Invasive Plants Species Management and Lowland Wet Forest Restoration in Hawai′i

A REPORT SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAI′I AT HILO IN PARTIAL FULFILLMENTOF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE
IN
TROPICAL CONSERVATION BIOLOGY AND ENVIRONMENTAL SCIENCE
PROFESSIONAL INTERNSHIP TRACK

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Abstract
This paper reports on two professional internships conducted as part of the Tropical Conservation Biology and Environmental Science M.S. Professional Internship program. The first was with the Big Island Invasive Species Committee (BIISC) learning about data and the metrics involved in capturing the effectiveness of control treatments. The second was working as the field crew leader with Liko Nā Pilina, a hybrid ecosystem restoration research project. These two internship opportunities were chosen based on my personal and professional interest in better understanding the landscape of invasive species management efforts.

Dedication

This is dedicated to my husband Tobias, children, Rokee and Toma, and the rest of my family near and far that continues to support and believe in me.

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I would like to thank the people that have contributed to this project including: L. Canale the TCBES Internship Coordinator, J. Sutton at the University of Hawaii, Hilo; K. Meehan, S. Kaye, B. Buckley, and J. Brunger from BIISC; N. DiManno, R. Ostertag, and the crew from the Liko Nā Pilina Project, A. Uowolo and S. Cordell at the USDA-FS Institute of Pacific Island Forestry; the TCBES cohort members.

To those who have inspired and facilitated my professional development as a scientist, thank you. C. Souza, R. Souza, R. Jacinto and the rest of the crew from Hawaiian Macadamia Nut Services, LLC; P. Groffman, L. Martel and the amazing people at Cary Institute of Ecosystem Studies; V. Dolja and E. Kurth, Botany and Plant Pathology Department, Oregon State University; R. Regan, Department of Horticulture, Oregon State University.

To my family who helped make this dream possible through their support and encouragement.

The most important acknowledgement goes to my husband Tobias, thank you.

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Introduction

My interest in pursuing a M.S. through the Tropical Conservation Biology and Environmental Studies stems from a couple of observations in professional and personal life. After moving to Hawaiʻi Island in 2015, I was hired as an Agricultural Associate in the research department of a large macadamia nut company with two 2600+ acre macadamia nut orchards located on the east side of Hawaiʻi. Around the same time my husband and I bought our first home. Professional goals bloomed from both experiences; the first helped identify a lacking skill set I became interested in obtaining to further my career, while the second resulted in a growing awareness of a problem that I wanted to address. With the mac nut orchard, the company was interested in increasing production in some of the lower producing areas of the orchards. What I lacked was the training and skill set to design a study, perform data analysis, and effectively communicate results that would identify affordable and feasible ways to increase production in a timely manner. At my home, it seemed like the landscape was composed mostly of invasive plant species and fire ants that prove extremely difficult to eradicate. The property is three acres of former agricultural land and no longer in production. What grew back was mostly invasive plant species like Albizia (*Falcataria moluccana*), Strawberry Guava (*Psidium cattleianum*), Melastoma (*Melastoma septemnervium*), Melochia (*Melochia umbellata*), Clidemia (*Clidemia hirta*), and Guinea grass (*Urochloa maxima*). My professional background is in agriculture and horticultural production, and so although I could see what the problem was, I did not have the knowledge or experience to know how to fix it. It did not take long before the challenges of managing such a degraded ecosystem became overwhelming, resulting in more questions than answers.

These initial observations grew into two overall objectives; 1) gain research study experience including study design, data collection, analysis, and results communication, 2) develop an understanding of invasive species ecology and effective land management strategies in Hawai′i.

To gain experience and satisfy both of my objectives, I conducted two professional internships while in the Tropical Conservation Biology and Environmental Science M.S. Professional Internship program. The first was with the Big Island Invasive Species Committee (BIISC) learning about data and the metrics involved in capturing the effectiveness of control treatments. The second was working as the field crew leader with Liko Nā Pilina, a hybrid ecosystem restoration research project.

As the two internships were conducted independently of one another I've structured this final report as such, first addressing the BIISC internship then following with the Liko Nā Pilina internship. In conducting both internships knowledge and experience was gained that helped me achieve my professional goals.

Big Island Invasive Species Committee Professional Internship

A. Background

Invasive Species and Hawai′i

Invasive plant species are introduced species which have the ability to grow and spread in a new range and can have a wide variety of negative effects on ecosystems which include altering the hydrology, productivity, nutrient cycling of invaded areas, species diversity, and community outcomes (Vitousek 1990, Mack 1997, Pysek et al. 2011). Invasive species are typically able to adapt to a range of habitats while native plant species tend to be more niche specific, especially on islands, making it harder for native species to adapt to environmental

changes (Funk et al. 2008). The adaptability of invasive species is one of the primary threats to native species and conservation efforts (Lohr et al. 2017).

The extreme geographical isolation of the Hawaiian Archipelago limits the type and amount of species that can naturally reach the Hawaiian Islands. The oceanic isolation has allowed the evolution of high numbers of endemic organisms, species that are only found in a particular area. Dawson et al. (2017) found that out of 186 islands and 423 mainland areas surveyed, the Hawaiian Islands had the highest amount of invasive species.

