Buried Alive: Assessing Soil Seed Bank Persistence to Assist in Invasive Species Eradication

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ABSTRACT

Understanding the seed biology of invasive plant species can assist managers in achieving eradication, particularly as it applies to scheduling treatment intervals (in conjunction with plant phenology) and monitoring for recruitment following removal of all target plants. Knowledge of seed bank potential, or how long seeds remain viable when in the ground, is critical to defining eradication for a taxon. Over the last ten years, the O'ahu Army Natural Resources Program (OANRP) collected mature fruits from nine naturalized or incipient invasive species to classify their soil seed bank type. Seeds from each of the species were kept in dark, wet conditions in the laboratory and/or buried in durable bags six inches below ground in the field. Bags and seeds were retrieved and sown at regular intervals to assess viability. As a result, taxa were classified as having transient, short-term persistent, or long-term persistent soil seed banks. This information will assist in developing control strategies and determining eradicability for these taxon, on a species and site level.

BACKGROUND

OANRP mitigates for threats that impact endangered species found in and around Army training areas (Fig. 1). This includes removal of both naturalized and incipient invasive plant species. While habitat restoration is the goal of most weed control efforts, select incipient invasive taxa are targeted for eradication. Determining the persistence of the soil seed of target weeds guides both habitat restoration and eradication efforts, and is critical to identifying if/when eradication of a specific infestation can be achieved. Species persist in the soil seed bank for varying amounts of time (Table 1).

Table 1. Soil Seed Bank Potential Definitions

Soil Seed Bank Type	Seed Viability
Transient	up to 1.5 years
Persistent, Short Term	1.5-5 years
Persistent, Long Term	longer than 5 years

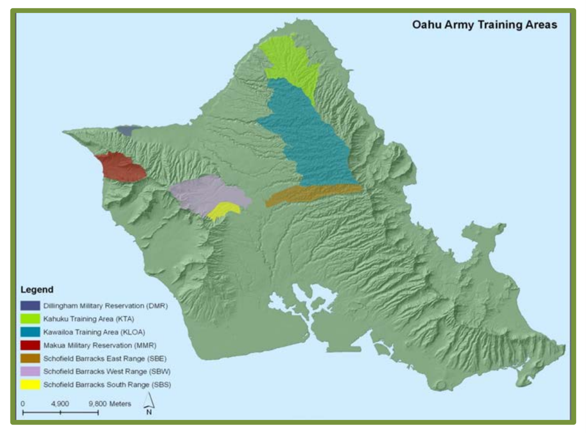


Fig.1. O´ahu Army Training Areas

METHODS

Seeds were opportunistically collected during weed removal activities in OANRP management areas.

<u>Initial Viability Assay</u>: Temperature, water, and light are important external factors affecting seed germination. Imbibition (uptake of water) of seeds is necessary for germination, while the presence of light can be a trigger for certain species. For this study, we considered a seed to have germinated when a radicle (root) and cotyledons formed. A subsample of each collection was sown in Petri dishes of 1% water agar in Percival© seed germination chambers (Fig. 2, exposed to light and moisture; average daily and nightly temperatures to mimic conditions at 2000' elev., northern Wai´anae Mountains).

Fig. 2. Seeds of *E. stipioides* germinating in an initial viability assay.

Fig. 3. (left to right) Collecting *C. odorata* seeds in the field. Installing *S. condensatum* buried seed trial. The *C. setaceus* buried seed trial; located in the taxon's preferred habitat .

<u>Field Trials</u>: Seeds were sealed in polyester fabric bags and buried 6 inches below the soil surface near existing populations (Fig. 3). Buried bags were retrieved at regular intervals.

- **Dark, Buried:** Seeds that had germinated in the buried bags were counted.
- **Light, After Buried:** Intact, non-germinated seeds were sown on agar and put in the growth chambers, exposed to light, and all germinating seeds were counted (similar methods as Initial Viability Assay).

<u>Lab Trials</u>: Seeds were sown on agar in Petri dishes, wrapped in one layer of plastic wrap, followed by two layers of aluminum foil to keep light out. Seeds had enough moisture to remain imbibed (absorbed necessary amount of water to allow for germination) throughout dark treatment. Dishes were placed in germination chambers and retrieved at regular intervals.

- **Dark, Imbibed**: Seeds that had germinated in the dark were counted.
- **Light, After Imbibed**: Petri dishes were unwrapped and intact, non-germinated seeds were sown on agar and kept in the growth chambers, exposed to light, and all germinating seeds were counted.

Results from these germination trials (Fig. 5) were interpreted to classify type of soil seed bank. Species with seeds that germinate in the absence of light (Dark, Imbibed treatment (Lab Trial)) were classified as transient or not likely to form persistent seed banks. Species with seeds where viability declined (or was projected to decline) to ~0% by approx. 5 years (or projected) when exposed to light upon removing from buried bag or dark/imbibed treatment were classified as persistent, short-term. Seeds with little decline in viability after 5 years were classified as persistent, long-term (Table 2).

