AMP as a basal application.

## Acknowledgements

This publication was sponsored in part by the USDA-CSREES Tropical Subtropical Agriculture Research Program. The authors would also like to thank JB Friday and Linda Cox (UH-CTAHR), Ian Cole (DLNR-DOFAW Natural Area Reserve Program), Hank Oppenheimer (DLNR-DOFAW Plant Extinction Prevention Program), Adam Radford (Maui Invasive Species Committee), Michael Constantinides (USDA-NRCS), Pat Bily (Hawaii TNC), and Vanelle Peterson (Dow Agrosciences LLC) for their thoughtful reviews of and comments on this document.

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## Part I - Funding Request for operation of University of Hawaii Tree Snail Conservation Lab, to the Oahu Army Natural Resources Program

**Date:** September 1, 2012 – August 31, 2013

**Address:** 337 Henke Hall

**Telephone:** (808) 956-6176

**Project Name:** *Captive Propagation of Endangered Tree Snails Operating Costs*

**Location:** Center for Conservation Research & Training, University of Hawaii

**Principal Investigator:** Dr. Brenden Holland (bholland@hawaii.edu)

**Amount Requested** $81,042.00

### Introduction, recent accomplishments, thoughts on future direction

On two days in February of 2012, OANRP, UH and USFWS personnel carried 340 (215 juvenile, 72 subadult, and 53 adult) endangered *Achatinella mustelina* tree snails from the UH Tree Snail Conservation Lab, and released them into the recently completed, state of the art snail enclosure in the Waianae Mountains of Oahu. This was an important event, as it was the first tree snail release in the history of this long-term collaborative program, and the successful culmination of multiple years of planning, hard work and meetings, which we hope represents the beginning of a new direction for efforts to save the Oahu tree snails from extinction. A second enclosure was recently finished in the southern Waianaes, and construction and planning of a third structure are ongoing for the Koolau Mountains, where *Achatinella lila,* the most abundant endangered snail in the UH Tree Snail Conservation Lab, will eventually be released.

On April 12, 2012 OANRP, USFWS and UH Tree Snail Conservation Lab personnel staff met at Kewalo Marine Lab primarily to discuss the evolving role of the UH lab in conservation efforts moving forward into the future. During the meeting we discussed the idea of rotating snails through the lab for limited periods of time, for example six months to one year, then releasing them and their offspring back into the wild. There was consensus at the meeting that this could be a good way to safeguard snails, as well as to increase the number of snails in the wild, based on excellent survival and the tendency of adult snails to reproduce in the early phase of time in captivity, especially for the first year. The rotation program will be conducted only in areas where predator control efforts have been implemented. Another major point of discussion focused on the Puu Hapapa release, including the performance of the enclosure structure in restricting access by key predators. In summary, shells representing 6% of

the released snails have been collected since the release. This indicates an extremely low inferred mortality rate, therefore the release has been deemed a success. Thus we see an increasing role of enclosure structures, plus targeted predator control with rotation through the UH lab to ensure to continued existence of the Hawaiian tree snails.

**Lab staffing, logistics and current status of captive endangered tree snail populations**

As of our latest count, we are caring for 837 Hawaiian tree snails. We have 13 species, 9 of which are endangered, the majority of which are members of the genus *Achatinella*, from Oahu, and are Federally endangered according to the USFWS Endangered Species Act. At current tree snail population levels, we are operating 5 environmental chambers, and culturing 76 potato dextrose agar plates of tree fungus per week. In addition either two or three personnel per week go hiking on Oahu trails for leaf collection. We currently have a crew of 8 technicians involved with care and maintenance of the captive tree snails.

**Figure 1.L-R:** *Achatinella livida* in petri plate, snail cages showing irrigation system, and environmental chambers.

**Budget description**

For this upcoming fiscal year's operating cost request, we have quantified tree snail care and maintenance activities into time estimates. Since the care and maintenance of endangered species requires a variety of different daily and weekly activities, we have factored in all of the relevant tasks from the Tree Snail Care Protocol, including: weekly cage changing, cleaning, counting and measuring new-born snails, recording births and deaths, cataloging, measuring and preserving the dead specimens as well as total number of live snails per cage, together with weekly leaf collecting hikes,

and preparation of Petri plates and growth medium, plus fungus culture, currently at 76 plates per week, and includes autoclaving potato dextrose agarose growth medium and sterilizing Petri plates. We also maintain and clean environmental chambers, including replacement of full spectrum fluorescent bulbs and ballast, de-icing heat exchangers, regularly clearing Tygon drain tubes, and scrubbing algal growth from cage trays.

Overall, for cages with less than 10 snails, we estimate effort invested at 2 hours per week, while cages of 10 snails or more require 3 hours per week. Maximum number of snails per cage is 50. Our staff consist of biologists and technicians with a range of experience, and accordingly are paid a range of different wages. In order to place a single value per hour, we have therefore used a dollar value intermediate between the senior and junior level personnel, at $17 per hour. We estimated the number of hours per week per cage, then present the annual cost per cage, again only for snails that occur on Army or Army-managed land. We present here the budget request in table form, consisting of 4 separate tables including: Table 1 - Historic Maintenance, Table 2 – Outgoing, Table 3 Incoming, Table 4 – Summary of Labor Costs.

## Table 1 - Historic Maintenance

| Species | Cage/ Population | Snails per cage | Hours per week | Annual cost |
|---|---|---|---|---|
| ***A. apexfulva*** | Poamoho | 1 | 2 | $1,768.00 |
| ***A. bulimoides*** | Poamoho | 8 | 2 | $1,768.00 |
| ***A. lila*** | Control 1 | 47 | 3 | $2,652.00 |
| | Control 2 | 38 | 3 | $2,652.00 |
| | Control 3 | 49 | 3 | $2,652.00 |
| | Cuttlebone 1 | 49 | 3 | $2,652.00 |
| | Cuttlebone 2 | 48 | 3 | $2,652.00 |
| | Cuttlebone 3 | 37 | 3 | $2,652.00 |
| | CaCO3 1 | 44 | 3 | $2,652.00 |
| | CaCO3 2 | 41 | 3 | $2,652.00 |
| | CaCO3 3 | 44 | 3 | $2,652.00 |
| | Population 1 and Cage 2 | 39 | 3 | $2,652.00 |
| ***A. livida*** | Cage 1 | 26 | 3 | $2,652.00 |
| | Cage 2 (East of Radio) | 21 | 3 | $2,652.00 |
| ***A. mustelina*** | Alaiheihe and Palikea Gulches | 16 | 3 | $2,652.00 |
| **TOTALS** | | **508** | **43** | **$38,012.00** |

**Table 2 - Outgoing**

| Species | Cage/Population | Snails per cage | Hours per week | Annual cost |
|---|---|---|---|---|
| *A. decipiens* | Cage A | 2 | 0 | $0.00 |
| *A. mustelina* | Recombined (up to 10 snails) | 1 | 2 | $1,768.00 |
| | 10,000 Snails | 11 | 0 | $0.00 |
| | Palikea Lunch | 5 | 0 | $0.00 |
| | Ekahanui Honouliuli | 7 | 0 | $0.00 |
| | Makaha | 4 | 0 | $0.00 |
| | Ohikilolo Makai and Mauka | 4 | 0 | $0.00 |
| | Schofield West | 10 | 0 | $0.00 |
| | South Range | 10 | 3 | $2,652.00 |
| | Kaala S-ridge | 1 | 0 | $0.00 |
| *A. sowerbyana* | Peahinaia | 1 | 0 | $0.00 |
| **TOTALS** | | **56** | **4** | **$4,420.00** |

**Table 3 - Incoming**

| Species | Cage/Population | Snails per cage | Hours per week | Annual cost |
|---|---|---|---|---|
| *A. decipiens* | North Kaukonahua | 10 | 3 | $2,652.00 |
| *A. mustelina* | Kahanahaiki | 90 | 6 | $5,304.00 |
| | Puu Palikea | 10 | 3 | $2,652.00 |
| | Ekahanui Honouliuli | 10 | 3 | $2,652.00 |
| | Makaha | 10 | 3 | $2,652.00 |
| | East Makaleha | 10 | 3 | $2,652.00 |
| | Schofield West | 10 | 3 | $2,652.00 |
| *A. sowerbyana* | Upper Opaeula | 10 | 3 | $2,652.00 |
| **TOTALS** | | **150** | **24** | **$21,216.00** |

**Table 4 - Summary of labor costs**

| Status | Snails per cage | Hours per week | Annual cost |
|---|---|---|---|
| Outgoing | 56 | 4 | $4,420.00 |
| Historic | 508 | 43 | $38,012.00 |
| Incoming | 101 | 24 | $21,216.00 |
| **TOTAL** | **665** | **71** | **$63,648.00** |

Care and Maintenance
Labor Subtotal ……..……..$63,648.00
UH Fringe (0.47%)……...$299.15

Required lab supplies, reagents

Petri plates, ethanol, replacement cages, screens, fungus culture medium, antibacterial detergent, trash bags, (for leaf collection/storage), chamber maintenance:……..……..$4,380.00

Overhead (17.5% indirect):…….$11,957.25

**TOTAL**

**COSTS:……$80,284.00**

## Appendix 3-2

**Vegetation Restoration Approaches and Site Considerations**

A great deal of vegetation was altered during construction of the predator proof fence at Hapapa. Numerous giant *S. terebinthifolius* were felled or heavily trimmed to make a corridor for the fence. Subsequently, there are large gaps in habitat suitable for snails within the enclosure. In order to restore high levels of vegetation cover, and enhance and maintain appropriate snail habitat, restoration will involve two methods: weeding and re-vegetation.

Formal access trails should be established to keep traffic out of seed sow areas and areas of natural recruitment, off of tree roots, and out of reintroduction areas. Traffic around snail reintroduction zones should also be limited in order to prevent harm to host trees and to any snails that may have fallen to the ground.

All gear, plants, and vegetation coming and going into the enclosure should be inspected for *E. rosea*.

***Weeding:***

There are currently no non-native canopy weeds within the enclosure; all were removed during fence clearing and preparation efforts for snail re-introductions. Also, almost all non-native understory vegetation was removed at one point after fence completion in order to eliminate habitat for remaining *E. rosea*, and to aid search efforts for this predator. As these weeds return, there should be a low tolerance for the suite of ecosystem altering weeds that occur throughout the greater Hapapa Bench area. In some dry, open areas with no understory cover, staff may consider leaving sun-loving aster species, as they may provide some cover and slope stabilization until *P. albidus* recruits or outplants create canopy in these areas. There should be a zero tolerance for the following species: *Blecchnum appendiculatum,*and *Nephrolepis multiflora* as these are significant understory altering weeds easily managed in a small area such as the snail enclosure. *Passiflora suberosa*, a fast-growing climbing vine, should also be heavily managed in the enclosure.

***Re-vegetation:***

While passive recruitment of native species is expected within the enclosure, re-vegetation with common native plants will be necessary to more promptly restore the integrity of the native forest within the enclosure. Propagation methods will take place both in the field and at the OANRP nursery and are as follows: 1) nursery outplants grown from seed and cuttings, 2)seed sowing, and 3)transplanting.

Re-vegetation can begin immediately, and much has already been done in the last year. Priority areas include open areas with bare dirt and low levels of canopy cover, and areas adjacent to or within known snail 'hotspots' to enhance vegetation structure and to create corridors between gaps in appropriate snail habitat. Secondarily, re-vegetation will take place in the buffer around the outside of the exclosure to keep canopy light levels down, moisture levels up, and to suppress nearby weed sources.

While it is difficult to know exactly how far away or how close founder stock should be collected for this restoration site to account for local adaptation and inbreeding depression respectively for each species, using material collected evenly from numerous founders throughout the Hapapa Bench area or throughout the Palikea seems a comfortable approach for dealing with these considerations. In some cases where seeds can be stored, re-collection can be eliminated as stock can be drawn from stored collections and used for future projects.

The following serves as a general guideline for how propagation techniques will be used and monitored.

**1) Outplanting of greenhouse produced plants:**

Plants grown in the greenhouse will be the largest source of plants for re-vegetation for the Hapapa enclosure. Growing the amount of plants desired is more reliable in the greenhouse than with field propagation techniques because the greenhouse is a highly controlled environment with staff available to make adjustments based on the needs of the plants. Plants will be grown from cuttings and from sown seed. As previously mentioned, collections of these sources should be made from across the MU, or at the very least, from many founders across the 'Bench'. Cuttings should be cleaned and prepared in the field as much as possible to prevent greenhouse contamination. Because there is a limitation on space in the OANRP nursery, and because it is important to get plants in the field as soon as possible, plants will be outplanted as quickly and as small as can produce healthy plants. There will be tight timelines on growing plants so that propagation of the next set of plants can begin. See the restoration action plan for outplanting timeline details.

Out-plantings should occur from October through March with the exception of trials conducted in the summer. Out-plants will require follow-up water depending on weather conditions. Plants should be checked no later than two weeks after the date of planting for water stress. Follow-up watering will be conducted as needed. Trials will also be conducted on out-plants to determine if Polymer products can reduce the amount of follow-up watering needed, and to determine if polymers can allow for common native plantings in the summer months. If it is suspected that plants could benefit from fertilizer in the field, trials may also be conducted to see if fertilizing is worthwhile.

As with all OANRP rare plant reintroductions, strict sanitation protocols will be followed to avoid the introduction of greenhouse pests to the enclosure. Plants will be inspected and treated for pests before outplanting.

*Monitoring:* All out-plants will be numbered, and will be monitored for vigor every 6 months for one year (beginning 3 months after date of planting) and annually thereafter until 3 years after planting date. A subset of some plants may be tracked with additional measurements for longer.

2) **Seed sowing**: Sowing can be done at start of the wet season and also opportunistically for longer lived seeds. Seed sowing can require minimal effort in the case of seeds such as *B. torta* which can be hand broadcast in open areas, but digging shallow holes or depressions to lightly bury seeds or fruits may be required for other species. Seed-sow areas should be flagged off to reduce trampling.

   Seeds may or may not need pre-processing before sowing. The Propagule Management Specialist can advise on seed processing needs. Trials should be done to determine best seed sowing practices for species where that information is not yet known. Trials have already been conducted with *B. torta* and seed sows are an effective method of establishing this plant on site. An ongoing list of techniques will be developed to inform future projects. Determination of best practices will consider germination success, overall vigor of plants, and effort required.

   *Monitoring:* A basic seed-sowing log of what, how much, techniques, where was sown, etc. will be kept ongoing as long as seed sows take place within the enclosure. Some of the more novel techniques and seeds used may be tracked and trialed more closely while others where sowing methodology is already known will only need pin-flags to mark off seeded areas.