Big Island Invasive Species Committee

Big Island Invasive Species Committee (BIISC) is a project supported by the University of Hawaiʻi Pacific Cooperative Studies Unit. The committee is made up of non-profit, private, and government organizations along with individuals who are interested in protecting the State of Hawaiʻi from harmful invasive species. The goal of BIISC is to protect the native forests, agriculture, and communities on the Big Island from invasive species threats. That is achieved through the prevention, detection, and eradication of invasive species throughout the Big Island. BIISC has invasive species outreach programs targeting Little Fire Ant (*Wasmannia auropunctata*) and albizia (*Falcataria moluccana*), which successfully engage the community to work together to eradicate those species.

A. **Purpose of the BIISC Professional Internship**

The purpose of the internship was to learn about the effectiveness of invasive species control treatments through data analysis, using an invasive weed field data set provided by BIISC. The objective of the internship with BIISC was to determine if the invasive species field survey data set contained metrics useful in evaluating whether the invasive species control

efforts were successful. The deliverable was a technical report containing the results of the data analysis and observations about the challenges encountered while attempting to analyze the data.

B. **Graduate Student Learning and Professional Development Objectives**

Professionally, my objectives have evolved from the start of this program to the present day. Initially, I was interested in developing the skill set needed to design a good study, analyze the data accurately, and communicate the results to stakeholders that would be funding said and or future work. On a larger scale I was interested in developing my communication and presenting skills, getting involved in conservation in Hawaiʻi, and increasing my knowledge of native Hawaiian plants. Over time, my initial goals broadened to include developing a deep understanding of the effects of invasive species on Hawaiian ecosystems, and the management actions being taken to reduce the impact of invasive species in Hawaiʻi.

C. **BIISC Professional Internship**

1. **Role**

My role with BIISC was as a graduate student gaining data analysis experience while determining if the BIISC field survey data set contained metrics useful in evaluating the success of invasive species eradication decisions.

2. **Responsibilities:**

Due to the nature of my internship with BIISC I had minimal responsibilities except for a technical report submitted at the conclusion of the internship.

3. **Description of Deliverables**

a. **Meaningful and Challenging Work**

My work with BIISC provided me the opportunity to grow professionally. I got to see what invasive species management looks like and the challenges involved. This gave me a

greater appreciation for the work they are doing and the dedication it takes to face such a challenge as invasive species management in Hawaiʻi. The perspective I developed from my time there is very meaningful and crucial in my professional development in the world of conservation.

b. **Knowledge of the Agency Ecosystem**

Initially, I knew very little about how BIISC as an agency operated, but over time developed a basic understanding of how it runs. To tackle many invasive species issues BIISC has multiple types of teams who respond to their respective responsibilities; early detection of invasive species, invasive species management actions, Rapid Ohia Death (ROD) management actions, and community outreach. Involved with all the teams are; the fiscal & program associate, GIS Specialist/data analyst, and agency manager.

c. **Parameters of the Agency's Purview**

The parameters of BIISC's purview include prevention, detection, and control of invasive species on Hawaiʻi to the extent the laws allow through grants, partnerships, and collaborations to eradicate invasive species on public, private, and government lands.

d. **Advocacy or Outreach experience**

Advocacy and outreach was not the focus of this internship and so experience was not gained in those particular areas. I have no doubt BIISC would have happily provided those experiences had I expressed the interest.

4. **Timeline**

To accomplish the objectives of the project, a timeline was created to illustrate the different phases and expected time it would take to complete them. The first task of the project was the pilot project which was a project for CBES 670 and designed to get me familiar with the

data set. Because I was unfamiliar with the sites and codes used to enter the data, the second task was to create metadata. The third task was the actual data analysis part of the overall project. The next was to perform GIS data analysis using ArcGIS. The final task of the project was to write the technical internship report for BIISC, and then finally the internship report fulfilling the TCBES program requirement.

BIISC Professional Internship Project Timeline

2019								2020					
April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
Pilot Project													
	Metadata												
			Data analyisis										
					GIS data analysis								
	Literature review												
								Internship report writing					

Fig. 1. Timeline of tasks to be accomplished to complete BIISC professional internship project.

Approach

BIISC has collected survey data on their eradication efforts since 2005. The data set I worked with for my internship project involves eight invasive plant species BIISC has targeted for eradication: Smoke bush or butterfly bush (*Buddleia madagascariensis*), Pampas grass (*Cortaderia jubata*), Silver-leaved cotoneaster (*Cotoneaster pannosus*), Rubbervine (*Cryptostegia madagascariensis*), Holly (*Ilex cassine*), Nile tulip (*Markhamia lutea*), Pereskia (*Pereskia aculeata*), Photinia (*Photinia davidiana*), and Moluccan raspberry (*Rubus sieboldii*). Data collected from 2011 to 2018 includes: invasive plant species, site, acres treated, treatment type, presence/absence of flowering, age (juvenile, adult), canopy stature (over-story, mid-story, upper-story), ecotype (Ōhiʻa (*Metrosideros Polymorpha*), Albizia (*Falcataria moluccana*) , Clidemia (*Clidemia hirta*)), and latitude/longitude.