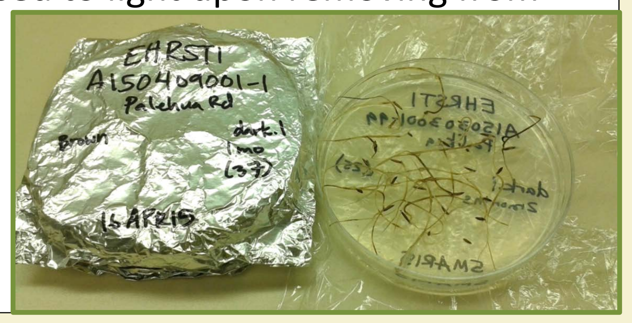


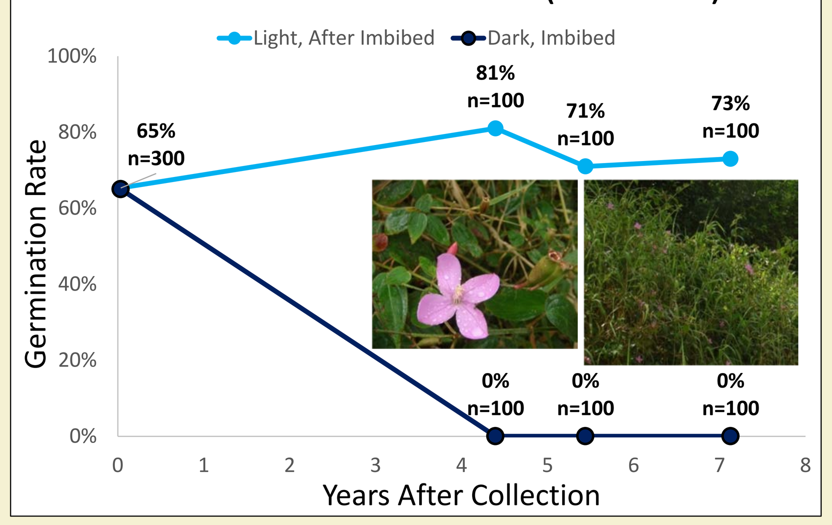
Fig.4. Seeds of *E. stipoides* that germinated during the Dark/Imbibed Lab treatment.

References:

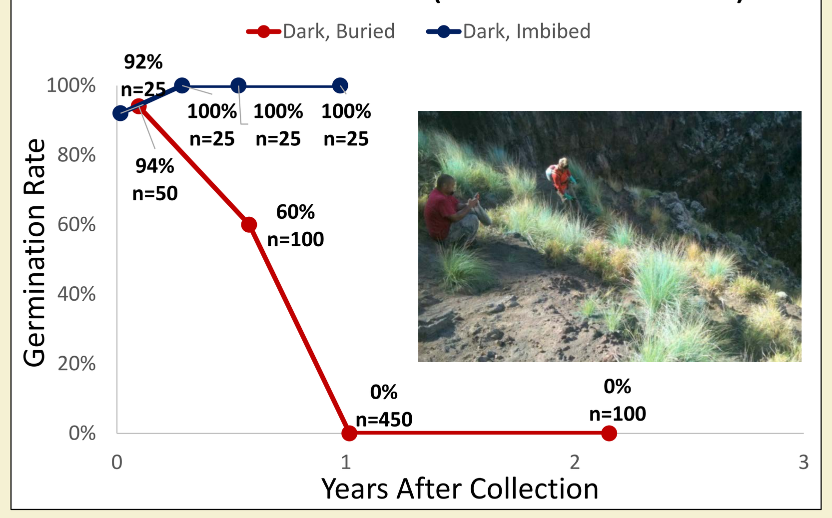
- Hawaii-Pacific Weed Risk Assessment. 2015. www.hpwra.org
- Walck et al. 2005. Defining transient and persistent seed banks in species with pronounced seasonal dormancy and germination patterns. Seed Science Research **15**: 189-196

RESULTS - SOIL SEED BANK POTENTIAL

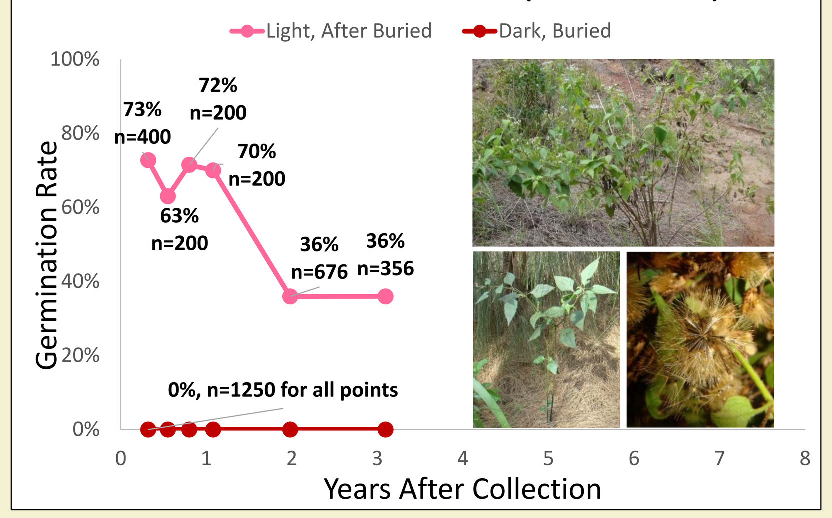
a *Arthrostemma ciliatum* (Lab Trial)



b *Cenchrus setaceus* (Field & Lab Trial)



c *Chromolaena odorata* (Field Trial)

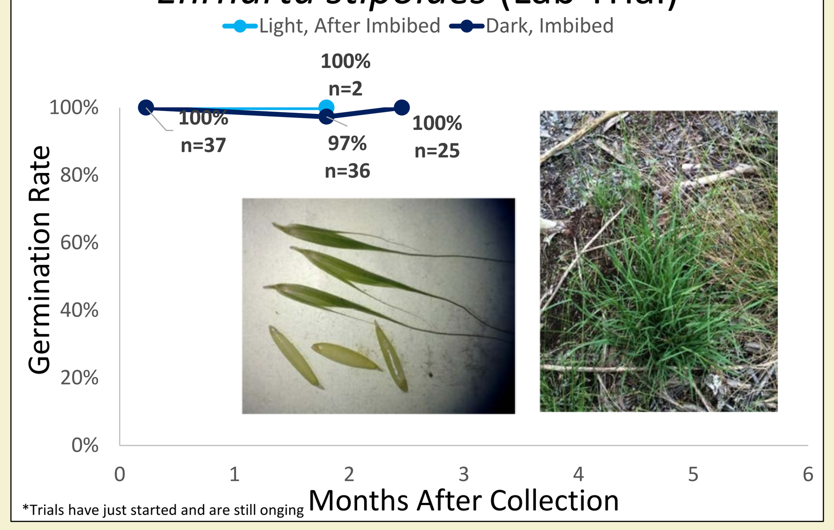


d *Crocosmia x crocosmiiflora* (Field Trial)