3) **Transplanting**: Transplanting consists of digging up small plants from adjacent areas and planting them in the enclosure. Transplanting seedling and saplings from under mother trees is a larger tax on the ecosystem than is fruit/seed collection, and survivorship without significant care in the field may be lower than greenhouse outplanted plants. Therefore, transplanting should be done with species difficult to collect fruit from, difficult or slow to grow in the greenhouse, or from plants where it is relatively easy to take divisions from. This technique can also be used for more uncommon species where only a few individuals are needed to complete the suite of diversity within the exclosure.

A great deal of effort should be given to keeping roots intact, and in some cases it may be easier to collect clusters of small plants as opposed to teasing out individuals. Transplants should be watered as much as possible for the first few months (depending on rain), and should not be planted in open areas prone to drying out. There was reasonably good success with transplants for certain species that have already taken place in the Hapapa enclosure. Most of these plants were watered several times a week for the first couple of months. If this level of attention cannot be committed to, transplanting may not be the best option. Size may also play an important role in the success of transplantings, and it is recommended that transplant size be limited to less than 20cm. For some viney species, there may be exceptions to this recommendation. Fertilizer may also help the effects of 'transplant' shock; greenhouse staff can advise on the most appropriate fertilizers.

***Inspection of all transplanted material is critical to prevent Euglandina or other invasive species from being introduced to the enclosure.***

*Monitoring:* All transplants will be numbered, and will be monitored for vigor every 6 months for one year (beginning 3 months after date of planting) and annually thereafter until 3 years after planting date.

**PLANTS FOR HAPAPA RESTORATION (Bold indicates species in larger quantities)**

| **Plant Taxa** | **Understory** | **Canopy** | **Propagation Technique** | | | |
|---|---|---|---|---|---|---|
| | | | Field | | Greenhouse | |
| | | | Seed sowing | Transplanting | Nursery propagule from seed | Nursery propagule from cutting |
| *Acacia koa** | | X | | | X | |
| ***Antidesma platyphyllum*** | | X | | | X** | X |
| ***Bidens torta**** | X | | X | | | |
| *Carex wahuensis* | X | | X** | | | |
| ***Dianella sandwicensis**** | X | | X** | X** (divisions) | | |
| ***Freycinetia arborea*** | X | | | X** | X | |
| *Kadua cordata* subsp. *cordata* (*H. schlechtendahliana*) | X | | X** | X | X | |
| *Labordia kaalae* | | X | X** | | X | |
| *Microlepia strigosa* | X | | | X | | X (in vitro) |
| ***Myrsine lessertiana*** | | X | | | X | |
| | | | | | | |
| ***Perrottetia sandwicensis*** | | X | | | | X |
| ***Pipturus albidus**** | | X | X | | | |
| ***Pisonia umbellifera*** | | X | X | | | |
| ***Planchonella sandwicensis* (*Pouteria sandwicensis*)** | | X | | X | X | |
| ***Psychotria hathewayi*** | | X | | | X | |
| ***Urera glabra**** | | X | | | | X |
| ***Urera kaalae**** | | X | | | X | |

*fast growing species (relative to others on list)
**trials needed for this technique

**Restoration Action Plan:**

Completed re-vegetation actions since construction of Hapapa enclosure to date:

- Out-planted: 39 *U. kaalae,* 2 *U. glabra,* 15 *L. kaalae,* 4, and *C. membranacea*
- Transplanted the following species (more trials needed with most of these to determine species that have highest rates of transplant success): *M. lessertiana, L. kaalae, Pouteria sandwicensis, Claoxylon. sandwicense Pisonia. brunoniana, C. membranacea, K. cordata* subsp. *cordata, D. sandwisensis, P. forbesii.*

- Conducted various seed sow trials: *M. lessertiana, F. arborea, U. kaalae, P. albidus, U. glabra,*

YEAR 1 (July 2012-June 2013):
The emphasis in this first year of out-plantings focuses on snail host trees to enhance known snail habitats and connect these habitats where possible. Seed sows in the most open areas with *P. albidus* and *B. torta* have successfully established plants that are expected to fill in overstory and understory cover respectively in these areas, eliminating the need to grow these types of plants in the greenhouse. These seed sows will continue through Year 1.

Numbers of plants desired are goals set for the entire year. Given the differences in growth rates among the species listed below and due to possible greenhouse space limitations, there may be several waves of planting to achieve these goals. These numbers are not limiting, and if more plants can be grown, they will be.

Re-vegetation actions:

- Collect seed for greenhouse propagation and storage:

| **Species** | **# Plants Desired for Year 1** | **Comments** |
|---|---|---|
| *A. koa* | 25 | Dibble pots |
| *F. arborea* | 50* | 2" pots |
| *L. kaalae* | 50 | 2" pots |
| *M. lessertiana* | 100* | 4" pots |
| *Planchonella sandwicensis* | 25 | 2" pots |
| *P. hathewayi* | 50 | 2" pots |

* Propagation in Year 1 for Year 2 out-planting

- Collect cuttings to use for greenhouse propagation:

| **Species** | **# Plants Desired** | **Comments** |
|---|---|---|
| *U. glabra* | 50 | Collect enough cuttings to grow 50 individuals. |
| *Perrottetia sandwicensis* | 50 | Collect enough cuttings to grow 50 individuals. |
| *Antidesma platyphyllum* | 25 | Collect enough cuttings to grow 50 individuals. |

- Outplant:

| **Species** | **Comments** |
|---|---|
| *A. koa* | Plant 25 in Year 1 |
| *L. kaalae* | Plant 50 in Year 1 |
| *Planchonella sandwicensis* | Plant 50 in Year 1 |
| *Pouteria sandwicensis* | Plant 50 in Year 1 |
| *P. hathewayi* | Plant 25 in Year 1 |
| *U. glabra* | Plant 50 in Year 1 |

- Seed sows
  - Continue *B. torta* seed sows opportunistically in open areas throughout enclosure
  - Conduct seed sow trials with the following species: *P. albidus* (anecdotally is an effective method, but would like more detailed information about best practices), *Carex wahuensis*¸ and *D. sandwicensis.*
  - Monitor ongoing seed sow trials with the following species: *M. lessertiana, P. brunoniana, F. arborea.*

- Transplants
  - Conduct more transplant trials with: *D. sandwicensis, Kadua cordata* subsp. *cordata, P. sandwicensis, M. strigosa*
  - Monitor existing transplants

# Captive-release of the Oahu tree snail, *Achatinella mustelina*, into a Waianae Mountain snail enclosure and post-release shell monitoring

A preliminary draft prepared by D. M. Sether, Ph.D., Recovery Program Invertebrate Biologist, for internal review by the Pacific Islands Fish and Wildlife Tree Snail working group, April 9, 2012.

## EXECUTIVE SUMMARY

Between February and May, 2010, 202 individual *Achatinella mustelina* from Puu Hapapa, in the Waianae Mountain Range of Oahu, Hawaii were collected by the Oahu Army Natural Resource Program (OANRP) with approval of the U.S. Fish and Wildlife Service and placed in the University of Hawai`i, Hawaiian Tree Snail Program, Captive Propagation laboratory (UH Lab) in order to protect them from the severe *E. rosea* predation that was occurring at Puu Hapapa in the Waianae Mountain range, Oahu, Hawaii. The snails reproduced in the lab, and the surviving population was released in February 2012, in a snail enclosure built at Puu Hapapa. The first release on February 8, 2012, was 171 *A. mustelina* snails comprised of 109 juveniles, 9 sub-adults, and 53 adults. The second release on February 21, 2012, was 169 snails, comprised of 106 juveniles and 63 sub-adults Size of captive-released snails ranged from 5 mm to slightly over 20 mm. Shells from newly deceased *A. mustelina* were collected from the ground of the release sites at approximately weekly intervals for 8 weeks. It has not been determined if the recovered shells in the sub-adult and juvenile size classes are from the captive-released snails, because they were not marked prior to release. For the purposes of this report, the recovered shells are putatively treated as if they are from the captive release. To date, mean overall mortality based on recovered shells and total number released is ≈ 6%. Within age classes, juveniles have the highest mortality at 9% (19/215) followed by adults 4% (2/53) and sub-adults 1% (1/72). The greatest numbers of shells recovered have been in the 6.0-7.9 mm and 8.0-9.9 size classes. Shell recovery on April 2, 2012, the most recent collection date, suggests mortality is continuing to occur. It has not been ascertained if the recovered shells in the sub-adult and juvenile size classes are from the captive-released snails, because they were not marked prior to release. Two predaceous rosy wolf snails, *Euglandina rosea*, 14 mm in length, and one, 18 mm in length, were found inside the enclosure area during shell monitoring on February 21 and April 2, respectively. A Jackson chameleon, *Triceros jacksonii jacksonii*, 10 cm long, was found February 27. These predators were removed from the enclosure.

## INTRODUCTION

Oahu tree snails, Pūpū kani oe, (*Achatinella spp*.) are endemic to the island of Oahu, Hawaii. The shells were highly prized for their beauty and used historically utilized in lei making. Of the 41 species of *Achatinella* now listed as endangered species, only 11 can be found. The remaining populations are restricted to native forests above 1970 ft elevation. The most

important threats to the persistence of Oahu tree snails are introduced predators which include the rosy wolf snail, *Euglandina rosea*, Jackson chameleon, *Triceros jacksonii jacksonii*, and flatworm, *Platydemus manokwari.* Between February and May, 2010, 202 individual *Achatinella mustelina* from Puu Hapapa were collected and placed in the University of Hawai`i, Hawaiian Tree Snail Program, Captive Propagation laboratory (UH Lab) in order to protect them from the severe *E. rosea* predation that was occurring at Puu Hapapa in the Waianae Mountain range, Oahu, Hawaii. This action was undertaken by the Oahu Army Natural Resource Program (OANRP) with approval of the U.S. Fish and Wildlife Service (Service). The snails reproduced in the lab, and the resulting population was released in a snail enclosure built at Puu Hapapa in the Waianae Mountain range and maintained by the Oahu Army Natural Resource Program in February, 2012. This preliminary report presents the results of post-release monitoring for *A. mustlina* shells.

**METHODS AND MATERIALS**

A tree snail enclosure, or predator-exclosure, approximately one-quarter acre in size, was erected on Puu Hapapa, elevation ≈2670 ft in the Waianae Mountains, Oahu. The perimeter is comprised of Predator Proof® fencing and is equipped with various anti-predator barriers on the exterior to prevent ingress of predators into the enclosure (**Fig. 1 A**). These barriers include a continuous below grade barrier and concrete skirt to protect against burrowing predators (**Fig. 1 B**). An additional continuous panel of metal is attached to the fence and is bent outward and downward to present an additional angular physical barrier to organisms crawling up the wall (**Fig. 1 A**). Above this, plastic 2 X 4's are mounted on the wall approximately 18 inches above grade (**Fig 1 A-E**). The 2 x 4's are equipped with a redundant, non-lethal electrical barrier on the outside face parallel to the wall and a copper mesh on the underside (**Fig. 1 C-E**). The redundant electrical barrier consists of two sets of a ground wire and wire receiving current from solar and battery sources. This barrier is a deterrent and is non-lethal to snails. This barrier is lethal to earthworms and flatworms (**Fig. 1 C-D**). The copper mesh is mounted perpendicular to the fence wall and is attached to the bottom of the 2 X 4. The outer most edge of the mesh is bent at a 90° downward angle to provide an additional barrier to crawling organisms (**Fig 1 E**). At the top of the fence, another electrical barrier that runs on continuous current from a battery provides a deterrent against chameleons and other predators (**Fig. 1 F**). Current interruption of the electrical barrier system is communicated through electronic email to designated OANRP personnel.

Plant material inside the enclosure includes endemic *Pisonia* sp*. Piptoris* sp. (mamaki)*, Ladonia* sp., *Ilex* sp., and *Urera* sp., and *Bidens* sp. (**Fig. 2**). Stumps and rocks have been removed from inside the enclosure to facilitate locating predators, such as *Euglandina* snails and Jackson chameleon from the enclosure. Leaf and stem debris are removed after each *A. mustelina* shell survey. Cardboard sheets (**Fig. 2 B yellow arrow**) dampened with water are placed on the

ground throughout the exclosure by Oahu Army Natural Resources Program (OANRP) personnel to provide humid areas to attract slugs and predaceous snails.

Two rectangular blocks (1 and 2) containing *Pisonia* sp. and mamaki trees, were selected and flagged within the enclosure. Block 1 was divided into six quadrants each 13 x 16 ft, and block 2 was divided into nine quadrants, each 16 x 16 ft. These blocks were the release areas for the lab-reared snails and also delineated the areas to be searched, post-release, for recently deposited (deceased) *A. mustelina* shells and other shells present on the ground.

Two captive-snail releases were made inside the predator exclosure (**Figs. 3 and 4**). Prior to release, captive adult snails greater than 12 mm in length were marked with a blue dot at the spire end (**Fig. 3 D, E**). Captive reared snails were acclimatized in the laboratory and transported on fresh *Pisonia* leaves to the snail enclosure at Puu Hapapa in a cooler. The snails were gently transferred to 12 vinyl mesh baskets containing leaves and stems (**Fig 3**). The baskets were tied in shaded locations to branches of *Pisonia* trees with blue flagging tape around 3:00 P.M. of each release day. Branches with leaves were placed vertically in the baskets to provide a bridge in case the snails did not choose to crawl up the vinyl mesh. The snails were allowed to move out of the baskets on their own for the first 48 hours following basket placement. After that, snails that remained were gently relocated to a leaf on a *Pisonia* tree. The first release on February 8, 2012, was 171 *A. mustelina* snails comprised of 109 juveniles, 9 sub-adults, and 53 adults. The second release on February 21, 2012, was 169 snails, comprised of 106 juveniles and 63 sub-adults The size of captive-released snails varied from 5 mm up to greater than 20 mm (**Fig. 4 B-E**). In addition to the captive-released tree snails, the enclosure includes *A. mustelina* that were present on the existing trees prior and during construction and additional snails that have been translocated into the enclosure from the surrounding area. *Ariculella* sp. are also present in the enclosure.

Monitoring for ongoing *A. mustelina* mortality was conducted by biologists thoroughly searching each quadrant on hands and knees for a maximum of 30 minutes per quadrant. Old and new shells were collected, measured with calipers, and categorized as new *A. mustelina*, old, *A. mustelina*, *Ariculella*-like, *Laminella*-like, and *Philonesia*-like. *A. mustelina* shells that appeared new were given a water test prior to placing in collection vial. This test consisted of placing the shell, aperture side down, into the cap of a vial containing approximately 2-3 mm of water (**Fig. 4E**). A foot would emerge from the aperture within 10 minutes if the snail was alive. Live snails were returned to Pisonia trees (**Fig 4 D**), then rechecked in two hours. During the measuring process, the *A. mustelina* shells were soaked in water and the inside scraped with a dental probe to monitor for the presence of tissue. Odor was also used to gauge presence of tissue.