A. **Strategies and Methods for Each Major Undertaking of the Internship**

To tackle the data analysis aspect of the internship I adhered to the steps as outlined in the data analysis cycle. The data analysis cycle outlines six steps in a data driven project: 1) Understanding the issues, 2) Understanding the data set, 3) Data preparation, 4) Exploratory analysis/modeling, 5) Validation, and 6) Visualization and Presentation.

The data used for my internship project was a data set provided by BIISC consisting of invasive plant species field data which encompassed the years 2011-2018. The objective was to determine whether that data set contained the metrics to show the effect of the eradication efforts over time. The variables included were the eight invasive species BIISC has targeted for eradication, the corresponding sites where each invasive species was found from 2011-2018, and all associated variables including plant counts, ecosystem type, and acres treated.

Excel was used to organize the data set, while R studio was used for all statistical analysis. The initial analysis was done as a pilot project for CBES 677, Quantitative Ecology. For the purpose of that project it was decided to limit the amount of variables by selecting only variables that had data collected consistently from 2011-2018 which included number of acres treated, site, immature and mature plant counts, and species. The initial attempt at analysis was unsuccessful due to incorrect assumptions made by combining site names during the third step of the data analysis cycle, data preparation.

A second attempt, restarting at step 4 (exploratory analysis) focused on looking at post treatment invasive species abundance overtime. The variables included were butterfly bush (*Buddleia madagascariensis*), year, site, and treatment type. This attempt also proved unsuccessful as it was ultimately determined that the included variables were not appropriate for the intended analysis model of logistic regression. This second analysis attempt marked the conclusion of the pilot project for CBES 677. At this point in the internship project it was

decided to try again starting at step 2 (understanding the data set) in the data analysis cycle to identify the appropriate means of analyses. Unfortunately, attempt three at statistical analysis was also unsuccessful because when the final cleaned up version of the data set was compared to BIISC's master data set, there were inconsistencies with reported counts between the two data sets.

In a fourth and final attempt to identify metrics contained in the data set useful in determining the result of the eradication efforts, the decision was made to try a different approach. Most of the variables included in the data set had been eliminated from consideration due to data entry errors or because many of the initially reported variables were not included in later years of the data set. The data I chose to focus on included only one site (Kaulana Manu), only one targeted invasive species (*C. pannosus*), juvenile and mature plant counts, and year. R studio was used to create a graph showing the change in both juvenile and mature *C. pannosus* plant counts from 2014, when data collection and treatment started at this site, until 2019. Kaulana Manu also called Kīpuka 21, is located not too far out of Hilo on saddle road just before the Mauna Kea scenic viewpoint. This site is also home to Kaulana Manu nature trail and is a popular place for birders to see some of Hawai′i Island's native forest birds. It should be noted that data collection at this site is ongoing and continued after the completion of this project. Updated data could affect the graphs.

B. Assessment Method to Evaluate Achievement

The objective of the internship project with BIISC was to determine if the invasive species survey data set contained metrics useful in evaluating the eradication efforts of the eight targeted invasive plant species. Multiple efforts were made to answer that question using

statistical analysis and when those efforts were unsuccessful changes to the approach were made to instead look at data graphically to satisfy the project objective.

Outcomes

A. **Deliverables**

The graphical representation of data shows a clear increasing trend in mature *C. pannosus* plant counts from the initial survey in 2014 until 2016 and then a steady decreasing trend. The immature *C. pannosus* plant counts follow a similar pattern except the counts increase until 2017, at which point they indicate a steady decrease in plant counts.

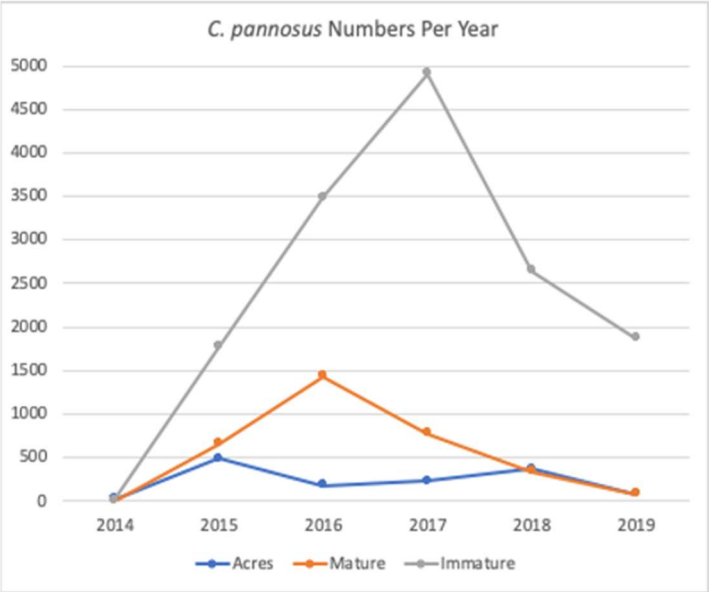

Figure 1. X-axis shows the number of plants, y-axis shows the year.