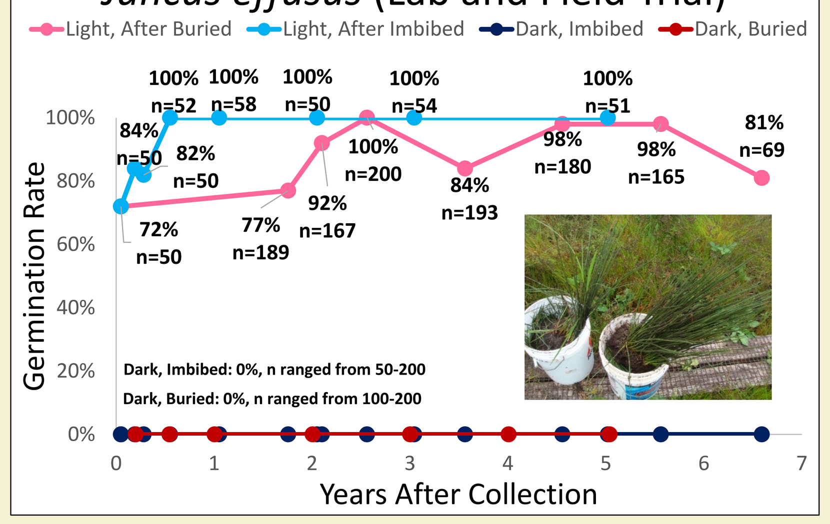
Time Since Collection	Germ (Dark, Buried)	Germ (Light, After Buried)
Initial Viability 60%		
4month	0%*	0%
6month	0%*	0%
1year	0%*	0%
2year	0%*	0%

*seeds likely germinated in buried bag and subsequently rotted

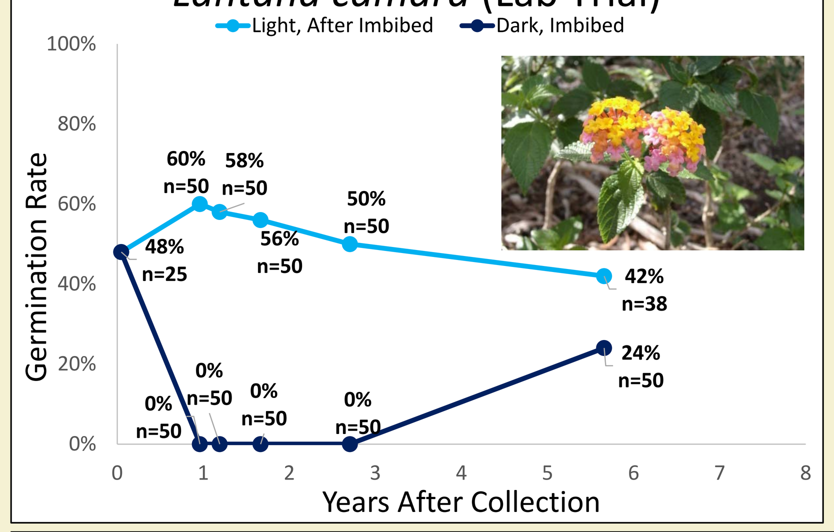
e *Ehrharta stipoides* (Lab Trial)



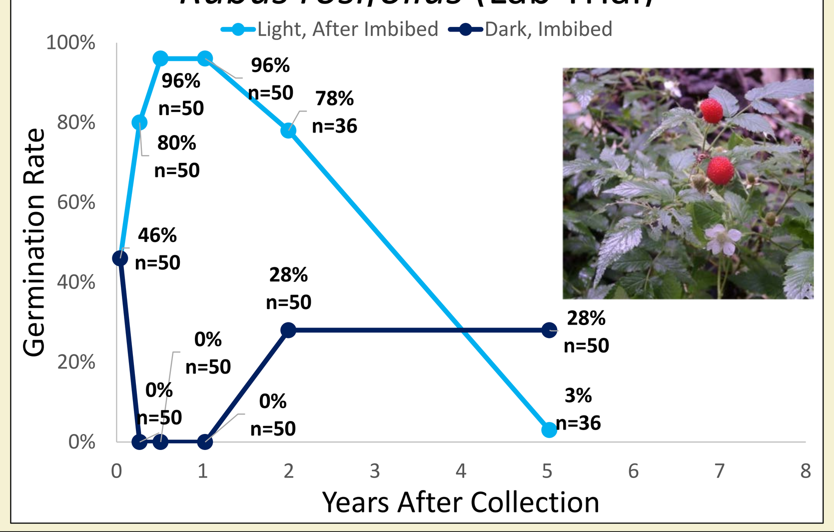
f *Juncus effusus* (Lab and Field Trial)



g *Lantana camara* (Lab Trial)



h *Rubus rosifolius* (Lab Trial)



i *Schizachyrium condensatum* (Field Trial)

	Initial Viability	Germ (Dark, Buried) 6 months	Germ (Light, After Buried) 6 months
Collection 1	56%	0%	37%
Collection 2	18%	0%	13%

Fig. 5. Seed Viability Graphs & Tables. Graphs a-c, e-h indicate Field Trial, Lab Trial, or both (see methods for definitions). For graphs a, b, and e-h navy blue lines indicate germination that took place while seeds were in the dark, imbibed treatment (Lab Trial); turquoise lines (not in b) indicate germination of those seeds upon exposure to light (unwrapped). For graphs b, c, and f, red lines indicate germination that took place while seeds were buried (Field Trial), and pink lines indicate germination of those seeds upon exposure to light (unburied). Each navy blue or red point on a graph represents the germination in the dark at one interval (either 2 bags of seeds or 1 dish) that was exposed to light (corresponding turquoise or pink point at same time (x-axis) interval).

Table 2. Species Summaries for Soil Seed Bank Persistence. The Hawaii-Pacific Weed Risk Assessment evaluates the potential invasiveness of non-native plant species. Scores above 6 indicate high risk for invasiveness. *C. crocosmiiflora* has not been evaluated, but is a recognized invasive species in Hawai´i. Species with seeds that germinate without light and upon imbibition do so when they have absorbed enough water for germination. Other species have seeds that can remain in dark/imbibed treatment for years before germinating. If more than one collection per species, initial viability is an average.