**RESULTS AND DISCUSSION**

The shells of juvenile *Achatinella mustelina* snails comprised the highest percentage of total new shells recovered during the seven monitoring trips (**Table**). Treating the number of *A. mustelina* shells recovered as a percentage of total captive-released snails over time in the two release blocks, suggests that mortality is still occurring (**Fig. 5** ). However, these results may be overestimating the mortality rate of the captive released snails because the origin of the juvenile and sub-adult shells recovered has not been ascertained. The shells may have been from captive-released or from wild-type snails also present in the enclosure. It should also be noted that the results could underestimate mortality if snails have been consumed by Euglandina predaceous snails or Jackson chameleons which can dissolve the shell. Shells may also be retained in the canopy or blown or washed out of the monitoring blocks. The later possibility has been addressed with searches around the periphery of the blocks and in water furrows that may have carried shells outside of the blocks. Expanded searches have been particularly important following high rainfall. The presence of rats has been monitored by chew tabs and traps and signs of rat predation on shells. No rat presence has been detected during the course of the monitoring. Unboxed snap traps were removed until boxes over the traps could be put into place. A greater percentage of the small shell size classes (6.0-7.9 mm and 8.0-9.9 mm) were recovered from the first release block (11%) than the second release block (4%), though number of juveniles released in each block was similar (109 and 106) (**Fig. 6**). Adults were released only in block 1. Two marked adults were found in this block. One of these adult snails was found dead in the release basket.

During monitoring, old *A. mustelina*, *Ariculella*-like, *Laminella*-like, and *Philonesia*-like shells were also collected and measured, and counted. Shells in the *Ariculella*-like group were collected in the highest numbers, totaling more than 3,000 in number. The trends for the other shell groups collected, show that recovery was decreasing with each collection and debris removal period (**Fig. 7**). The increase observed during the April 2 collection period may be explained by the two-week accumulation and though surveyor influence cannot be ruled out.

Two, *Euglandina rosea*, rosy wolf snail, 14 mm in length, and one, 18 mm in length were found inside the enclosure area during shell monitoring on February 21 and April 2, respectively. A Jackson chameleon, *Triceros jacksonii jacksonii*, 10 cm long, was found February 27. These predators were removed from the enclosure.

**OTHER ISSUES**

The redundant electrical barrier lines are exhibiting corrosion where stapled to the 2 x 4's, possibly a sign of electrolysis. OANRP personnel are looking into alternative materials (stainless or copper) which each have advantages and disadvantages.

A recurrent issue will likely be the presence of flatworms and earthworms becoming stuck to the electrical barrier and requiring removal. It may only be a problem during high rainfall periods. The presence of flatworms, which can and do follow tree snail trails up a tree if a film of moisture is present, could be an issue if established inside the enclosure or if they gain entry. The redundant electrical barriers appear to provide an adequate barrier to entry into the enclosure. But the redundancy should also be echoed in power source and not have both sets being feed by the same battery or source, should an outage occur.

Power outages, regardless of cause, will provide opportunities for predator ingress if not monitored and fixed rapidly. Removal of foliage to prevent shorts, solar back-ups to batteries, and the addition of a monitoring and email notification system for interruption of electrical current help reduce the vulnerabilities of the enclosure to electrical problems. Redundancy of power source is recommended.

**ACHKNOWLEDGEMENTS**

The assistance provided by shell monitoring volunteers from PIFWO has been greatly appreciated. Volunteers to date are: Fred Amidon, Ian Bordenave, Vickie Caraway, James Kwon, Christine Ogura, Dan and Hunter Polhemus, Cheryl Phillipson, and Rachel Rounds.


**Figure 1.** (**A,B)** Predator-Proof® wall of the predator exclosure with angular physical barrier, plastic 2 X 4 with various barriers, and concrete skirt; **(C, D)** Redundant non-lethal electrical barrier mounted on 2 X 4; **(E)** Copper mesh under the 2 X 4; (F) Electrical barrier on top of exclosure wall


**Figure 2.** Images of release block 1 **(A-D)** and 2 **(E-H)**. Predominant plant composition in the exclosure incluldes *Pysonia* sp*. Piptoris* sp. (mamaki)*, Ladonia* sp., *Ilex* sp. , and *Urera* sp. Yellow arrow points to dampened cardboard used to create humid areas.


**Figure 3. (A-H)** Vinyl mesh release baskets placed in mamaki and *Pisonia* trees; **(D,E)** Snails over 10 mm were marked with a blue dot at the spire tip; **(H)** Snail that preferred the blue flagging tape. Snail was eventually moved to a *Pisonia* leaf.


**Figure 4. (A)**Signage at Puu Hapapa; **(B**) Sizes of captive reared *Achatinella mustelina* snails to be released; **(C**) Marked adult *A. mustelina* snail on a mamaki leaf; **(D)** Live *A. mustelina* released after passing water test; **(E)** Shell being evaluated for life in a water test after being found on ground. If alive, the snails foot will emerge from the aperture. **(F)** *Ariculella* snail that joined an *A. mustelina* on the same plant. It's a party.

**Table.** Number of captive tree snails, *Achantinella mustelina*, released in each monitoring block, and the number and percentage of shells recovered in each age class. *Unknown if shells recovered are derived from captive release snails that were too small to mark at time of release.

| Age | Block | No. released | Shells recovered [No. (%)] |
|---|---|---|---|
| Juveniles | 1 | 109 | 12 (11%)* |
| Sub-adults | 1 | 9 | 0 (0%)* |
| Adults | 1 | 53 | 2 (4%) |
| All | 1 | 171 | 14 (8%)* |
| Juveniles | 2 | 106 | 7 (7%)* |
| Sub-adults | 2 | 63 | 1 (2%)* |
| Adults | 2 | 0 | 0 (0%) |
| All | 2 | 169 | 8 (5%)* |
| Juveniles | 1 & 2 | 215 | 19 (9%)* |
| Sub-adults | 1 & 2 | 72 | 1 (1%)* |
| Adults | 1 & 2 | 53 | 2 (4%) |
| All | 1 & 2 | 340 | 22 (6%)* |

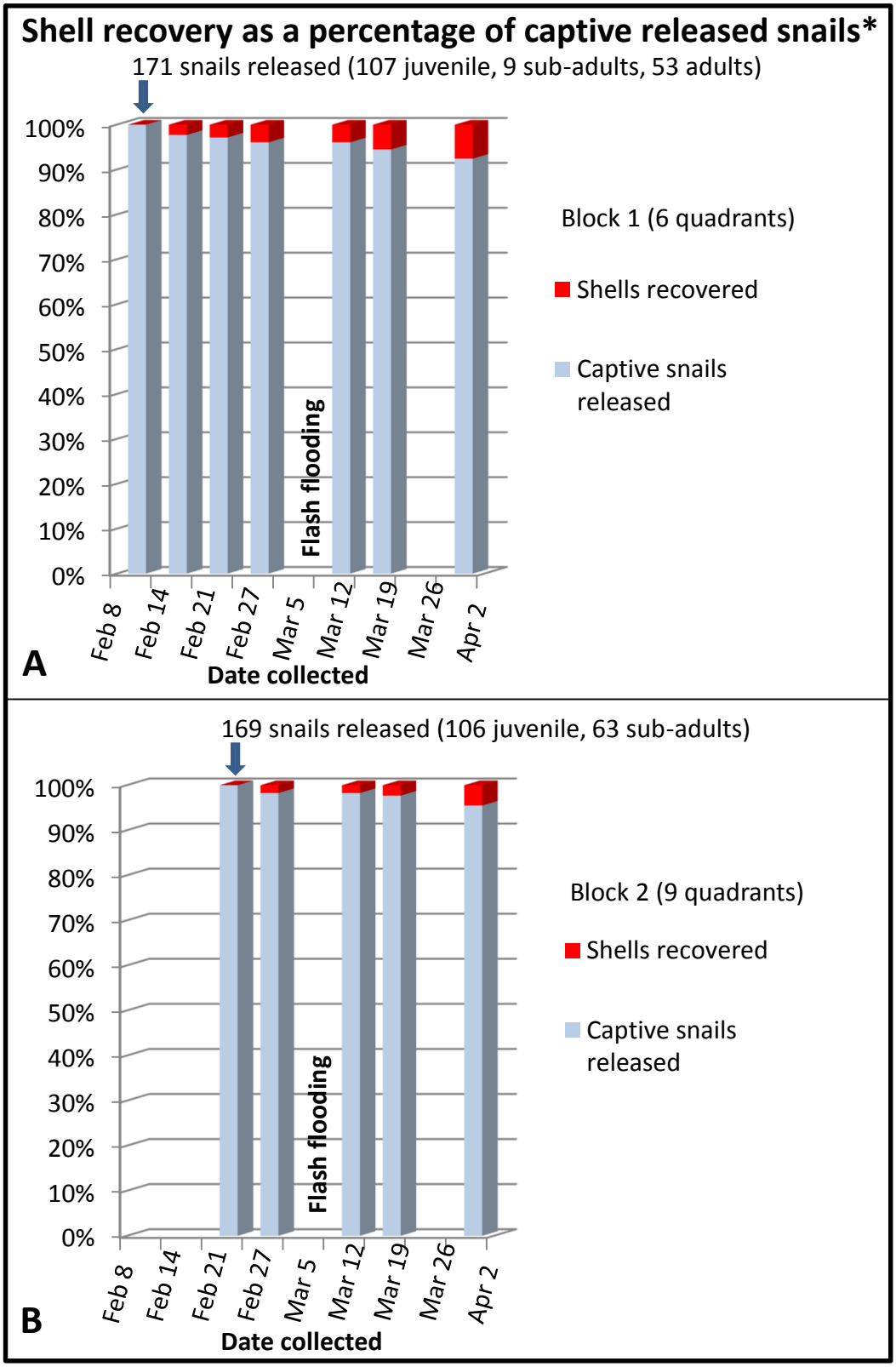



**Figure 5.** Shell recovery (red percentage) of *Achatinella mustelina* released in block 1 **(A)** and block 2 **(B)** for each monitoring date. *Recovery percentages may overestimate percentage of captive release.