The overall deliverable for the BIISC internship was a technical report submitted to BIISC. The report was based on the work put into the data analysis cycle using the invasive species data set.

Discussion

The aim of this project was to determine if the data set is useful in determining if BIISC eradication efforts have been successful. *C. pannosus* plant counts clearly show a consistent decrease in both mature and immature over time. Yet, the results of the project raised the question: why did plant counts increase for several years despite BIISCs efforts utilizing both manual and chemical control methods? It was suggested that this was the time required to exhaust the seed bank or at least get ahead of it enough to make obvious progress in the effort to eradicate *C. pannosus* from Kīpuka 21. While specific information on *C. pannosus* seed bank persistence was not available there is speculation that the seed bank persistence can be relatively short or last as long as several years (Bossard et al. 2000; Western Australian Herbarium 2017). What is known is that many cotoneaster species require stratification and/or cold temperatures to break dormancy so ingestion by animals could be crucial in aiding the spread of *C. pannosus* (DiTomaso et al. 2013). Research suggests that it takes a couple of years for *C. pannosus* to reach maturity and produce fruit containing the seeds. The abundance of birds at Kīpuka 21 can aid significantly with *C. pannosus* dispersion.

Some of the challenges encountered in this internship included my limited knowledge of data analysis, unfamiliarity of the field sites and data collection method, and common data analysis issues, such as data entry errors. For example, my original plan was to transition into using ArcGIS to further analyze the invasive species data set. However, I overestimated how much I remembered about how to work in ArcGIS and made the decision to drop the advanced ArcGIS class which was scheduled for the fall term and enroll in the introductory ArcGIS class in the spring. My internship with BIISC concluded with the fall 2019 term. Fortunately, in the spring 2020 term I started my second internship, in order to learn more about invasion dynamics,

which was with the Liko Nā Pilina hybrid restoration project; and was able to use one of their data sets for a final mapping project in the GIS class, CBES 670.

Liko Nā Pilina Internship

A. Background

Hawaiian Lowland Wet Forests

The lowland wet forests of Hawai′i are endangered due to historical and continued introduction of alien species and ecosystem alteration by humans (Zimmerman et al. 2008). Because the lowland wet forest has been so heavily altered, we do not have a clear idea of what native species originally inhabited it. This proves challenging in efforts to restore this native ecosystem because traditional or historical ecological restoration maintains the goal of returning a degraded or damaged ecosystem to a previous state in which it was considered healthy.

The Keaukaha Military Reservation (KMR) in Hilo, Hawai′i resides within a highly modified lowland wet forest on a 1200-year-old lava flow (Ostertag et al. 2009). When compared to other lowland wet forests on younger lava flows in East Hawaii, KMR is especially susceptible to invasions by high nitrogen use plants due to the increase in available nitrogen found on older lava flows (Zimmerman et al. 2008). Characterized as a closed canopy wet forest on an ‘a‘a lava between 750-1500 years old, though highly degraded, it is one of the few lowland wet forests still in existence in Hawai′i (Zimmerman et al. 2008). The over-story is composed mainly of the native trees ‘ōhi‘a (*Metrosideros polymorpha*) and lama (*Diospyros sandwicensis*). The mid and under-story are made up of a variety of ferns, shrubs, and smaller trees (DiManno, 2020). While the over-story is still composed mainly of native *M. polymorpha* and *D. sandwicensis* in some places, KMR is facing increasing pressure from invasive plant species. The three most prevalent invasive tree species are strawberry guava (*Psidium cattleianum*),

bingabing (*Macaranga mappa*), and melastoma (*Melastoma septemnervium*) (Cordell et al. 2016). The increasing onslaught of invasive plant species is negatively affecting native seedling regeneration (Zimmmerman et al. 2008, Ostertag et al. 2009).

Cyrtandra

Cyrtandra, the largest and most widespread genus in the Gesneriaceae family, has over 500 species dispersed throughout the pacific and southeast Asia (Clark et al. 2009). As widespread as the genus is, the endemic species within *Cyrtandra* are very narrowly dispersed, often occupying only a single valley, island, or archipelago (Clark et al. 2009). There are 60 shrub and small tree species endemic to the Hawaiian Islands which are usually found in wet forests, occasionally mesic forests (Johnson et al. 2015). About half of the Hawaiian *Cyrtandra* species are classified as extinct, rare, or endangered (Native Plants Hawaii 2009).

Cyrtandra nanawaleensis and KMR

The endangered *Cyrtandra nanawaleensis* is known to exist at Keau‘ohana Forest, Puna, and KMR. It was found at three different locations within KMR in January 2014, between the three populations there were a total of 34 plants. As an understory plant species, C. *nanawaleensis* is very sensitive to light levels and has specific dappled lighting requirements. By February of 2019 all the wild populations at KMR had unfortunately died and it is suspected to be due to changes in the light levels caused by a combination of loss of Ohia canopy due to ROD and increasing invasive tree canopy (DiManno 2020).