Species	Family	HPWRA Risk	Habit	Year Test Began	Field Trial	Lab Trial	Initial Viability	Germinates Without Light?	Soil Seed Bank Type
Arthrostemma ciliatum	Melastomataceae	High (7)	herb	2007-ongoing		x	65%	no	Persistent, Long Term
Cenchrus setaceus	Poaceae	High (26)	grass	2012-2013	x	x	92%	yes (upon imbibition)	Transient
Chromolaena odorata	Asteraceae	High (28)	herb	2011-ongoing	x		73%	no	Persistent, Short Term
Crocosmia x crocosmiiflora	Iridaceae	-	herb	2008-2010	x		60%	yes (upon imbibition)	Transient
Ehrharta stipoides	Poaceae	High (19)	grass	2015-ongoing		x	100%	yes (upon imbibition)	Transient
Juncus effusus	Juncaceae	High (21)	rush	2007-2015	x	x	72%	no	Persistent, Long Term
Lantana camara	Verbenaceae	High (32)	shrub	2005-2012		x	48%	yes (after 5 years)	Persistent, Short Term
Rubus rosifolius	Rosaceae	High (10)	herb	2005-2011		x	46%	yes (after 2 years)	Persistent, Short Term
Schizachyrium condensatum	Poaceae	High (13)	grass	2013-ongoing	x		37%	no	Persistent (ongoing)

MANAGEMENT IMPLICATIONS

- Seed dormancy can complicate the assessment of soil seed bank persistence and needs to be identified and considered in determining soil persistence.
- Additional, extended trials are necessary for replication to verify seed bank classification and to continue testing species with suspected long-term persistent soil seed banks.
- Assuming no ingress of seeds or other propagules, isolated infestations of species with transient seed banks (*C. setaceus, C. crocosmiiflora,* and *E. stipoides*) have a good prognosis for eradication. Such infestations should be monitored at least 1.5 years following the removal of the last mature plant.
- Given that plant detection rates vary widely based on terrain, vegetation, staff, detectability of small size classes, etc., it is prudent to assume that some plants will escape detection for one or more control trips. Conservative managers may therefore choose to define eradication as no plants found for at least two times the duration of the soil seed bank.
- Species which form persistent, short term seed banks pose a greater challenge for eradication than those which form transient seed banks, and may require a decade of monitoring following eradication of the last known individual plant. Species which form persistent, long term seedbanks will require decades of consistent effort to achieve eradication.
- If habitat restoration, rather than eradication, is the goal, seed bank persistence is one factor to consider when determining time between weed control trips and setting realistic tolerance levels for select weeds in work sites.

No Need for Devil Weed: Eradication Efforts and Challenges in Controlling *Chromolaena odorata*

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Oʻahu Army Natural Resources Program

ABSTRACT

Chromolaena odorata, an Asteraceae commonly known as Devil Weed or Siam Weed, is native to North America, from Florida and Texas to Mexico and the Caribbean, and is a documented agricultural and ecological pest in tropical Asia, West and South Africa, and parts of Australia. The species has been referred to as one of the 100 worst weeds in the world (IUCN). *Chromolaena* was first reported in Hawaii by Oahu Army Natural Resources Program (OANRP) staff in 2011 when it was spotted on an annual road survey in the Army's Kahuku Training Area. Since detection, OANRP has repeatedly swept over 370 hectares across the Kahuku infestation, and spent nearly 2.000 person hours in this effort. Delimiting surveys were completed in Kahuku in 2013, and few populations outside the core infestation area were detected. However, smaller populations of *Chromolaena* have since been detected on Oahu at Aiea, Kahana, and two additional Army training ranges. OANRP current control strategy is to: 1.) survey and control across the defined infestation area every six months to a year; 2.) control locations with high densities of plants (hotspots) before the annual reproductive season (November - April); 3.) conduct annual aerial sprays of the core infestation (approximately 4 ha) before reproductive season; 4.) survey an 800 meter buffer around the infestation area and outlier populations, documenting and controlling new plants. Additional necessary but challenging efforts to eradicate this taxa from the island include surveying high-priority areas across the entire island of Oahu, securing funding and staff for control efforts, improving spray equipment, broadening public outreach efforts in high-use areas where *Chromolaena* is present, and supporting sanitation and inspection protocols within the Army. OANRP is dedicated to eradication of *Chromolaena* on Army lands, and supports eradication island-wide.

BACKGROUND

C. odorata not only an ecological threat but a toxic agricultural threat as it can cause diarrhea or in extreme cases, death to livestock through ingestion of the leaves. To humans it can cause skin reactions and asthma in allergy prone people. Ecologically, the species can tolerate a broad range of climates and soil conditions and can tolerate severe dry periods. It is very suitable for tropical climates and prefers open sunny areas to partial shaded areas. It rapidly colonizes disturbed or cleared areas and once established is alleleopathic. The plant is also a known host for pests, pathogens, and fungal diseases

Fig. 1. (above left) New flowers usually starting in November. **(middle)** Mature fruit lasting until around April. **(right)** Leaves

REPRODUCTIVE BIOLOGY AND SEED BANK PERSISTENCE

C. odorata can mature in one year and begin producing seed which can reach a count of 800,000 per individual per year. A seed burial trial was conducted where seeds were sealed in polyester fabric bags and buried 6 inches below the soil surface near an existing population in Kahuku. Buried bags were retrieved at regular intervals.

- **Dark, Buried:** Seeds that had germinated in the buried bags were counted.
- **Light, After Buried:** Intact, non-germinated seeds were sown on agar and put in growth chambers, exposed to light, and all germinating seeds were counted.

Results: *Chromolaena odorata* initially had a 73% germination rate when exposed to light but after 2 year had dropped to a 36% germination rate. This is a substantial drop in viability after 2 year. This seed trial is still ongoing but we predict that the amount of germination will continue to drop, and anticipate this species will have a short-term (5 years) persistent seed bank.