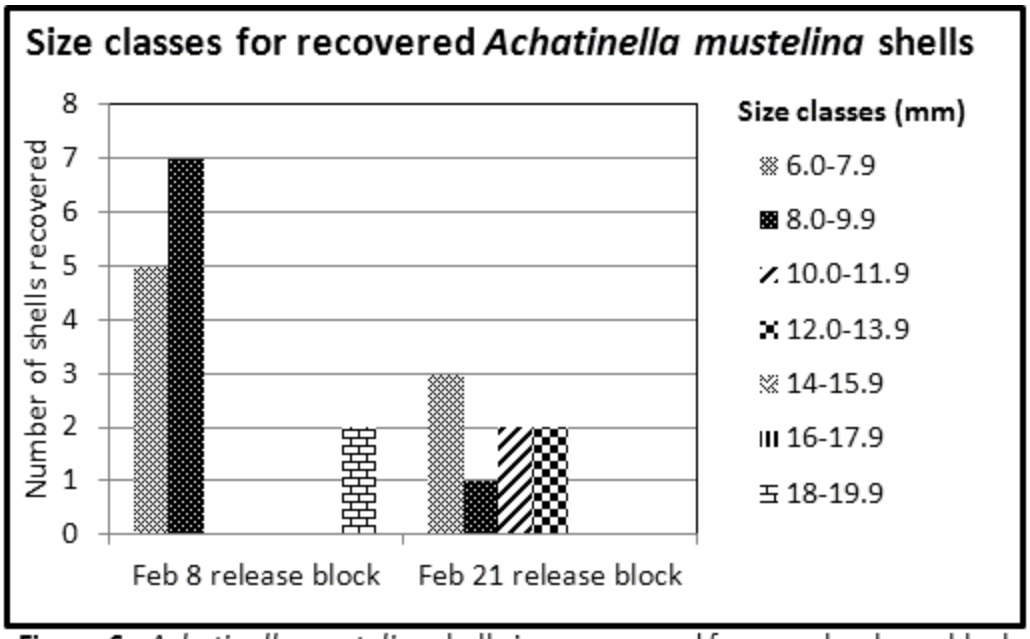



**Figure 6.** *Achatinella mustelina* shell sizes recovered from each release block.

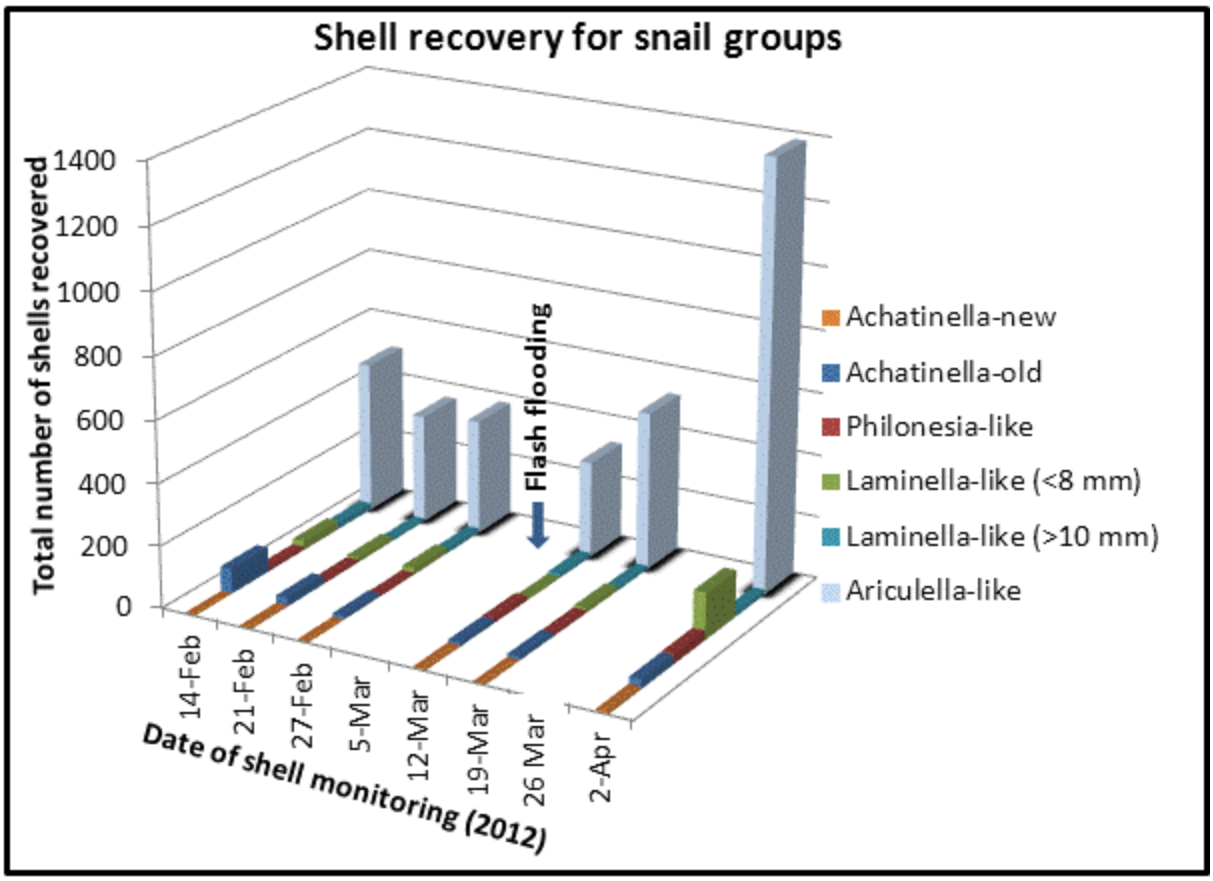



**Figure 7.** Recovery of Ariculella-like shells in the monitoring area.

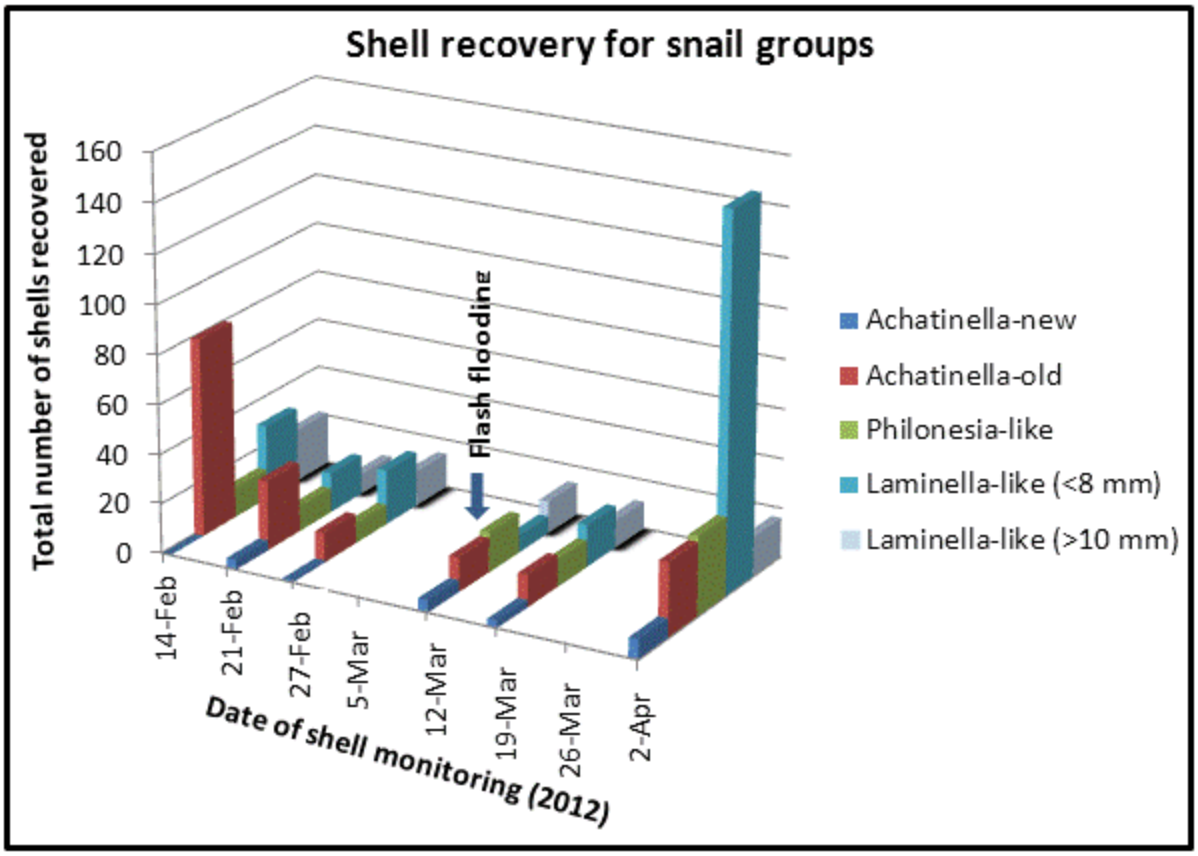



**Figure 8.** Shell recovery for different snail groups for each monitoring date.

# *Euglandina rosea* Control Plan at the Puu Hapapa enclosure

**Goal:** Eradicate *Euglandina rosea* from the 0.38 acre area enclosed by the Puu Hapapa predator proof fence (hereafter called enclosure). Survey the enclosure quarterly to ensure no incursion of new snails.
**Priorities**:

1. Continue to concentrate effort on manual removal of remaining *E. rosea* from within the enclosure.
2. Conduct regular monitoring to make sure enclosure is secure against *E. rosea* incursion.
3. Check for signs of *E. rosea* presence within the enclosure (*e.g.* fresh shells, eggs).

*Euglandina rosea* **reproductive biology**: The following data are all taken from (Jerlach 1994)[i]. Under optimal laboratory conditions (between 77 and 86$^{o}$ F and full feeding) *E. rosea* can reach sexual maturity in 263 days (this was the shortest duration observed to maturity) and at a minimum size of 35.4 mm. On average, they did not lay eggs until they were over 40 mm and were 386 days old. Generally, 9 eggs are produced per clutch and these hatch in 31 days. All eggs hatch at temperatures above 50$^{o}$ F. Based on growth rate data, the snails can be broken down into the following size/age categories.

| Age class | Description | Size | Age |
|---|---|---|---|
| Hatchling | prior to shell thickening | <10 mm | 0-41 days |
| Juvenile | thickened shell, immature | 10-30mm | 42-311 days |
| Subadult | sexually mature, not full grown | 31-40mm | 312-460 days |
| Adult | full grown | >40mm | 460-550 days |

These data can be used to advise us on whether the snails discovered are reproductive. We are fortunate that this species takes almost a year to mature and I recommend that in future we take time to measure the size of snails collected.

*Euglandina rosea* **feeding**: Jerlach (1994) found adults preferentially consumed 100% of prey offered at the smallest size class (<15 mm). They consumed 80% of prey between 16-20 mm and 40% of prey between 21-30 mm. This preference was found to be flexible (Meyer & Cowie 2010)[ii]. Prey that was formerly rejected when paired with smaller prey was later consumed when paired with even larger prey. Consider that *Achatinella mustelina* are about 4 mm at birth (Meyer & Cowie 2010) and may take up to 3.5 years to exceed a size of 10 mm (Holland, *pers. comm*.). We have removed much of the potential prey for *E. rosea* by removing leaf litter and killing all slugs encountered. At the same time we reintroduced 287 juvenile and subadult *A. mustella,* all <10 mm (the preferred prey size range for *E.* rosea) and 53 adults (>10 mm, slightly less preferred) from the laboratory into the enclosure. When presented prey between 1 and 30 mm, 1 *E. rosea* ate as many as 3 snails per day (Meyer & Cowie 2010). At that rate, a single *E. rosea* could consume all of our reintroduced snails in 4 months.

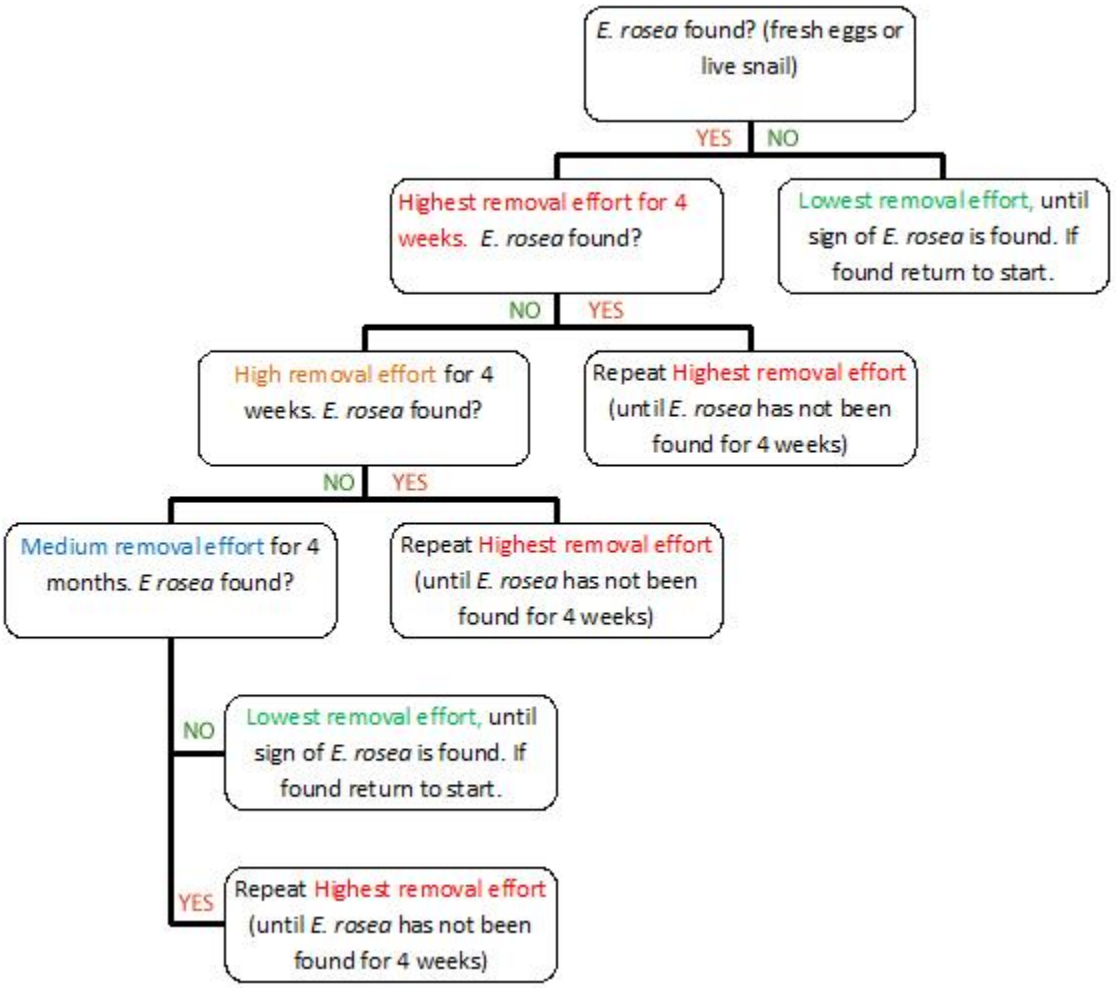
*Euglandina rosea* **removal effort:** Below I describe four levels of *E. rosea* control; each would be triggered under varied conditions outlined in a flow chart to be presented later. As some people are more skilled than others in finding *E. rosea,* it would be preferable to have experienced searchers. Also, daytime searches are preferable to nighttime searches. Half of the search time should be spent looking on the ground, the other half, in the trees.

**Highest removal effort = severe risk of *E. rosea* in enclosure:** Three staff spend two days a week at 4 hours per day for 4 weeks. This would total to 24 hours of search time per week, 96 hours total for the month.

**High removal effort = high risk of *E. rosea* in enclosure*:*** Three staff dedicate one day a week for 4 hours per day for 4 weeks. This would total to 12 hours of search time per week, 48 hours total for the month.

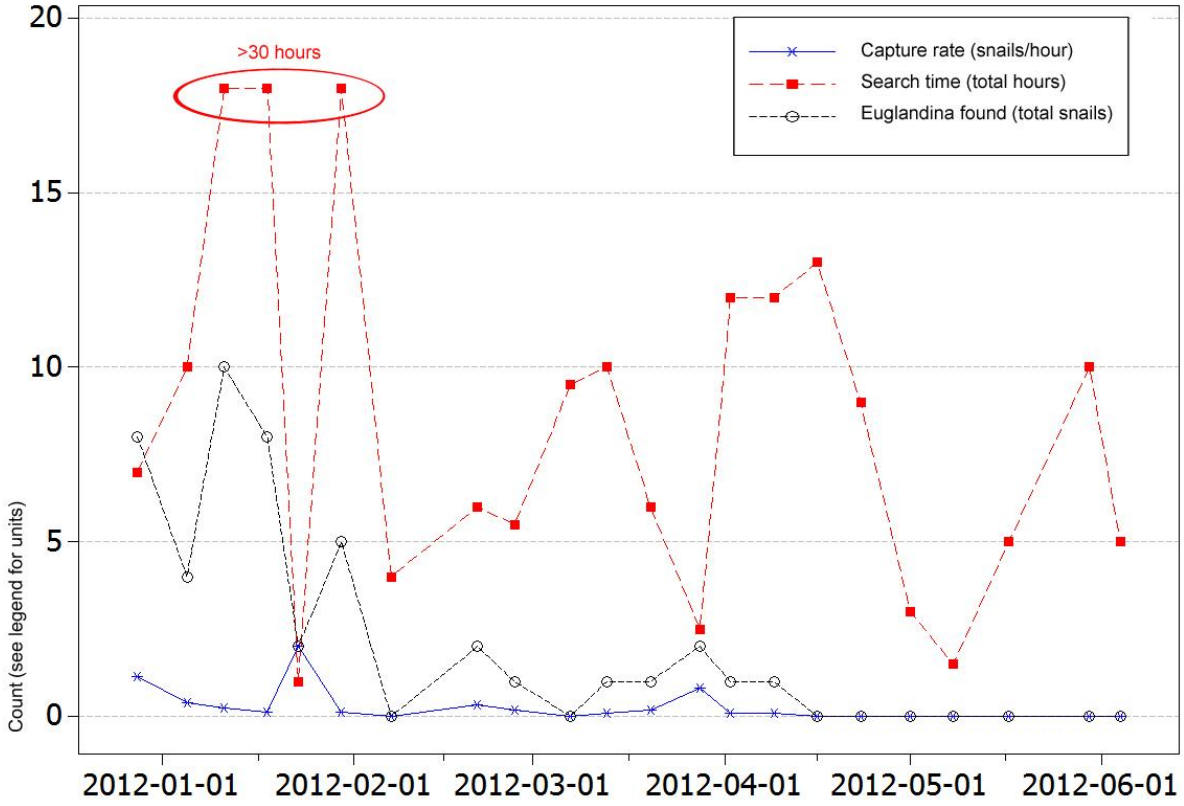
**Medium removal effort = some risk of *E. rosea* in enclosure**: Three staff dedicate one day per month at 4 hours per day for 4 months. This would total 12 hours search time per month.

**Lowest removal effort = low risk of *E. rosea* in enclosure:** Between 2 and 3 staff dedicate one day per quarter to sweep interior of the enclosure for a minimum of 10 hours total.




**Results to date:** The last *Euglandina* large enough to reproduce was removed from the enclosure in December. The last live *Euglandina* was found about 2 months ago (April 9). Since finding this snail, staff followed the high removal effort recommendation for 4 weeks. Nothing was found. In May staff continued to search for *Euglandina* weekly, but at an intensity between the high and medium removal

effort (We searched for *Euglandina* approximately 5 hours per week in the month of May for a total of 20 hours). The medium removal effort requires a minimum of 12 hours per month, the high effort requires 48 hours per month.