Invasive Resistance Strategies

The global scale introduction of alien species into new ecosystems due to human assistance, deliberate or not, has increased to the point where very few ecosystems in the world

are unaffected (Hobbs et al. 2006). Eradication of an invasive species as a strategy may not always be enough to facilitate system restoration (Zavaleta et al. 2001, Ostertag et al. 2009). Increasingly, conservation managers are tasked with managing ecosystems in varying stages of degradation. To address the challenges in the current landscape of ecosystem restoration, managers need multiple strategies and tools to combat the rapid spatial changes (Hobbs et al. 2014).

Forest ecosystem restoration

Historical ecosystems

Traditional ecological restoration is the process of actively repairing an ecosystem which has been damaged or degraded to some degree by human activity. Some of the strategies include removing invasive or unwanted plant and animal species, reestablishment of endemic and native species (Higgs 2003).

Novel ecosystems

Novel ecosystems are ecosystems with combinations of species within a biome which have not been seen before. Ecosystems need to have three main characteristics to be considered novel (Hobbs et al. 2006, Higgs 2016).

1. New mixes of native and non-native species with the ability to affect some function of ecosystem in a way that did not exist before human disturbance.
2. The novel ecosystem can sustain the new species composition and does not require active management.
3. Novel ecosystems cannot realistically be restored to historical species composition and function.

Hybrid ecosystems

Hybrid ecosystems are considered a combination of both historical and novel ecosystems.

Liko Nā Pilina Project

Liko Nā Pilina is a hybrid ecosystem restoration project started in 2013, located at Keaukaha Military Reservation (KMR) in Hilo, Hawai′i. The name of the project, Liko Nā Pilina, loosely translates to 'growing new partnerships'. The goal of the project is to restore and protect the degraded lowland wet forest using a hybrid forest restoration strategy which allows for both non-native, non-invasive species and native species to create plant communities that can provide invasive resistance, increase carbon sequestration, support native biodiversity, is suitable for military training exercises, and requires very little management. The project is evaluating four different treatments of native and non-invasive non-native tree species. The species chosen for outplanting were selected based on their functional traits.

A traditional approach was tested at the same site where the invasive plant species were removed, and the native species were left intact. The results of the study showed that even with the removal of non-native invasive species, the resulting regenerating forest was mostly non-native. It was determined that even though there was native seed presence in the seed rain, the seed bank was flooded with non-native invasive species. Without continuous weeding efforts, non-native invasive plant species would continue to invade and replace native species in lowland wet forests (Ostertag et al. 2009, Cordell et al. 2009, Cordell et al. 2015). It was determined that to save and protect Hawaiian lowland wet forests from the constant and increasing threat of invasive species, new restoration strategies would need to be evaluated. From this initial study on the effects of non-native species removal in Hawaiian lowland wet forests, Liko Nā Pilina was born.

In April 2018, DLNR DOFAW issued an annual permit (renewed in April 2019) to the Liko Nā Pilina team allowing for the collection and propagation of *C. nanawaleensis* for research and species preservation.

The permit includes three objectives:

1. Collect seed and leaves from wild populations to grow in a greenhouse and outplant at Keaukaha Military Reservation (KMR) into areas with suitable microhabitat conditions.
2. Conduct research on wild populations to determine suitable microhabitat conditions.
3. Conduct research on wild populations to determine the functional trait expression of this species.

Research conducted by James Melcher in 2017 for his undergraduate senior thesis identified key microhabitat characteristics for *C. nanawaleensis* to thrive in Hawaiian lowland wet forests. The primary characteristics Melcher's study identified included light levels and substrates preferences.

In August 2018, a NSF grant was awarded to the research team which facilitated a project looking at the effect plant functional traits have on multitrophic interactions. The objective of the arthropod functional diversity project was to evaluate the effect of the planted communities on the microarthropod communities thriving there.

B. Purpose of the Internship Project

The purpose of the internship was to develop a deeper understanding of lowland wet forest ecology in East Hawaii, hybrid forest restoration; native and non-native invasive plant species, care and propagation of endangered Hawaiian plant *C. nanawaleensis,* and the necessary metrics and tasks involved in a research project.

C. Graduate Student Learning and Professional Development Objectives

The interest I developed in invasive species management evolved into an interest in specific forest restoration strategies to better protect Hawaiian forest species which led me to the ORISE internship working on the hybrid ecosystem project Liko Nā Pilina.

My goals entering the internship included:

- grow my knowledge of invasive, exotic yet non-invasive, and native plants of the lowland wet forest and associated ecology at KMR and in Hawai′i.
- Learn about data collection strategies for forest restoration research
- Lead field crew in recurring data collection tasks
- Contribute to the project goal of propagating and outplanting *C. nanawaleensis*

The overarching objectives of the internship were to perform field data collection tasks in a manner to support the project, continue the effort to successfully propagate, grow, and outplant *C. nanawaleensis,* and develop as a conservation resource manager in Hawai‘i.

D. Liko Nā Pilina Internship

1. Role

My role with Liko Nā Pilina is as the field crew leader.

2. Responsibilities

Litter collection: Litter from each treatment plot is collected during the first week of the month to inform on outplant litter fall contributions.