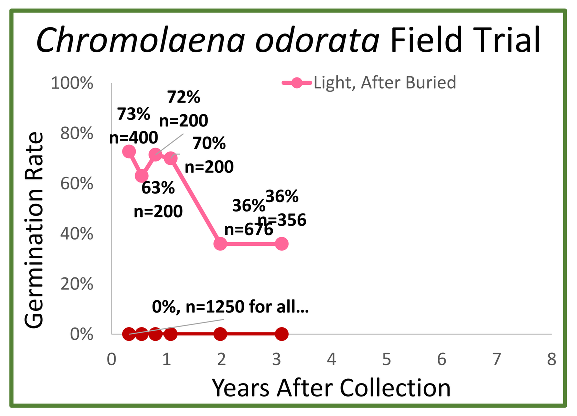


Fig. 2. For this graph, red lines indicate germination that took place while seeds were buried (Field Trial), and pink lines indicate germination of those seeds upon exposure to light (unburied). Each red point on the graph represents the germination in the dark at one interval (either 2 bags of seeds or 1 dish) that was exposed to light (corresponding pink point at same time (x-axis) interval). `

DISPERSAL CHALLENGES

DISTRIBUTION

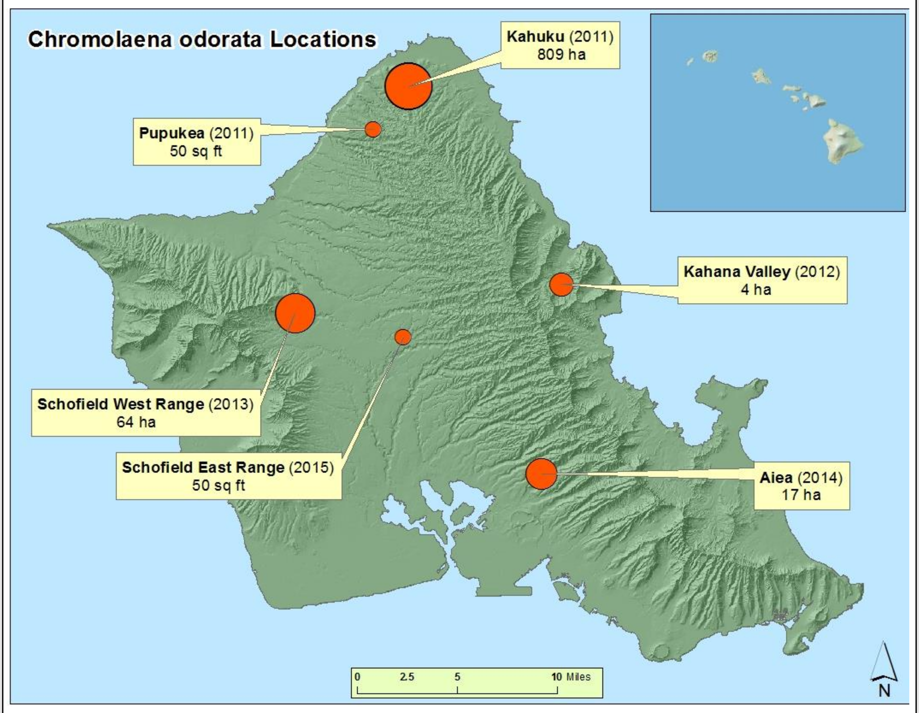


Fig. 3. This Map shows the general locations of *Chromolaena* known on Oahu. The size of the dots represents the population size (number of plants found to date) with the Army's Kahuku Training Area as the largest infestation.

ARMY

What is being done to control the spread by the Army and soldiers?

- Training area BRAVO 1 containing the highest density of plants in KTA has been closed to training.
- No Mowing signs and roped off areas have been set up.
- Policy memo has been published enforcing mandatory use of vehicle washrack.
- Non-functioning washrack has been rebuilt and is now fully operational.
- Posters and fliers have been posted at KTA Range Control office.

Fig. 4. (left to right) "No Mowing" signs set up in Schofield West Range. Soldier washes down vehicle at washrack.

OUTREACH

Since this is not just a problem on Army lands, how do we inform the public or other relevant parties?

- Create informational fliers and posters and distribute them to all necessary parties.
- In 2012, OANRP and the Oahu Invasive Species Committee (OISC) gave a presentation to the Hawaii Motocross Association and community urging riders to clean all vehicles and gear and to report any finds of Devil Weed.
- Contact partner agencies and the conservation community via list serve and email. Our cooperation with OISC on this project is ongoing and constant as they are working on *Chromolaena* sites outside of Army lands.
- Contact Marines who also train at KTA.

CONTROL TECHNIQUES AND STRATEGIES

GROUND SWEEPS

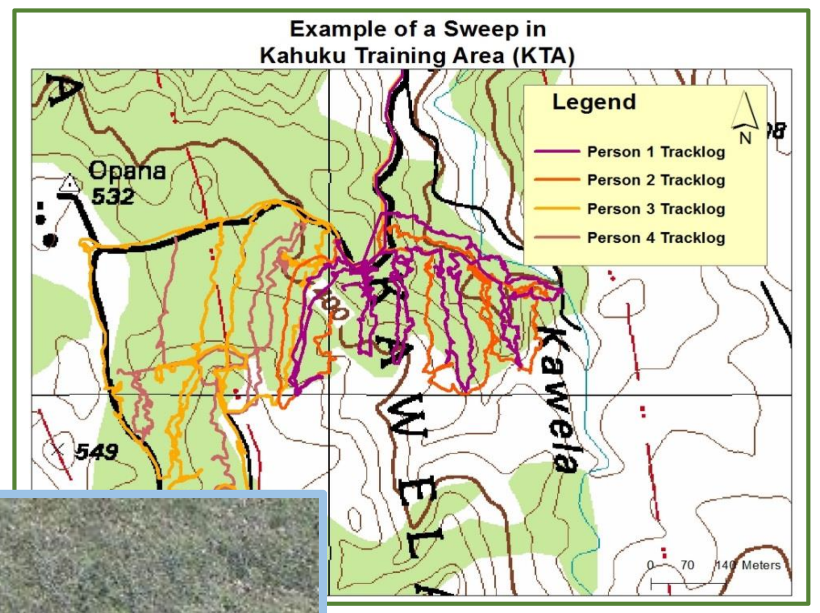


Fig. 6. (Left) Field crew lines up to sweep. **(Right)** An ideal sweep where all team members are lined up and spaced out evenly to get the best coverage.