[i] Jerlach, J. 1994. The ecology of the carnivorous snail *Euglandina rosea.* Wadham College Oxford, UK. PhD Thesis

[ii] Meyer, W. and R. Cowie. 2010. Feeding preferences of two predatory snails introduced to Hawaii and their conservation implications. *Malacologia*, **53**(1): 135-144.

# Snail Fence InteleCell – Deployment Guide

## Preparation

1. Prepare deployment trip by making sure you have the following materials and tools when you fly up to the site:
    - InteleCell
    - NEMA Enclsoure (grey plastic case that houses the InteleCell)
    - NEMA Case mounting hardware (two curved bracket pieces per rail that slide into the rail and are bolted together, and nuts and bolts to secure those bracket pieces)
    - Desiccant pack (large, goes into NEMA case to keep it dry inside)
    - Tripod with stakes and guy wire kit
    - 20W Solar Panel with Mounting Bracket and two pipe clamps to attach it to tripod (make sure they are the right diameter, or have enough slots to close them tightly around the tripod mast)
    - InteleCam with mounting bracket (has a “ball-joint” swivel clamp attachment bracket which also attaches to the tripod, make sure you got both pieces, not just the camera)
    - Long (70ft) fence monitoring cable
    - FVA (should already be attached to monitoring cable)
    - High-Gain Omnidirectional antenna (white fiberglass antenna) with mounting bracket
    - Optional: High-Gain Directional Yagi-Antenna with mounting bracket (in case RF link with Omni antenna is too weak)
    - Large and small Philips head screwdrivers
    - Large and small flat head screwdrivers
    - Wire cutters
    - Wire strippers (can use knife in not available)
    - Multimeter
    - Silicone (to seal cable-feed-through hole in NEMA case)
    - Grease (to grease the NEMA case rubber seal)
    - Optional: Butane-powered soldering iron (to make a better connection between 12V snail wires and monitoring cable)
2. Verify that the InteleCell you’re taking has worked well in the office until now: (http://www.intelesense.net/data/intelecell/0000001100020025 or http://www.intelesense.net/data/intelecell/0000001100020017). Put it into hibernation mode by first waking it up, and then scrolling to menu item “10-Hibernate”, press Enter, scroll to “Yes” and press Enter again. Package the InteleCell in its NEMA case, along with camera, desiccant pack, and plenty of bubble wrap to keep it safe during the flight. Close NEMA case securely.
3. Solar panel can be attached to bracket ahead of time, it’s pretty rugged. Wrap cable securely.

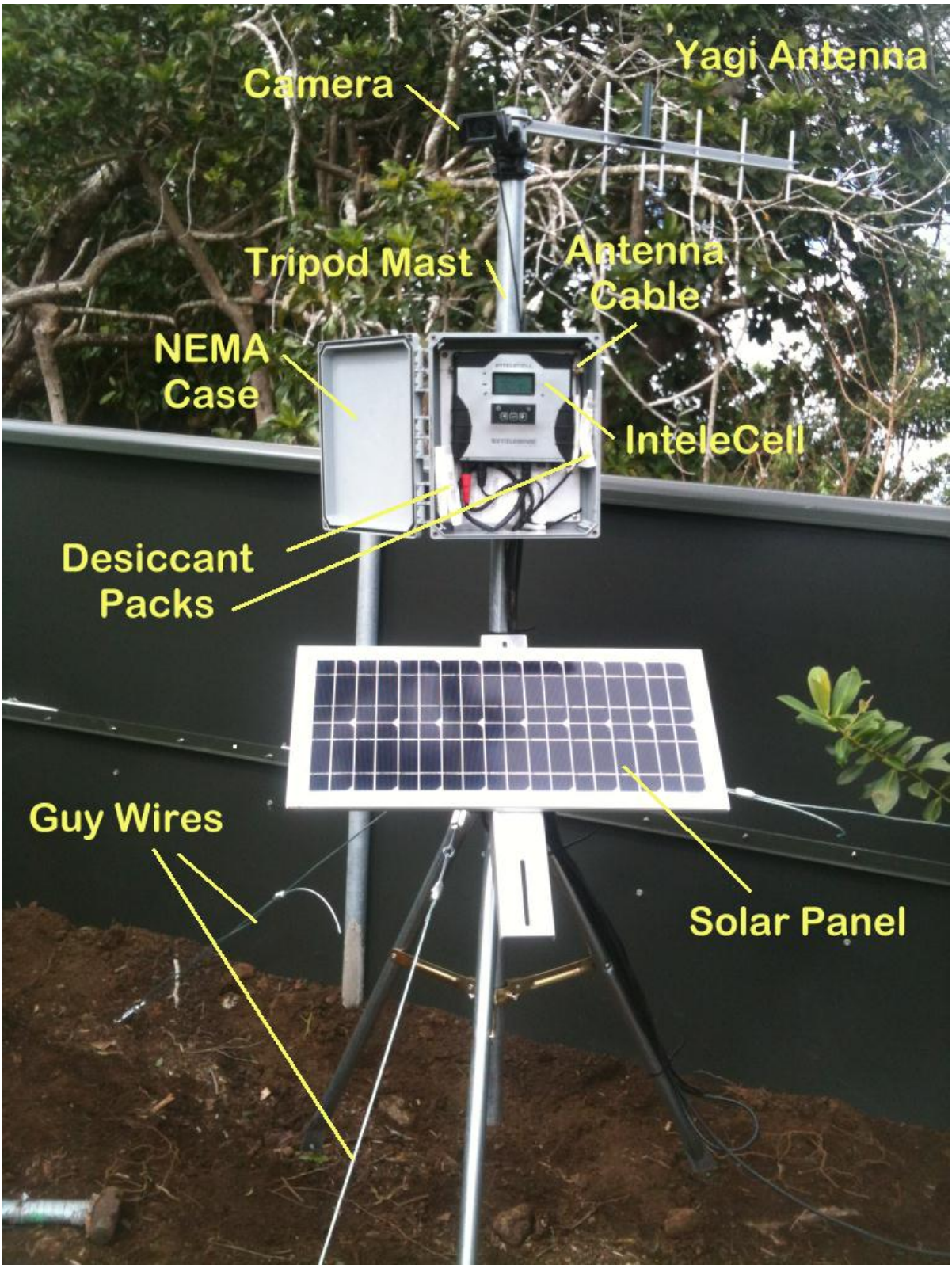
4. Package all other materials and tools as best as possible. Yagi antenna needs good protection.
5. Fly everything up to the site.

## InteleCell Setup

6. Take a good look at the site before deciding on a location for the InteleCell. Ideally, the tripod is set up inside the fenced area, this worked out very well at Pu'u Hapapa, for various reasons (protection, access to FVA, no cables running across path where people walk, shorter cable needed from fence to InteleCell, etc.) Make sure to pick a spot that gets plenty of sun at least for 4-5 hours every day. Look for south exposure to get a lot of sun during the middle of the day. But more importantly, make sure the site you pick has good line-of-sight to the base station InteleCell. Cut away any branches if necessary.
7. Do some RF testing before deciding on your site. Find the High-Gain Omnidirectional Fiberglass antenna. Attach the 10ft antenna cable to the antenna connector (large N-type plug) and the other end (smaller RPSMA-type plug) into the InteleCell's RF jack on the RIGHT SIDE of the IntleCell. Ask another person to hold the antenna up high, vertical, grabbing it low at the base or antenna connector, while you do the range testing. Range testing is performed by waking up the InteleCell by pressing the wakeup button, and scrolling to menu item number "5-Wakeup Network". Press the Enter button, scroll to "2-Find Neighbors" and press Enter again. The LCD will say "Find Neighbors scheduled…" until the full minute is reached (seconds = 00), at which point all InteleCells globally will wake up for a few seconds. At that time, your InteleCell's display will change to "Discovering nighbors…" indicating that it's now sending out pings to detect other InteleCells. Any InteleCell that hears those pings will respond, and the responses will be collected by your InteleCell and displayed on the LCD after about 20 seconds of pinging ("Neighbors discovered: xx). Now you can press the right arrow button to scroll to menu item "6-List Neighbors" and review the InteleCells that were discovered. Of particular interest is your base station InteleCell at the office, with ID 0000001100020023. You want to discover this InteleCell, and you want its RSSI to be at least 20%. Perform several "Find Neighbor" operations in a row to get a good feel for the range of values you're getting, and also for their repeatability. We'd rather see low 20s consistently, than 10%, 35%, 13%, 28%, etc. A good link is one that's consistently stays above 30%. If you get low readings just around 20 or below, I suggest you use a Yagi antenna. Regardless, it's always a good idea to do some range testing with both antennas to see the difference. Keep in mind though that you can only use a Yagi antenna if no other InteleCell has to rely on your InteleCell to repeat its packets. Or if there are InteleCells that do, they need to be located in the 15 degree cone-shaped field in front of the Yagi antenna.
8. Level the site if that's necessary before setting up the tripod. Unpack tripod and set it up. Use stakes and guy wire kit to secure it.
9. Mount the NEMA case on the tripod at about eye level by sliding the curved bracket pieces into the top and bottom rails (2 per rail), so that they wrap around the tripod mast. Secure them

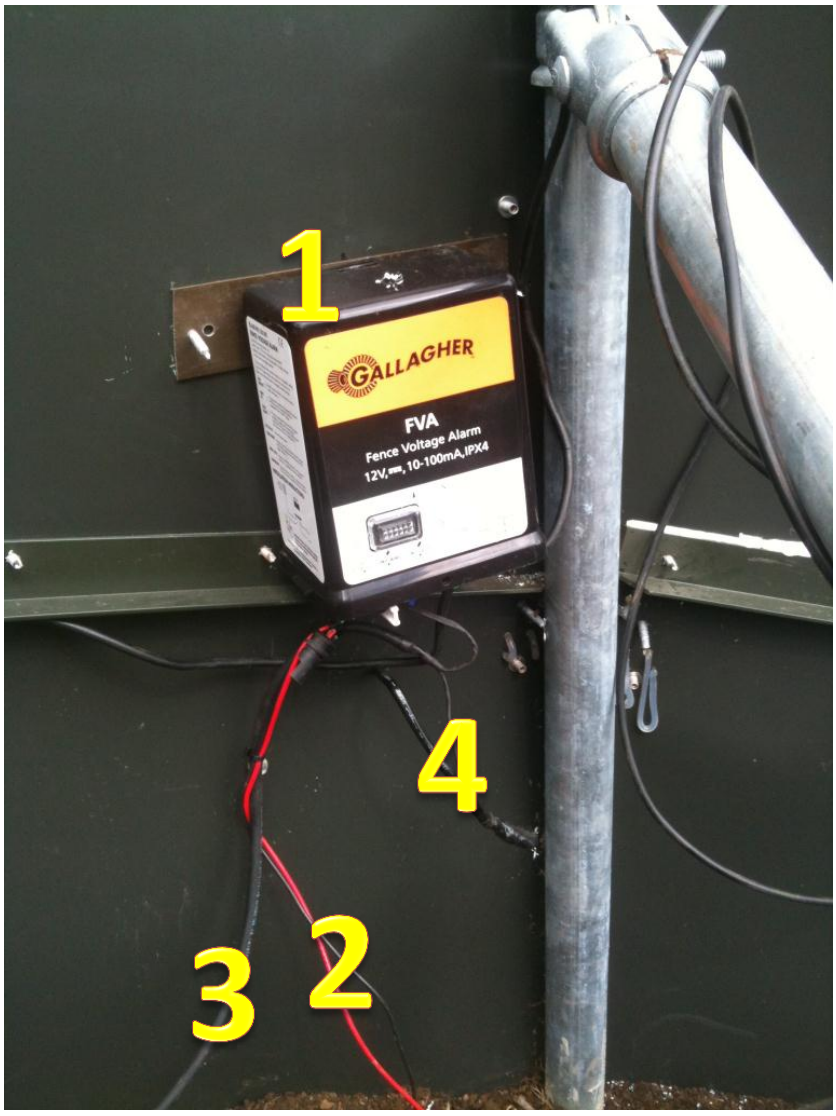
with the nuts and bolts that come with those brackets. Stick the InteleCell into the NEMA case (it's held by Velcro, very professional, I know. But works great.)

10. Mount the solar panel below the NEMA case with pipe-clamps, far enough away from it so that the NEMA case doesn't shade the panel if the sun is high. Threading the pipe-clamps through the slots of the bracket is a bit of a pain, it helps to pre-bend them before threading them in. Also verify that the two bolts holding the solar panel on the bracket are still tight, they might have loosened during transport. After mounting the panel, provide strain relief for the solar panel cable by feeding it through the gap between panel and bracket, and cable-tieing it to the bracket. Feed the plug-end of the cable through the large hole in the bottom of the NEMA case and connect it to the InteleCell's charge port (left-most port, only one with 3 pins.) By doing this right away we ensure that the InteleCell battery stays charged while you set up the rest of the system.
11. Mount a high-gain omni-directional fiberglass antenna to the very top of the tripod mast. The picture above shows a Yagi antenna, but I want you to try it with an omni-directional dipole first. Attach the 10ft antenna cable to the antenna connector (large N-type plug) and the other end (smaller RPSMA-type plug) into the InteleCell's RF jack on the RIGHT SIDE of the IntleCell. Leave the left RF jack un-connected.
12. Feed the FVA monitoring cable through the hole in the bottom of the NEMA case and plug it into Port 4 of the InteleCell. Feed the camera cable through the same hole and plug it into Port 1.
13. Your setup should now look as shown below (except for the antenna.)
14. Wakeup the InteleCell and verify operation of the system as you've set it up so far. You don't want to wait with that and discover later that the site you selected doesn't give you a good connection to the base station after all. And there's always a slight difference between RF testing while holding the antenna in your hand vs. RF testing with a properly mounted antenna (which doesn't necessarily make it better, sometimes the link is slightly weaker after mounting.)
15. Sample sensors (menu item "2-Sample Sensors") which will cause the camera to take a picture, and read the voltages on the so far unconnected FVA monitoring cable. The data that was just acquired/generated will be collected by the base station InteleCell during the next data collection. The base station InteleCell is configured to collect data every 30 minutes, at 11 minutes after the hour, and at 41 minutes after the hour. It's a good idea to watch the LCD display during those times to see if the InteleCell sends its data or not. It should select a gateway (Ideally your base station 0000001100020023), and then send all or part of its enqueued packets to that gateway (ideally you see all packets that were enequeued also get acknowledged, e.g. "Pkts acked/enqueued: 35/35", but that's not absolutely necessary. Any packets not acknowledged (i.e transferred) will get resent during the next data collection.
16. Verify that the InteleCell battery is being charged (1-Display Status, press Enter, scroll to "Vcharge", should be >9V.)