Seed collection: Seed rain was collected to determine the mix of native, non-native non-invasive, and invasive plant species seed rain occurring within the four different treatments.

Phenology: The presence or absence of fruiting and flowering data is collected during the third week in the month from specific outplanted species in the treatments.

Leaf area index (LAI) and canopy photos: LAI measurements and canopy photos are taken once a year to provide data on changes in lighting levels and canopy closure overtime.

Weekly hours data collection: Weekly hours are collected to determine the amount of time spent on a task and whether that changes over time. This is particularly useful when it comes to weeding and evaluating if treatment plots are requiring less weeding over time and has informed an economic evaluation of this restoration approach.

Monthly solar and fence perimeter checks: The plots are protected from ungulates and requires monthly checks to ensure the solar boxes powering the electric fences are working and in good order. The fences themselves need to be checked for fallen limbs and trees across the fence, allowing easy access to ungulates. A climate station, located in one of the experimental restoration plots, gets a fresh desiccant pack weekly or bi-weekly to ensure moisture does not interrupt the climate data collection process.

Weed surveys & weeding: Annual weed surveys and weeding are conducted to control weed pressure in the treatment plots with the hope of reaching a point where the hybrid ecosystem can resist invasive pressures, no longer requiring consistent human intervention.

Care of and propagation of Cyrtandra nanawaleensis: The *C. nanawaleensis* is housed in a greenhouse at KMR and is checked three times a week, more frequently when the weather is fluctuating unpredictably (i.e. storms, sudden hot days). Monthly mortality checks are conducted in order to keep track of surviving plants, successful propagation methods, and mortality timelines. During these visits the plants are checked for signs of disease and vigor, stress, other pests, and water needs. Lighting may be adjusted if it seems prudent along with water applications. Repotting was necessary multiple times due to sudden situational changes and new information on media types *C. nanawaleensis* could find preferable. The goal is to figure out

propagation techniques and methods that allow the *C. nanawaleensis* to thrive and be able to be outplanted at KMR.

3. Description of Deliverables

a. Meaningful and Challenging Work

The internship with Liko Nā Pilina was really interesting because it provided me with an opportunity to learn about and work with native forest trees and the effect of invasive tree species on Hawaiian lowland wet forest ecology.

The field work was challenging due to the rugged nature of the sites along with learning to do a new task in such a physically demanding environment in combination with leading a crew to do said task. It took as much mental stamina as it did physical, maybe more. Fortunately, the tasks are recurring and the crew experienced, so the initial challenges dissipated as I became more familiar with the site and tasks. What was left was a growing sense of confidence and enjoyment with the responsibilities tasked to me.

Another challenge was the care of the endangered Hawaiian plant species *Cyrtandra nanawaleensis*. This is the first time I've worked with an endangered species and I think that adds a little extra pressure and motivation to contribute to its success. It is a privilege to get the opportunity to give back in this way. Unlike the field tasks, there is not entirely an established protocol with *C. nanawaleensis.* Fortunately, some research has been conducted on this species locally (Ann Kobsa at Keauo'ohana Forest Reserve & Jaime Enoka at Volcano Rare Plant Facility) and by the Liko Nā Pilina research team at KMR, so there is a certain amount of existing knowledge about what this particular species cannot tolerate and what it needs to survive. In order to contribute to this project and continue to move toward the goal of outplanting *C. nanawaleensis* at KMR I had to do some troubleshooting and practice adaptive management.

For example, in February 2020 a few of the people working on the Liko Nā Pilina project got the chance to visit the Rare Plant facility in Volcano, HI to get to see first-hand the propagation methods they are using with *C. nanawaleensis.* Based on those techniques I propagated five cuttings using two and a half leaves, that is all the plants could safely spare. Two of the five cuttings had plantelets as of April 2020. Based on care methods used by the Rare Plant facility and advice from senior members of the research project I changed the substrate media for the existing seedlings at the same time I propagated the leaves.

b. **Knowledge of the Agency Ecosystem**

This project has three principal investigators; Rebecca Ostertag (University of Hawaiʻi, Hilo), Susan Cordell (USDA Forest Service at the Institute of Pacific Island Forestry), Peter Vitousek (Stanford University) and Robert Peck (University of Hawaiʻi, Hilo). Other team members include Nicole DiManno, formerly Jodie Schulten both with UH Hilo, and Trebor Hall also with UH Hilo. Other Forest Service staff include Amanda Uowolo and formerly Taite Winthers-Barcelona and Laura Warman. The project has also worked with post docs and many student interns conducting their own research. There have also been many student employees and volunteers who have supported the project over the years. As typical for a scientific study, publications on the results of the projects are also produced.

c. **Parameters of the Agency's Purview**

It is the goal of this project to identify lowland wet forest hybrid restoration outplanted communities from a mix of native and non-native non-invasive plant species that provide invasive resistance in order to protect endangered Hawaiian lowland wet forests from extinction.

d. **Advocacy or Outreach experience**

There was the opportunity for outreach experience, unfortunately I had a scheduling conflict which kept me from participating in the outreach event.