METHOD:
The "Sweep" technique is used to reduce the number of plants that are sometimes missed during a survey by lining up as team and spacing each team member out evenly. Then the team moves a set compass bearing in search for plants. Communication throughout the sweep is crucial to keep the line organized and to respond to any new plants found.

BUFFERS:
When outlier plants are first detected, 200 meter and sometimes 800 meter buffers are drawn around the point(s) and the entire buffer is swept . If more plants are found, the buffers will keep expanding until the population is delineated. See Surveys section to the right for an example of a buffer.

THE ROLE OF OUR PARTNERS:
OANRP pays the Oahu Invasive Species Committee to sweep half of the KTA infestation biannually.

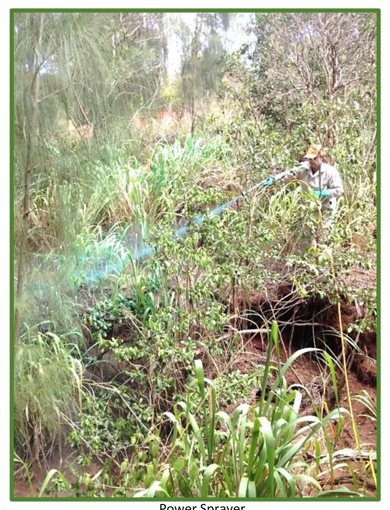
HOTSPOT TREATMENTS

Fig. 5. A typical *Chromolaena* hotspot in a disturbed, open area in KTA complete with a motocross trail down the middle of it. All brown branches seen here are Devil Weed.

WHAT'S A HOTSPOT YOU ASK?
We define a Hotspot as any Devil Weed population that either has more than 10 mature plants (containing fruits or flowers) present OR any population that has a significant seedling recruitment potential, i.e. a number of matures had just seeded and it was in prime habitat for recruitment (sunny and open).

HOW DO WE CONTROL HOTSPOTS?

- **Power Spray:** This is by far the most effective and successful tool in our shed because its pressure can penetrate through patches of plants and treat the soil with pre-emergent herbicide.
- **Backpack Spray** any hotspots that are not accessible via vehicle and power sprayer. This is less efficient, especially if you need to put out large volumes of herbicides for large patches of target plants.
- **Aerial Spray** any hotspots that are not accessible via power or backpack spraying. These hotspots once found, must be flagged well for aerial treatment so that the pilot can easily identify the area from the air as Devil Weed is difficult to see from the air.
- The **ATV sprayer** seen in the picture was used but proved to be less effective than expected. It was limited in the places it could go because the sprayer and tank made it extremely top-heavy thus giving it the potential to flip.



Power Sprayer

Aerial Sprayer

ATV Sprayer

AERIAL HOTSPOT SPRAYS

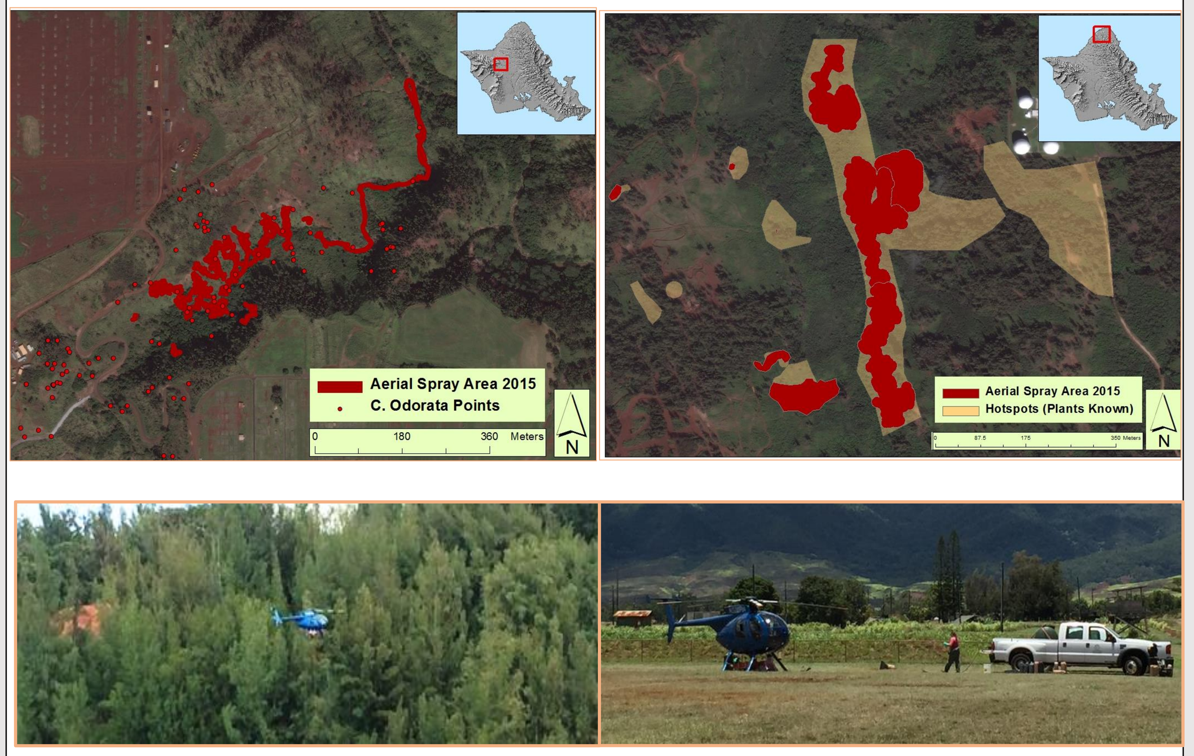


Fig. 6. (Above) Aerial Spray in action in Kahuku and a closer look at the spray "ball" nozzle. **(Below)** A map showing what has been aerially sprayed to date.