Yagi Antenna
Camera
Tripod Mast
Antenna Cable
NEMA Case
InteleCell
Desiccant Packs
Guy Wires
Solar Panel

## FVA Setup

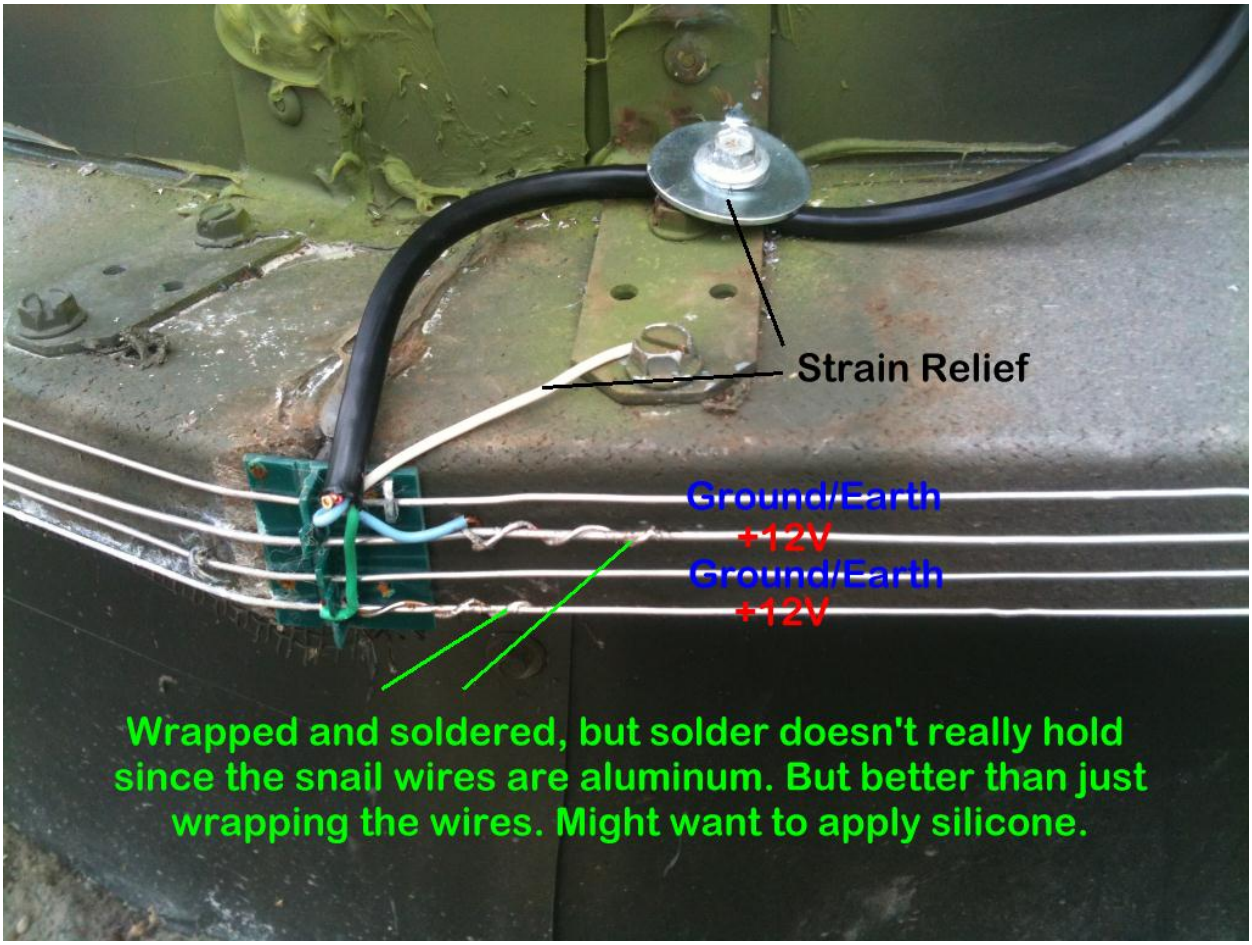
17. Find an easy to access place near the tripod and inside the fence where you can mount the FVA.
18. Take a look the following two pictures to become familiar with the FVA wiring. You have to essentially replicate the setup shown in the two pictures below. The 12V power for the FVA may be provided by a separate battery instead of coming from the High Voltage Power Source unit, but that's the only difference.




1 – Fence Voltage Alarm (FVA)
2 – FVA Power cables (12V, red +, black -)
3 – InteleCell FVA and 12V Snail Wire Monitoring Cable
4 – Connection of 12V monitoring wires to InteleCell Cable

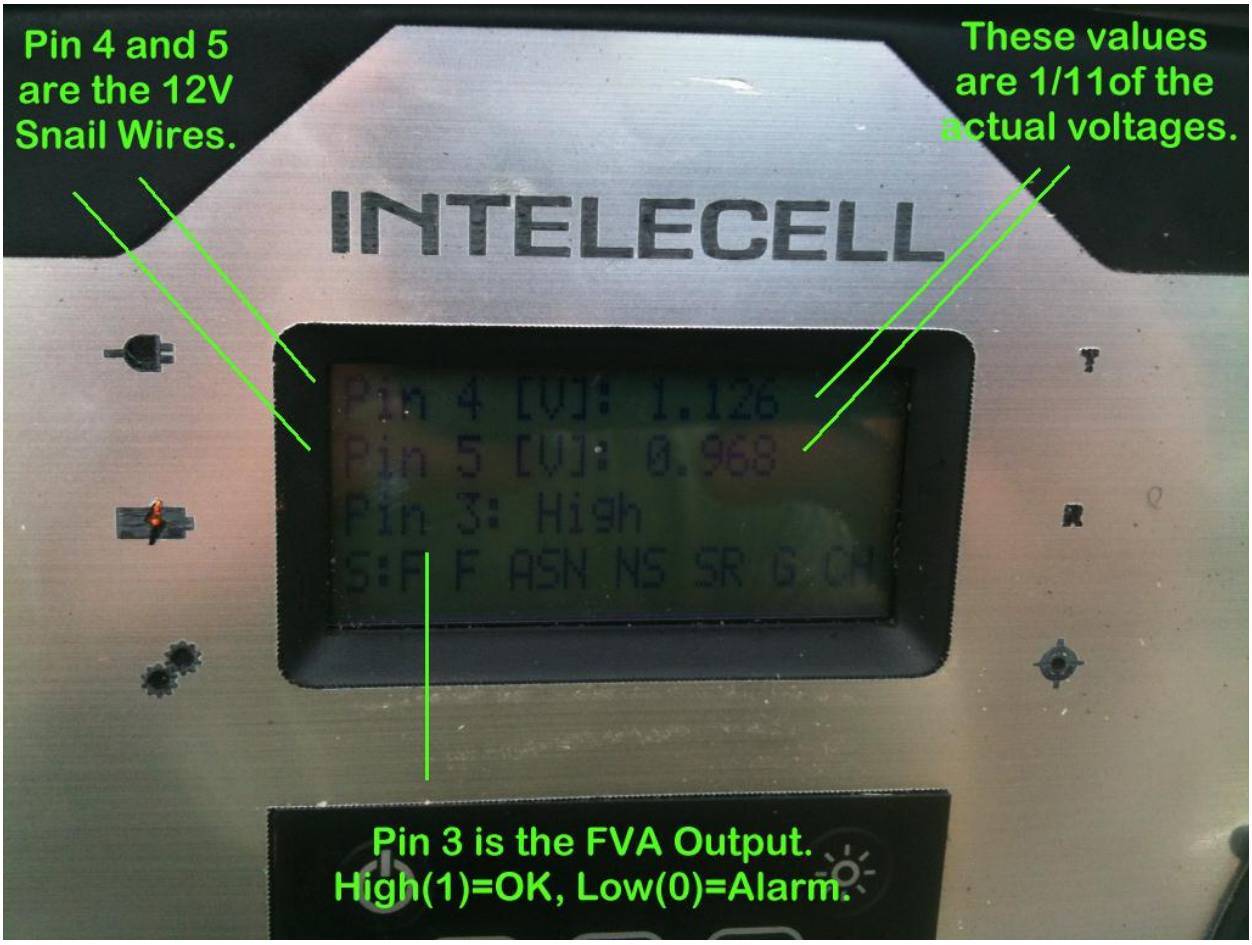

5 – High Voltage Wire
6 – Earth (Ground) Wire
7 – High Voltage Power Source (“S50”)

19. Connect a 12V battery (or the 12V output of the “S50” High Voltage Power Supply (“Energizer”) to the FVA 12V power cable. When looking at the FVA, this cable is located at the bottom left. There may be terminals instead of cable coming out, not sure. But the terminals are NOT the big green and blue ones, those are for connecting the high voltage from the Energizer.
20. The InteleCell-FVA monitoring cable should already be connected to the FVA. If it’s not, call Carsten at (408) 310-0200 to have him walk you through the steps of reconnecting it. In short: brown goes to Ground and orange goes to the “NC” pin of Relay 2 inside the unit. But hopefully those wires are still connected when you get to the site.
21. In addition to the orange and brown wires that go to the FVA, there are two more bare wires that need to be connected to the 12V wires running around the perimeter of the fence (the “Snail Wires”). They are green and blue, and it doesn’t matter which one is connected to which wire. If you want to maintain consistency across all three snail sites, you should connect the blue wire to the positive wire of the upper pair, and the green wire to the positive wire of the lower pair, as shown in the picture below. Note that the white wire that’s attached to the screw on the rail is just for strain relief, it’s not connected to anything. The screw with the big washer near the top of the picture is there for the same reason:




22. I used a short (3ft long) piece of sprinkler cable that I pushed through a hole drilled into the fence wall. Inside the fence I connected the ends of the blue and green wires of the sprinkler cable to the blue and green wires of the FVA monitoring cable. Twist them together, and if you

have a soldering iron apply some solder. But okay with out, just twist them well. Insulate the wrapped ends with electrical tape. Once the snail wires are connected to the FVA cable, it's time to connect the high voltage to the FVA. This should have been done as part of the Fence installation. Tell everybody who's working near the area that you're about to energize the fence. Turn on the Energizer ("S50" unit), and flip the switch of the FVA to arm it. The Energizer light should turn on (go green) indicating that it's operating. Sample Sensors on the IntelCell, and when the voltages are sampled (after the camera picture was downloaded from the camera), you should see voltage on Pin 4 and Pin 5 near 1V, and the reading for Pin 3 should be "High":




If you miss the display of those readings, you can go to "3-View Data" afterwards and scroll through the values. For Pin 3, the result will be displayed as a numeric value, so instead of "High" you would see "1", and instead of "Low" you would see "0". "High" or "1" means the FVA is not sounding an alarm. This could either mean there is high voltage, or it could mean that it's turned off, but powered. Still need to figure out a solution to distinguish between those two states.

23. Now perform an end-to-end test by waiting for the next data collection and having someone check if all data made it through ok (or use your mobile phone, you can use the http://www.intelesense.net/data/mobile/ link to access InteleCell data with a phone.)
24. DONE!

# ***Achatinella mustelina*** **monitoring timed count**

**Management Objective:**

- Detect A. mustelina population trend over time
- If negative trend is detected, arrest decline via adaptive management strategies

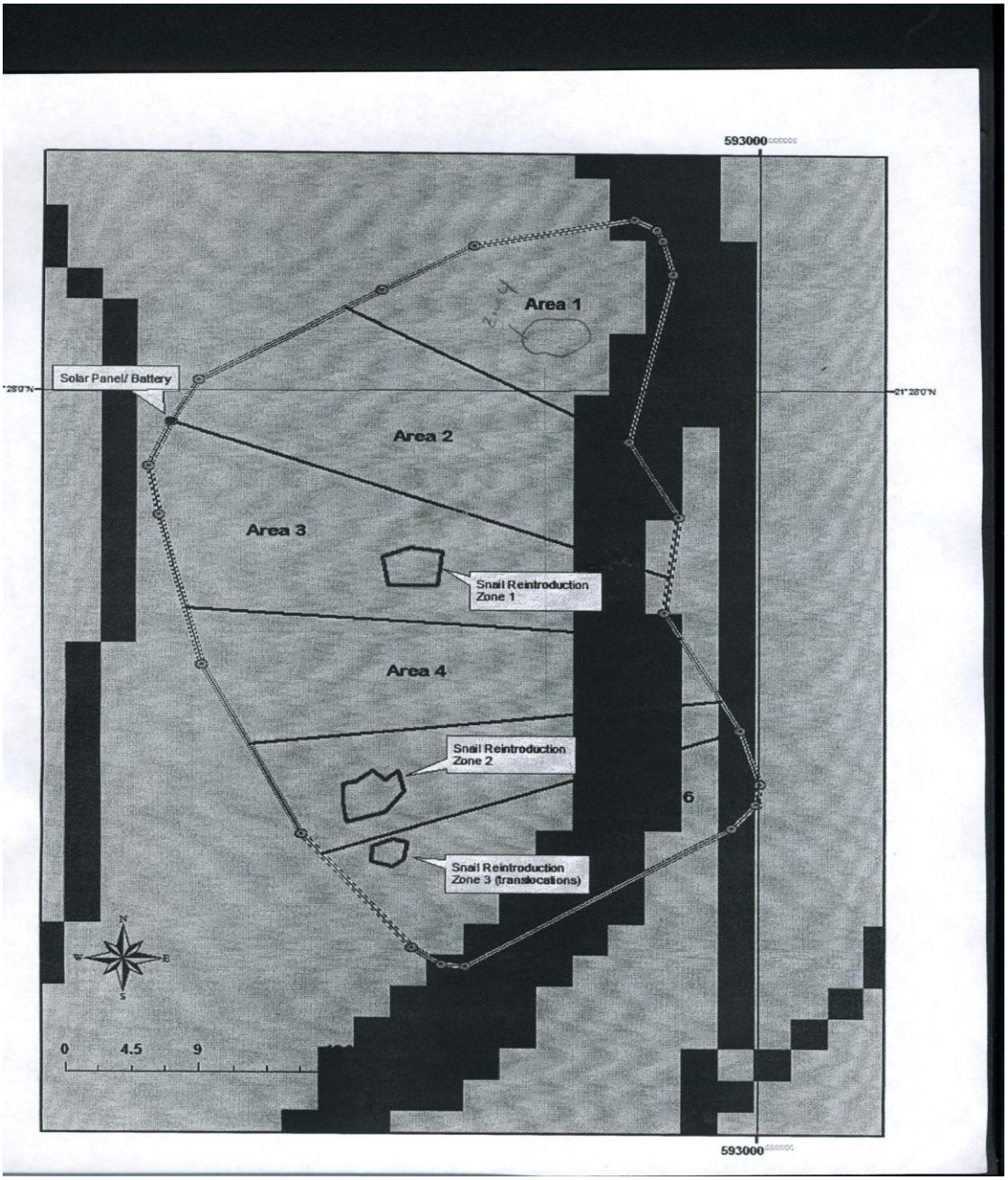
**Sampling Objective:**

- With a 90% confidence level, detect a 20% change in the A. mustelina population within the enclosure.