4. Timeline

My internship was approximately 5 ½ months long, starting December 23, 2019 and ending May 31, 2020. The main field tasks I was responsible for included; litter collection, phenology, plot weeding, fence line and solar box maintenance, and care of *C. nanawaleensis*.

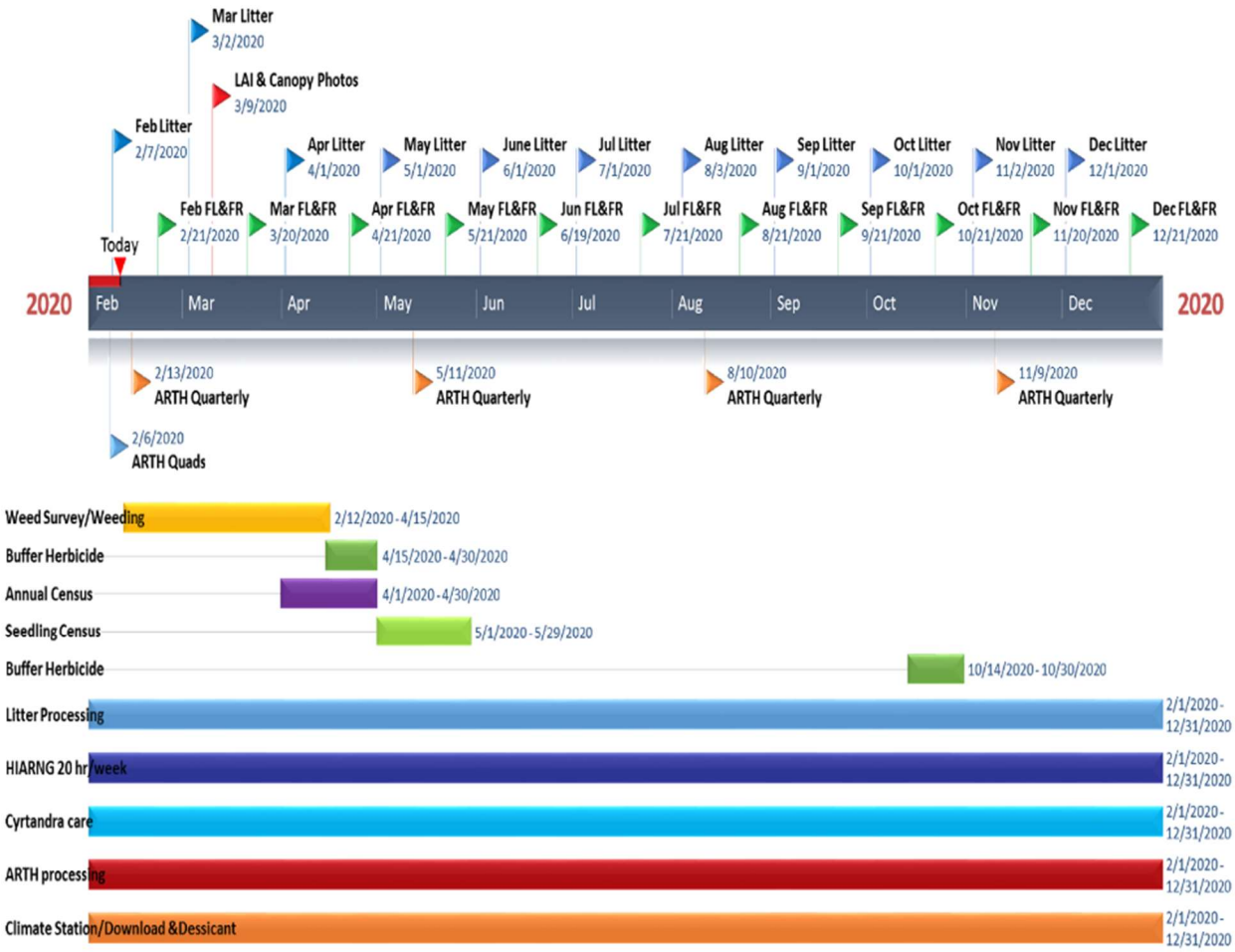

Figure 3. 2020 timeline for data collection and field tasks supporting the Liko Nā Pilina project.

Approach

The study site at KMR includes four blocks, within each block are five plots. Each block contains one of each of the treatments and a reference plot, totaling 20 plots: 16 treatments and 4

reference. The treatments consist of 10 native and 10 non-native woody species selected based on their functional traits and outplanted in 2013 after the treatment plots were cleared of any invasive plant species. Native plants species contained within the plots were not removed. Some of the traits considered in species selection included leaf thickness, photosynthetic rate, and seed size. The size of the plots is 30 x 30 meters, the actual treatment plots are 20 x 20 with a 5 meter buffer around the whole plot. The plots are further divided into 15 quadrants except Moderate Carbon Redundant treatment which have 20 quadrants.

The four treatments are Slow Carbon Complementary, Slow Carbon Redundant, Moderate Carbon Complementary and Moderate Carbon Redundant. The treatments each have 15 large trees for per plot with the exception of Moderate C Redundant which has 20 large trees per plot. Slow and moderate carbon storage outplanted species were selected based on carbon storage functional traits to foster slow and moderate carbon turnover (i.e. wood density, leaf area, LMA, and leaf C:N). The complimentary and redundant species selected for outplanting were based on the similarity and divergence on their functional traits.