Fig. 7 . (Above) Beginning of aerial spray operations at West Range. **(Below)** A map showing what has been aerially sprayed in West Range to date and the locations of historic *Chromolaena* plants.

SURVEYS

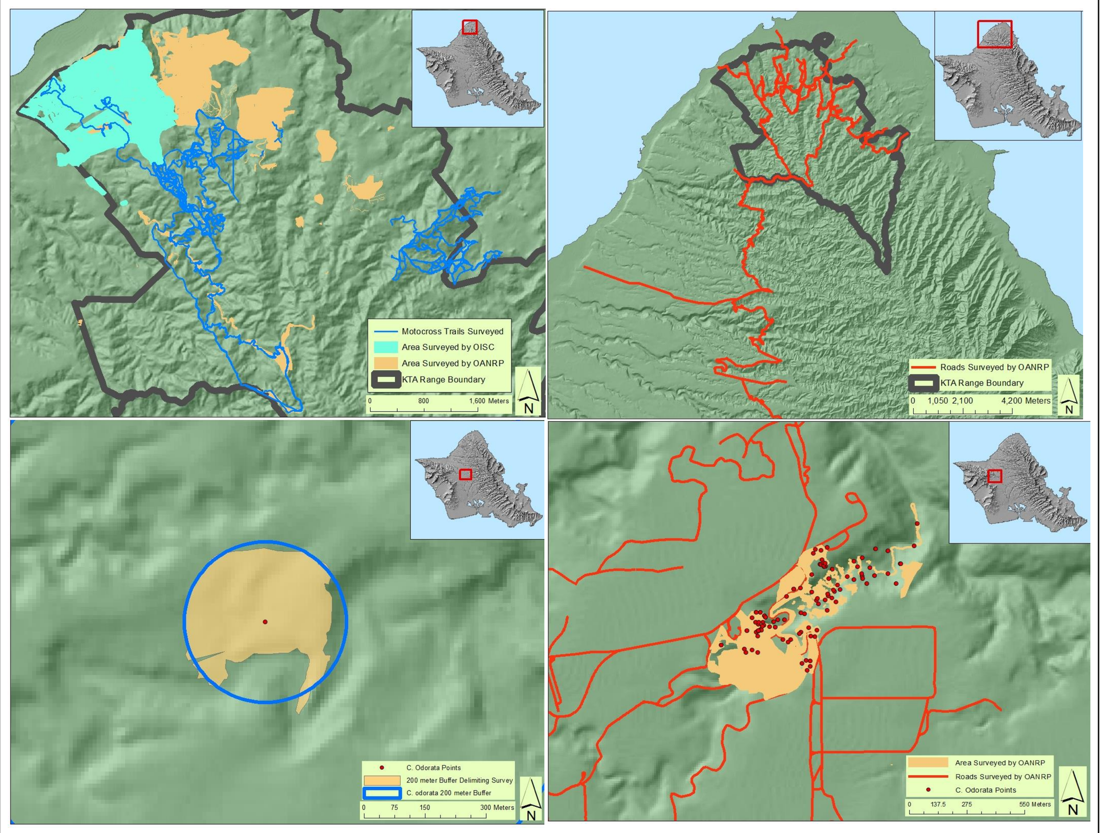


Fig. 8. (Above left and right) In Kahuku Training Area, 490 hectares have been annually swept, 274 km of trails surveyed, and 367 km of roads have been surveyed to date. **(Bottom left and right)** These maps show the East and West Range *C. odorata* site where surveys have been done.

DISCUSSION

It is clear that a much larger effort is needed if *C. odorata* is to be eliminated from Oahu. New finds at Schofield's East Range and Aiea this year alone highlight the ease with which *C. odorata* moves on vehicles and humans. It seems likely that there are other, unknown infestations located off Army training facilities; surveys need to be conducted across the island to better understand the scope of the infestation and set realistic goals. Securing adequate funding for surveys and control is essential to the eradication goal. Furthermore, biosecurity plays a vital role in preventing further establishment of *C. odorata* on Oahu from likely sources like Guam, where the species is widespread and can easily come over to Oahu via military vehicles, gear and personnel. In particular, quality inspections and enforcement of incoming troops and military shipments is key to ensuring that there are no further introductions of Devil Weed to either Oahu or the island of Hawaii, where there is the Army's Pohakuloa Training Area. It would also be beneficial to explore and fund research for biocontrol since this species, once established, takes so much effort and resources to contain.

REFERENCES

1. Holm, LeRoy G., Pluncknett Donarld L., Pancho, Juan V. The World's Worst Weeds: Distribution and Biology. University Press of Hawaii. 1977. Pg. 212
2. *Chromolaean odorata*: A Highly Invasive Weed . manoa.hawaii.edu/hpicesu/DPW/chrodo_flier.pdf

Assessing the most effective weed control re-treatment interval for *Clidemia hirta*-dominated areas at Opaeula Lower Management Unit, Oahu

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INTRODUCTION

The goal of this study was to guide Oahu Army Natural Resources Program (OANRP) weed control planning for *Clidemia hirta* at Opaeula Lower Management Unit (MU), where dense understory cover of this weed occurs (Fig. 1). This species is targeted due to its ecosystem altering characteristics and tendency to create thick monotypic stands. Several questions are addressed pertaining to the effect of weeding *C. hirta*-dominated areas. To what extent does *C. hirta* and other weed taxa rebound if an area is not re-weeded for 6, 12 or 18 months? In the course of weeding a small degree of understory native vegetation trampling occurs. Does re-weeding at 6 months cause further damage to native vegetation? How does species diversity change in response to weeding at different intervals? How long does it take for <10 cm tall *C. hirta* plants (typically not treated during weeding) to become reproductive? Does canopy cover change in response to understory weeding within 18 months?