**Monitoring Protocol:**

- Spend two hours surveying Zone 1 and 2 and one hour at Zone 3 and 4. Record the number of snails by size class (Small < 8m, Medium 8-18, and large > 18mm) for each zone. Summarize snail counts by zone and total enclosure.
- Bring calibers to measure each snail from apex to aperture (if accessible).
- Conduct monitoring shortly after dark, making sure that each team has their own spot light and binoculars.
- Make sure snails are not being counted twice by communicating snail location and size class to each other.
- Make notes on what the weather was like the day before and night of monitoring.
- One person should be designated as the time keeper to ensure search effort is consistent.

Map of the zones:




**Notes:** The area surveyed and time spend monitoring needs to be consistent. The zones should be clearly delineated (using flagging and detailed vegetation maps).

**Effort:** 21 hours per quarter

**Additional Monitoring Considerations:** Spend 1 hour searching around the delineated boundary of each zone for snail migration.

# Pu‘u Hapapa Snail Enclosure Restoration Plan Addendum

For a complete overview of the area and its resources, please see the “Hapapa Bench/Land of 10,000 Snails Restoration/Re-vegetation Plan” in the 2011 IP year end report (http://manoa.hawaii.edu/hpicesu/DPW/2011_YER/021.pdf).

A predator-proof fence (perimeter = 160 meters; area = 0.387 acres) was completed at Hapapa in 2012. The fence was designed to repel intrusion by predators of native *Achatinella* snails, particularly rats and carnivorous snails. Extensive work has been done at this snail enclosure, including predator control and removal, weed control, native plant restoration, and reintroduction of *Achatinella mustelina*. This addendum aims to update the original 2011 restoration plan and its goals, and identify clear actions for the coming year.

**Sanitation Protocols:**
Avoid introducing *Euglandina* and other snail predators and invasive weeds into the snail exclosure. All items carried into the exclosure should be checked prior to crossing into the fence. This inlcudes the ladder used to access the exclosure, buckets, field packs and gear, staff, and outplants.

- Place a sign on the outside of the exclosure, reminding staff to check gear.

**Predator-Proof Fence Maintenance:**
The monitoring anf mantenance of the predator proff fence is critical to the success of the *A. mustelina* recovery efforts in the area. All personel active in the area shall review this document and a have a good understanding of the maintenace requirements.

1. Maintain fence
    a. Check fence for damage, fallen logs, overhanging branches, etc. Remove any material that crosses or overhangs the fence.
    b. Check for gaps where fence panels overlap. Caulk as needed.
    c. Check for gaps where plastic 2x4 meets fence. Use caulk and self-tapping screws as needed.
2. Electric snail exclusion barrier: The bottom four wires around the fence are an electric barrier to snails. When a snail touches two of the wires at the same time, they complete a circuit and get zapped. There are two independent ststems (the top two wires and the bottom two wires). They operate on a 12 volt system. The electronics for the fence are in a clear plastic box inside the fence.
    a. Visually inspect barrier wires (the four wires at the bottom of the fence) looking for:
        i. Corrosion
        ii. Crossed wires
        iii. There are metal staples that hold the wires in place. Look for staples that are broken or pulling out. Re-staple as nessisary.
        iv. Check the connections between the wires and the electronics.
        v. Check the connections between the wires and the intelecell.
    b. Check voltage of the batteries.
        i. There are two batteries in the clear box. There is a multimeter in the box with the electronics. Set it up as show below (turn the knob to 50 DCV). Touch the red to the + and the black to the –. The voltage should read ~11-13. Notify Rare Invertebrate Conservation Technician if the batteries are dead.
    c. Check voltage on the wires.

i. Touch the red lead from the muiltimeter to the top wire and the black to the wire below. The multimeter should pulse regularly to about 10 V. Repeat for the bottom two wires.


d. Check for continuity of electrical snail barrier.
   i. Unplug the electronics from the fence (best acomplished by unpluging the batteries). NOTE: If you don't do this you will blow the fuse in your multimeter.
   ii. Set the multimeter to the continuity setting (see Rare Invertebrate Conservation Technician or multimeter directions).
   iii. Touch the multimeter leads together. You should hear a tone.
   iv. Touch one of the multimeter leads to the top copper wire, and the second lead to the second copper wire. If the wires are isolated (which is good) then there should not be a tone.
      1. Test all the wire combinations (1,2: 1,3: 1;4, 2;3, etc.). If the wires are good, the only time you should hear a tone is if you touch the same wire with both contacts (both on wire 2 for instance)
   v. If there is a tone when you touch two different wires, then there is a short (an electical connection) between the two wires, and it needs to be fixed. You can look for obvious shorts (like things on the affected wires or staples that are out of place), but if you can't identify the problem, notify the current Rare Invertebrate Conservation Technician.

e. Clean copper exclusion wires (the four wires towards the bottom of fence).
   i. At this point, we don't know how much of an issue this will be, or what the best method for cleaning the wires is. At this point we are testing several cleaning methods including TSP (Trisodium Phosphate) and salt-lemon mixtures.

3. FVA – The Fence Voltage Alarm system alerts us to a breach in the fence. It includes the high voltage wire along the top of the fence, a battery, solar panel, and the FVA itself. NOTE: When the fence is on, it carries a voltage >7,000 V. It WILL shock you if you touch it.
   a. Check the wire along the top of the fence.
      i. Look for corrosion.
      ii. Look for anything that could cause a short circuit between the wire and the fence.
   b. Check wire insulators (the black brackets that the wire is on). Look for any bent or brokens ones, and replace as needed.
4. Physical exclusion barriers – The fence has two physical exclusion barriers, a copper cut-mesh barrier attached to the underside of the 2x4 on the outside of the fence, and an angled piece of flashing below the 2x4.
   a. Check angled flashing for obvious damage.

b. Check cut mesh for obvious damage.
c. Trim any plants growing within the exclosure which stretch outside of it and may contact the electric lines, shorting the system.
d. Pull any plants against the outside of the fence, that have grown, or will grow taller than the physical exclusion barriers, within 2m of the fence.
    i. Weed outside of fence, paying close attention to plants that could grow above the physical exclusion barriers. Encourage low-growing plants within 2m of fence.
    ii. Install 0.5m wide strips of astroturf directly abutting the fence. Use weed cloth next to astroturf, to a width of 1m. Check ground cloth quarterly and repair as nessesary.
    iii. Install water bars and erosion control meaures to maintain the integrity of the buried fence.

5. Weather Station
    a. Ensure that weather station is vertical.
    b. Check wires between the station and into the intelecell for damage.

For more detailed information about the Intelesense FVA, please see Appendix A, "Snail Fence Intelecell – Deployment Guide."

***Achatinella* Monitoring:**
On 8 Feb 2012, 171 snails (109 small, 9 medium, 53 large) were released by OANRP, FWS, and UH Snail Lab staff within the enclosure. On 21 Feb 2012, 169 additional snails (106 small, 63 medium) were released. In all, 340 snails (215 small, 72 medium, 53 large) were placed into the enclosure. Monitoring the survival of reintroduced snails and estimating the total population of *Achatinella* in the enclosure is an OANRP goal for the coming year.

For a complete discussion of goals and monitoring techniques, please see Appendix B. (LB, VC)

**Vegetation Restoration:**
The construction of the snail enclosure necessitated the removal of a lot of canopy trees. While this was unavoidable, major changes in micro-climate occurred, including increases in light level and possibly decreased humidity. Fortunately, many alien plant species were also removed, in particular *Schinus terebinthifolius*. As a result, the snail enclosure has large open areas which are a high priority of restoration. Staff assume that a full canopy, dense/structured understory, and low weed presence provide *Achatinella* with the best possible habitat.

Weed control goals and actions: (JB)

1. Zero tolerance for alien canopy within enclosure. No alien canopy currently; maintain by conducting understory control (see #3)
2. Zero tolerance for alien grasses within enclosure. Control grasses as needed; monitor at least twice per year.
3. Low tolerance for alien taxa in understory. Control understory weeds regularly, sweeping entire enclosure twice a year (or less, if justified). Focus on species that can persist in shady environments, species that grow into canopy, and species that are habitat altering (including Phypar and Passub). Minimize control of annual asters in open sunny areas.
4. Maintain low vegetation in 2m buffer around outside of exclosure; vegetation within 1m of wall should be lower than the height of the hood.

For a complete discussion of vegetation restoration goals and actions, please see Appendix C. (JG)

**Snail Predator Management:**
*Achatinella* are threatened by a variety of predators. It is assumed that removing these predators from the enclosure will increase the likelihood of *Achatinella* survival and recruitment. Please see the following paragraphs and Appendices D and E (SJ) for a discussion of that status of management efforts and actions for the predators listed below. Also see a summary of control efforts in June 2012, compiled by VC in Appendix F.

*Euglandina rosea,* Rosy Wolf Snail
*Chameleo jacksonii*, Jackson's Chameleon
*Rattus rattus,* Black Rat
Other Potential Predators– *Oxychilus alliarus*, Garlic Snail; Insectivorous Birds;
Concerning Taxa - Slugs; Flatworms; Skinks

Rat Control Discussion: (KF)

Since the contruction of the exclosure, no small mammals have been detected in any of the six snap traps or tracking tunnels that have been repeatedly set and monitored inside the exclosure. Snap traps are now housed inside wooden boxes to reduce non-target catches (birds) and to prevent accidental triggering. On-going rat actions include quarterly resetting of snap traps and tracking tunnel monitoring (tunnels are set out for one night and collected the next day). If any small mammal presence is detected in a snap trap or tracking tunnel, corrective management actions will be taken.

Other Potential Predators: (SJ)

Birds are documented predators of gastropods, however, the extent to which they may impact *Achatinella* is unknown. Some take by birds is strongly suspected by the Rare Snail Specialist. The gut contents of five non-native bird species were investigated by Dr. Brenden Holland. In a single *Leothrix lutea* he found two extremely small native snails (<8 mm). They were found in the crop of the bird and were likely consumed within the hour. Identification revealed one was Pacificellinae, the other he believes may have been in the genus Pleuropoma. Due to this find, more data is needed to determine whether birds might be responsible for our failure to relocate many of the released Achatinellae. We are currently in the process of writing up a research proposal which would allow for at least 20 individuals of each alien bird species to be sampled.

Concerning Taxa:

- Kill/remove any slugs seen. Remove refugia material (cardboard/shade cloth) from inside exclosure.
- If find flatworms, do not kill by cutting in half (results in 2 animals); either put in ziploc and bring down to trash at baseyard, or throw out of the exclosure.
- Melissa Wright, a student, is getting a permit to study skinks at Hapapa.

## Appendix 6: Goodnature® A24 Automatic Rat Trap Study Proposal

### Introduction/Purpose of Study

Since 1995 the Oahu Army Natural Resource Program (OANRP) has managed over 50 endangered species; these include plants, invertebrates, and one bird species. Introduced rats pose significant threats to native Hawaiian ecosystems; they are known predators of native plants, invertebrates and birds (Stone 1985). Isolation and rugged terrain make rat control in Hawaii difficult. Since 1997, the OANRP has primarily controlled rats through the use of diphacinone rodenticide in bait stations in combination with rat traps in close proximity to the bait stations. However, using toxicants is undesirable because they are expensive, controversial, heavily regulated and highly variable in efficacy. Trapping grids have also been implemented for rodent control, but they are labor intensive to maintain, involve heavy foot traffic in fragile ecosystems, and can be inefficient as bait is often quickly removed by slugs/insects.

A new automatic self-resetting rat trap that can reset up to 24 times may provide a viable alternative. In collaboration with Kalaupapa National Park and the State of Hawaii, OANRP has commenced a trial in Pahole Natural Area Reserve to investigate the use and efficacy of the automatic traps. This project is one of the first to assess how the traps can be used for natural resource management in remote a Hawaiian forest setting.

Forty five traps will be deployed in a 200 meter circular buffer around the outplanted population of *Cyanea superba* in Pahole. Forty two of the traps will have automated counting devices on them to record when the trap has been triggered. The duration of this project may be up to one year to collect sufficient data for analysis.

There are possible advantages of using this new tool. Primarily, long-term rat control costs could be significantly reduced with the use of automatic traps because they don't need to be serviced as often as traditional traps thereby reducing staff time spent re-baiting, fewer traps may be necessary for the same level of rat control, and helicopter time would be reduced due to less frequent servicing of traps in remote areas. Even with the high cost per trap, the automatic traps could save a significant amount of money in long-term labor costs.

For example, in Kahanahaiki, typically four staff reset 464 snap traps twice a month and typically fewer than 60 rats are killed each month. Since 2009, the average labor cost for installing and maintaining the grid each year has been over $40,000. If automatic traps were used in a grid layout of 100 meters by 50 meters (as suggested by D. Peters, pers. comm.), there would be 54 traps. At the highest catch rate generally seen of 60 rats per month, it would be 21 months before all traps would need new $CO_2$ cartridges. In reality, the traps could probably be checked 2-4 times a year by fewer staff to refresh the bait and replace $CO_2$. This roughly equates to less than 20% of the labor currently required for grid maintenance. Finding bait that lasts as long as possible is crucial to maximize the utility of the traps.

Risks to staff will also be reduced with these traps as there will be less helicopter time and reduced handling of rat carcasses. Additionally, Hawaii's natural resources could benefit from increased protection from rats because these traps are designed to always be baited and set unlike traditional snap traps; this might be especially useful in remote settings where access is limited and snap traps are often found sprung and ineffective. Furthermore, these traps may be one of the most humane ways to conduct pest control (Jansen 2011). Lastly, OANRP's use of these traps will provide valuable information to partner agencies in Hawaii regarding new methods of pest control.

## Goodnature® A24 Automatic Rat Trap Details

Designed by New Zealand conservationists to humanely kill rats of any species or age class, each Goodnature® A24 automatic rat kill traps can kill up to 24 rats using a single $CO_2$ cartridge and are designed to be baited with a long-lasting attractant (see Figure 1). When a rat triggers the trap, a captured bolt (approximately 20mm) delivers a lethal blow to the head. This effectively crushes the skull causing spontaneous central nervous system suppression, killing the animal quickly and humanely (Goodnature® 2012). A trap costs $149.50 NZD or about $123 USD.


*Figure 1. Goodnature® A24 Automatic Rat Trap with $CO_2$ cartridge. Photo courtesy of www.goodnature.co.nz.*

## Additional Information Regarding Trap Humaneness

A field evaluation of humaneness of the A24 traps confirmed that the traps killed black rats (*Rattus rattus*) quickly and effectively, meeting the New Zealand National Animal Welfare Advisory Committee kill trap testing guidelines; there are no similar guidelines in the United States regarding humaneness of rodent traps. In the study, the traps consecutively rendered 10 ship rats irreversibly unconscious in less than 30 seconds. This time includes the lag between the trap triggering and the ability of the assessor to travel to the trap and conduct a reflex test (see Jansen 2011).