A. Strategies and Methods for Each Major Undertaking of the Internship

The field work and data collection have established protocols and are recurring so my overall strategy with each task was to follow the protocol and draw upon the experience of those training and working with me. In order to become more familiar with the location and orientation of the plots I printed out a map on waterproof paper to consult when necessary (frequently). Specific to the phenology, the selected trees are marked with red and white striped flagging. Some of the flagging has fallen off and I started to replace the missing flagging to decrease the amount of time I spent locating the phenology species.

To address the physical challenges presented by the site I started by figuring which type of footwear is the most effective for me, rain boots when it was continuously pouring down rain and running shoes otherwise. Footwear is very important at this site. The jagged and sharp lava really chews through some materials. Second was listening when it was suggested I pay close attention to my hydration. Between the work, humidity, and heat it is easy to become dehydrated. The third strategy I used was to stay mentally focused on the task and paid attention to the ground I was walking on.

Caring for *C. nanawaleensis* required me to conduct my own research, make observations and changes crucial to plant survival, keep an open mind, and communicate with Nicole and the Liko Nā Pilina team and Jaime Enoka from the Rare Plant Facility to come up with new solutions.

B. Assessment Method to Evaluate Achievement

The established protocols contain timelines for each task and so I used this in part as a way to evaluate my performance on a task. Completing the tasks within the established time frame was not always achieved due to my inexperience and/or availability, as well as crew availability.

Outcomes

A. Deliverables

The deliverables for this internship included the field and data collection tasks, *C. nanawaleensis* care and propagation, and a report on my internship. Initially, completing the monthly tasks like phenology on time was challenging due to my lack of familiarity with the species and plots. However, as I became more proficient in the field, the amount of time it took to complete the tasks decreased.

The care and propagation of *C. nanawaleensis* was more challenging because despite my initial efforts the plant numbers continued to decrease. Multiple events beyond my control (i.e. flooding, sudden hot weather) contributed to the mortality rate. Media composition was changed and domes were added to the tops of the tanks to allow more controlled air flow. A couple of seedlings have continued to grow, and after my propagation effort on Feb. 20, 2020, there are a couple of new plants.

Discussion

This internship provided me with extensive opportunities for learning and growth. The field work allowed me to learn and practice data collection techniques, time management, leadership, and develop a deeper understanding and appreciation for lowland wet forest restoration in Hawaiʻi. I was able to see first-hand the effects of invasive species and learn about the benefits of designing a hybrid ecosystem using plant species functional traits. The Liko Nā Pilina project was more challenging than I anticipated in large part due to my limited schedule and other commitments (i.e. graduate school, two small children). There were many times where I felt like I really needed to put in more time but I just did not have it to give. However, as the internship progressed I found myself increasingly comfortable with the tasks and felt confident that I would have continued to increase both my project knowledge and ability to fulfill my role as field crew leader. Unfortunately, due to the Covid19 pandemic the study site was shut down with two months remaining in my internship.

The *C. nanawaleensis* work was more in my wheelhouse because I have a horticulture background and have been very interested in working with endemic and native Hawaiian plants. While we did not outplant any *C. nanawaleensis* during my internship I do believe it will happen

and hope that some of the decisions I made while caring for them ultimately contributes to their success at KMR.

Conclusion

The two internships differed in what they required of me, but they fit so well together I cannot have imagined only doing one of them. They both provided the opportunity to grow professionally and achieve the two objectives I had going into the TCBES program which were to; 1) gain research study experience including study design, data collection, analysis, and results communication, 2) develop an understanding of invasive species ecology and effective land management strategies in Hawaiʻi.

Through the professional internship with BIISC I was able to learn about the data analysis cycle and grow my knowledge about the impacts of invasive species in Hawaiian ecosystems. I also learned about the metrics involved in data sets to determine success using eradication methods. My internship with BIISC also deepened my personal interest in controlling invasive species at my own home and helped instill a sense of responsibility to the community.

The professional internship with the Liko Nā Pilina project took my interest in invasive species management and refined it into an interest in invasive resistance. The opportunity to be the field crew leader strengthened my communication and leadership skills, helping refine me in ways I had not anticipated. Part of my strategy to be a good leader was to listen to the stories from the other about lessons learned. The physical challenge of the field site taught me the importance of focusing on the terrain, weather, hydration, and task in order to collect accurate data. Those things do not need to slow down the work pace, but they can if allowed to and it can lead to sloppy data collection. As a field crew leader, I needed to ensure that data were collected in a timely and accurate manner. The work I did with *C. nanawaleensis* allowed me to fulfill a

professional goal of working with native plant species. Because *C. nanawaleensis* is endangered, the sense of accomplishment and contribution was especially meaningful.

The TCBES M.S. Internship track program, along with my two internships refined me personally and professionally in ways I will benefit from and reflect on for years to come. The feeling I am left with is a profound sense of gratitude and a self-imposed obligation to continue the conservation work I was exposed to.

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