## Site Selection Details

Several key criteria were used as guidelines for site selection for this project. Specifically, the sites chosen need to be easily accessible, pig free, have a low risk for vandalism, have native/rare resources that will benefit from rat control, and be similar to each other in size/ecosystem type. Pahole Natural Area Reserve, owned by the State of Hawaii and managed by the Department of Land and Natural Resources, emerged as an excellent site to deploy the automatic traps. Additionally, because there is no

ongoing rat control at Pahole, it will be possible to observe how the natural rat population is affected by the automatic traps. Pahole is adjacent to Kahanahaiki Valley, which is owned by the Army and managed by OANRP. Monitoring rat activity at Kahanahaiki serves as an ideal comparison to Pahole as extensive research has been conducted on rat populations at Kahanahaiki (Shiels 2010) and there is existing research studying the effects of an extensive rat trapping grid on resource response at Kahanahaiki versus Pahole where no rat control occurred (Pender et al. 2012). Additionally, Kahanahaiki has other similar attributes as Pahole. These sites provide an ideal situation to compare rat activity between the sites with different rat control methods. See Figure 2 for a map of the area.


*Figure 2. Map of Pahole and Kahanahaiki. Locations of Cyanea superba that may be used in this project are shown as well as the trapping grid at Kahanahaiki Management Unit (MU).*

**Research Questions and Methods**

The overall goal of this study is to begin the process of collecting data on the utility of these traps to become more knowledgeable regarding how they function and whether or not they reduce rat activity enough to protect natural resources. OANRP will apply the lessons learned from this trial to adapt management with these new devices as OANRP develops a best practice. These objectives will be met in two phases: Phase 1 will be preliminary data collection on the functioning of a subset of traps and using cameras to record rat activity; Phase 2 includes installing a grid of 45 automatic traps centered around *C. superba* at Pahole gulch to monitor rat predation on fruit and running tracking tunnels to assess changes

to rat activity. *C. superba* fruits are impacted by rat predation (Pender et al. 2012) and these plants will provide with a reference for how the automatic traps affect rat predation on this rare resource.

It would be ideal to be able to experiment with multiple baits to find the ideal bait(s) for this new trap style and be able to try out multiple grid arrangements to find the ideal spacing for the traps. However, this first trial will be limited to using peanut butter bait and a single grid spacing.

***Grid Design at Pahole***

Since the traps are relatively expensive compared to traditional snap traps, eventually the goal is to find the optimal spacing of the traps to minimize the number of traps needed while maximizing the desired resource response. For example, if the traps are determined to function well (as described in Phase 1) but there is still an unacceptable level of *C. superba* fruit predation by rats (defined as greater than 20% predation), next season the traps may need to be spaced more closely together to improve protection.

However, the research goal of this project necessitates that the grid spacing is determined prior to the beginning of the field study and that it does not change throughout the duration of the study for data analysis purposes. The chosen grid layout for this project is determined by reviewing literature, conferring with New Zealand experts, and assessing site specifics such as topography and resource locations.

The grid at Pahole will be centered around *C. superba* to provide a buffer of protection from rats in order to monitor resource response. Additionally, the rat control area at Pahole must be comparable in size/ecosystem type to the control area at Kahanahaiki that will be monitored.

According to the Department of Conservation (DOC) in New Zealand, there should be at least one trap available in each rat's home-range. According to DOC, home-ranges for black rats in New Zealand range in length from 100-200 meters during the breeding season and longer other times of the year. DOC suggests placing the traps on transects spaced 100 meters apart with traps 50 meters apart on the transects (D. Peters, personal communication). At Kahanahaiki, it is known that black rats have overlapping home-ranges that are 4.01 ± 0.35 hectares (Shiels 2010). This layout provides many traps (up to 15) per rat home-range. This spacing should provide enough protection for the resources and an adequate number of traps with which to experiment.

The size of the automatic trap grid at Pahole is determined by estimating the coverage area that the snap trap grid at Kahanahaiki provides for the Kahanahaiki *C. superba* population. Because Kahanahaiki is a long and skinny management unit and the *C. superba* are at the north end of the MU, the plants range from 35-300 meters away from the edge of the grid, depending on the actual location of the plants. The north end of the Kahanahaiki MU is slightly less than 12 hectares. Based on this, a circular grid extending 200 meters from the *C. superba* in Pahole deploying traps across an area of 12.6 hectares was chosen to be the layout. There will also be additional traps on the perimeter to provide a barrier to rats from areas outside because that is the best practice for snap trap grids and there is similar buffer in Kahanahaiki.

In summary, the traps at Pahole will be installed in a 100 meter by 50 meter grid that extends approximately 200 meters in every direction from the *C. superba* with eight additional traps along the perimeter (Figure 3). In this scenario, a total of 45 automatic traps will be deployed. This grid layout creates a buffer of protection for the *C. superba* at Pahole that is somewhat comparable in size to the buffer of protection for the *C. superba* at Kahanahaiki. See Figure 2.

The automatic traps need to be installed and functioning by late October in order to achieve an adequate knock down of the rat population to prepare for *C. superba* fruit monitoring.


*Figure 3. Map depicts the automatic trap grid layout at Pahole NAR that is centered around the C. superba population (indicated by stars). Each black symbol represents one trap. The trap lines (A, B, C, D, E) are spaced 100 meters apart and the traps are each 50 meters apart on the trap lines. Eight additional traps are deployed on the perimeter between traplines for a total of 45 traps. This grid spacing of 100 m x 50 m is in accordance with the New Zealand Department of Conservation's recommendation for trap placement. The circle represents a 200 meter buffer around the C. superba plants; the squares are an example of the home-range size of a black rat (~4 ha, Shiels 2010).*

***Bait Selection for Traps***

One of the main obstacles in the snap trap grids is bait persistence; slugs and ants remove bait often within 24 hours. The automatic traps have a bait dispensing system that allows the traps to be active for long periods of time without visitation for re-baiting. Finding bait that persists in the field, is suitable for these traps, and is attractive to rats is crucial. As mentioned, it would be preferable to experiment with a variety of baits over time to find baits that work with the trap design, persist in the field for months, and are attractive to rats. However, there is no time to conduct bait trials due to the need to protect *C. superba* fruit before they mature. Baits cannot be altered during the data collection phase of this study for analysis

purposes, so it is prudent to choose a bait that is known to be attractive to rats, works with the trap design, and is recommended by the Department of Conservation (DOC) in New Zealand and Goodnature®.

In this project, peanut butter will be used as the bait as it is highly attractive to rats and can also be used on the snap traps at Kahanahaiki for comparison. The peanut butter will need to be refreshed/checked for freshness more frequently than desired in actual practice; a small amount of fresh peanut butter will be applied to the automatic traps on the same interval as the snap traps in Kahanahaiki for comparison. In this study the automatic traps will likely be checked more frequently than would normally be required so the bait won't need to have the longevity that is eventually desired.

As mentioned previously, the traps will be pre-baited with peanut butter on site prior to becoming active in order to attract and accustom rats to the traps.

***Data Collection Phase 1***

The primary objective for Phase 1 is to basically determine how well the traps work. Specifically:

**1. Do they kill rats and how quickly?**

*Explanation:*
The purpose is to ensure the traps work well in the field and also that they kill rats quickly. In this study, the study of humaneness by Jansen (2011) to determine time to death will not be replicated; rather staff will observe rat kills at the traps to confirm that no rats are left injured (yet alive) and indeed die quickly. If any anomalies are observed, this will be recorded and reported. This phase of the study will last approximately 3 weeks.

*Methods:*
To answer this question, there will be 3 cameras to record rat activity at the traps. The expectation is to see that rats are able to trigger the traps and that they are killed quickly. The total number of rats observed triggering the traps will be recorded. Any rat that is observed to be left alive/injured will be recorded and reported.

Ideally, these traps would have counters on them to record the number of times they are triggered. It would be possible to determine if the counters are accurately recording kills by cross referencing them with the video footage. The goal is to determine whether the trigger counters are a reliable representation of how many rats are killed.

In this initial phase of the study, there will only be a few traps installed in the field to collect this baseline 'kill' data. These traps will be checked often (multiple times a week) for inspection, collecting video footage, and to check for animal carcasses. During this period, all traps involved in the study will be placed on site and pre-baited to accustom rats to the traps and reduce any offensive smell.

***Data Collection Phase 2***

In Phase 2, the goals are: 1) To discover how rat activity is affected by the installation of the automatic traps, and 2) To observe how predation on natural resources (such as *C. superba*) is affected by the addition of the traps at Pahole. The bulk of data collection will be from this phase. Research objectives are as follows:

1. **How does rat activity in tracking tunnels change over time since the addition of the traps at Pahole and how does it compare with rat activity at Kahanahaiki (large snap trap grid)?**

   *Explanation:*
   The Program wants to compare rat activity at the two sites over the course of this study to ascertain any difference rat activity with the different control methods. The rat control area at Pahole will be similar in size and ecosystem characteristics to the area monitored in Kahanahaiki (12.6 ha and ≤12 ha, respectively). Tracking tunnels will also be installed at Kapuna MU where no rat control is occuring as a control site. Kapuna MU lies to the East of Pahole and serves as an adequate comparison site.

   *Methods:*
   Rat activity will be monitored using footprint tracking tunnels. Tracking tunnels use ink-pads and paper to record animal tracks. They are baited with peanut butter and set out for one night. Tracks will be scored by animal taxa and counted as either present or absent; no inference on the number of individuals is possible. Tracking tunnels are used to compare relative abundances of rodents within similar habitat types.

   Tracking tunnels will be set out prior to the beginning of this project to census pre-treatment rat activity at all sites. After the initial knock down of the rat population at Pahole, rat activity monitoring will occur at regular intervals (approximately monthly) at all sites for comparison.

2. **What is resource response to the automatic traps at Pahole?**

   *Explanation:*
   For the two rat control methods at given trap densities, rat predation on resources such as *Cyanea superba* fruit between sites will be compared to give an indication of the effectiveness of the automatic traps. OANRP will be able to determine whether the traps protect the *C. superba* fruit better than in previous years when there was no rat control. Additionally, OANRP will compare how the traps perform in comparison to the control in Kahanahaiki as indicated by fruit predation.

   *Methods:*
   Rat predation on *C. superba* fruit will occur at both Kahanahaiki and Pahole. OANRP will compare how *C. superba* fruit predation has changed at Pahole since the installation of the automatic traps compared to predation at Kahanahaiki with the trapping grid. This will be accomplished by comparing our data with data from Pender et al. (2012).

   In the study, Pender et al. (2012) found that predation by rats on *C. superba* fruit from December 2009 – January 2010 was higher than in Kahanahaiki where the trapping grid had been running since May 2009. This difference is assumed to be due to the lack of rat control in Pahole. Using their dataset, it will be possible to detect the change in fruit predation after automatic traps are installed in Pahole in 2012. If both Kahanahaiki and Pahole change similarly over time (either positively or negatively), then the addition of the automatic traps has had no effect on fruit predation (e.g. rats have not been controlled). If the change in the amount of fruit consumed by rats between the 2009/2010 fruiting season and the 2012/2013 fruiting season is significantly reduced in Pahole vs. Kahanahaiki, then it could be asserted that the automatic traps are more effective than no rat control and thereby comparable to the snap trap grid.

   Because the only significant change that has occurred between the sites since the study by Pender et al. (2012) is the addition of the traps at Pahole, this method of comparison controls for any ambient

changes that may have occurred. The grid at Kahanahaiki is largely the same and is maintained in the same manner as it was in 2009/2010.

OANRP will monitor fruit predation by following the steps outlined by Pender et al. (2012). To summarize, *n* number of plants will be monitored at each site for rodent damage every 2-3 days starting in mid December (or when fruit begin to mature). Preference will be given to plants that were part of the Pender et al. (2012) study and then randomly selected within that group or out of remaining plants. The monitoring of fruit will continue through to the completion of fruiting, which is likely to be around the second week of January. The total number of fruit on each infructescence will be counted at each visitation. The following is an example of data that may be recorded (as a percentage of the total number of fruits present):

- Natural fruit fall - fruits will be counted on the ground where they occur
- Fruits that have been damaged or eaten by rodents - the percentage of the whole fruit eaten will be estimated
- Fruits that have been wholly or partially eaten by birds
- Fruits that have rotted on the plant

In addition to the monitoring of *C. superba* fruit predation, rat predation on other native resources may be monitored between sites throughout the duration of this project. This may include placing attractive fruit on tracking cards at both sites periodically (possibly monthly).

**Other Project Goals**

1. Assess long term cost of maintaining traditional snap trap grids vs. automatic trap grids
    a. Initial cost versus reduced labor costs

2. Kalaupapa National Park Service (Molokai) will visit Oahu rat control sites to learn about various rat control/monitoring/data recording methods

3. OANRP staff will visit Kalaupapa to assess rat control needs and use of automatic traps

4. Produce a final technical report at the end of the project (project duration ~ 1 year).

5. OANRP will be able to recommend an initial design for the practical application of these traps in the field as a tool for ongoing natural resource management

**Additional Information: Snap Trap Grids**

The purpose of this section is to provide information about the trapping grid at Kahanahaiki that will be used to compare to the automatic traps in Pahole.

OANRP has installed large scale trapping grids in three management units (MUs). The first grid at Kahanahaiki was installed in May 2009, the second grid at Palikea was installed in September 2010, and the third grid was installed at Ekahanui in January 2011.

These grids are designed for large-scale lethal trapping for Black, Norwegian and Pacific rats (*Rattus* sp.) across MUs. The overall goal is to reduce rat activity within an MU to a level that benefits the endangered plants, *Achatinella mustelina* (Oahu tree snail), *Chasiempis ibidis* (Oahu Elepaio), native insects and the native ecosystem as a whole. The grids are designed to target rats because they are the

largest rodent threat to the natural resources OANRP protects. Mice have a much smaller home-range size than rats and the grids are not designed for effective trapping of mice. Prior to these grids, rat control in these areas consisted of using small-scale diphacinone bait station grids and snap traps surrounding an individual plant, small groupings of plants, individual snail trees or nesting locations of Elepaio. The large-scale trapping grids follow the New Zealand Department of Conservation's current best practices for kill trapping rats. Wooden rat trap boxes and tracking tunnel monitoring equipment were purchased from New Zealand in 2009. The box is designed to exclude non-target species, guide target species, prevent accidental triggering, and maintain the integrity of the trap from weather. Equipped with Victor® snap traps (Woodstream Corp., USA), the wooden boxes are deployed at Kahanahaiki. All 464 traps in the Kahanahaiki grid are normally checked and re-baited every two weeks; usually there will be fewer than 30 rats killed in the entire grid every two weeks.

Natural resources have shown a positive response to these trapping grids; however, as mentioned previously the grids are labor intensive to maintain, cause a lot of impact due to heavy foot traffic, and are inefficient as bait is often immediately removed by non-target taxa (slugs, ants). With an ideal bait, OANRP hopes that the automatic traps will be an effective, cost-efficient, simple, humane, environmentally friendly, and exemplary method for controlling rats in a Hawaiian forest setting.

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