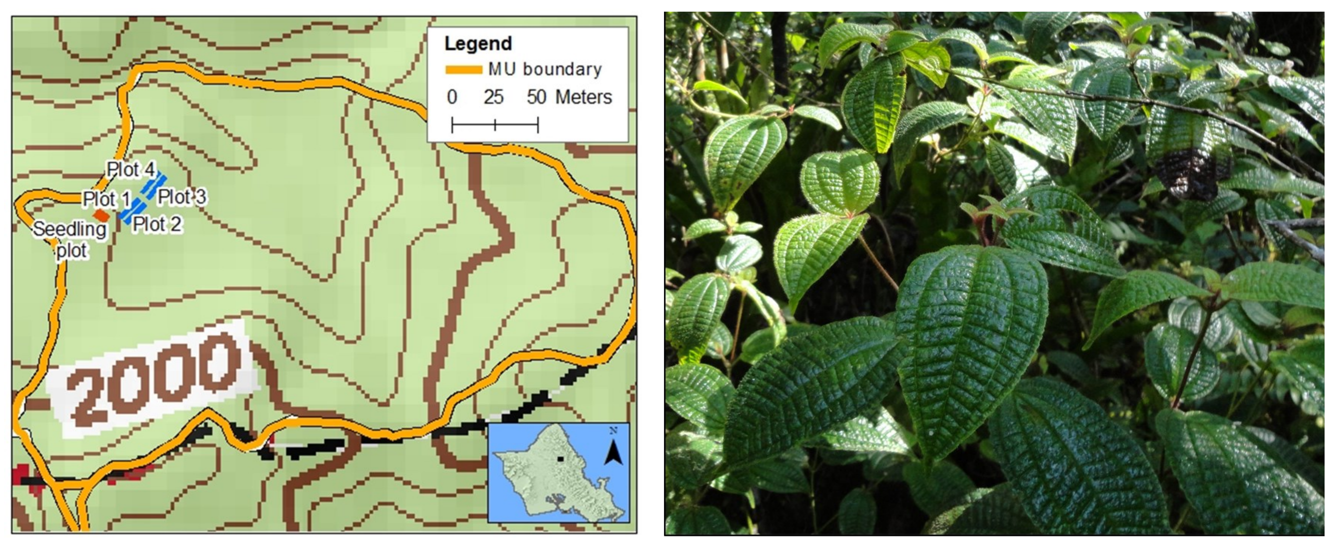

Figure 1. a) Locations of study plots at Lower Opaeula Management Unit, Oahu, and b) photo of *Clidemia hirta*

METHODOLOGY

Field Methods: Plots (5 x 21 m) were monitored in May 2013 (month 0) and November 2014 (month 18) among 4 weeding treatments:

Plot 1: control plot – not weeded
Plot 2: weeded at 0 & 6 months
Plot 3: weeded at 0 & 12 months
Plot 4: weeded at 0 months

Understory percent cover (using point intercept, n = 80 points), species richness (in 1 m^2 quadrats, n = 20), and canopy openness (using hemispheric photographs, n = 20) were monitored. To assess *C. hirta* maturation time, 50 individuals < 10cm tall were tagged within a 5 x 5 m plot, and monitored every 6 months from May 2013 to November 2014. Weeding included all non-grass mature and immature plants and most seedlings.

Data Analysis: Analysis included chi-square and Fisher's exact tests for change in understory cover within plots over time, and differences between plots at the end of the trial; t-tests for species richness change over time; and ANOVA with Tukey's post-hoc comparisons for differences in species richness between plots at the end of the trial, and for canopy openness in hemispheric photographs derived using Gap Light Analyzer (GLA), Version 2.0 software (Frazer et al. 1999). Analysis of change in non-grass weeds and non-vegetated area was based on initial weed cover in Plot 1, as Plots 2, 3, and 4 were weeded prior to baseline monitoring. Anecdotal observations determined that weed cover was similar among all 4 plots at the start of the trial.

RESULTS

Non-native understory percent cover: There was a significant decrease in *C. hirta* ($p < 0.001$) and total weed cover ($p < 0.001$), but a significant increase in total weed cover excluding *C. hirta* ($p < 0.001$), among all weeded plots (Fig. 2 and 3). The most commonly occurring grass, *Paspalum conjugatum*, also increased significantly from very low (Plots 2 and 4) and low (Plot 3) to moderately low cover in all weeded plots. At the end of the trial, *C. hirta* cover differed significantly among all plots, ranging from very low to high in relation to the time elapsed since the last weeding effort (6, 12, and 18 months prior for Plots 3, 2, and 4, respectively, and Plot 1 never weeded). Total weed cover differed among plots ($p < 0.001$) except for Plots 2 and 3, ranging from moderate to very high, also in relation to time since weeding last occurred. Total weed cover excluding *C. hirta* differed among plots ($p < 0.001$) with the exception of Plots 3 and 4, ranging from moderately low (Plot 1) to moderate (Plot 2) to moderately high/moderate (Plots 3 and 4).

Native understory percent cover: There was a significant increase in native cover (from low to moderate) for Plots 2 and 3 ($p < 0.001$). Though initially absent, by the end of the trial, *Acacia koa* was present in all plots at very low cover, representing a small significant increase in Plots 2 and 4 ($p = 0.024$). *Cibotium chamissoi* had a small significant increase in the control plot ($p = 0.044$), and a larger increase in Plots 2 and 3 ($p < 0.001$). *Nephrolepis exaltata* subsp. *hawaiiensis* had a significant increase (from very low to low cover) in Plot 2.

Non-vegetated percent cover: There was a very small significant increase in non-vegetated area in Plot 2 ($p = 0.022$) from very low to low percent cover.

Species richness: Non-native species richness increased significantly in Plots 3 ($p < 0.001$) and 4 ($p = 0.001$) (Fig. 4). At the end of the trial, there were significant differences in non-native species richness between plots ($p = 0.001$), with pairwise differences between Plot 1 and Plots 3 and 4 (Plot 1 vs. 3: $p = 0.001$; Plot 1 vs. 4: $p = 0.049$). There was a marginally significant increase in native richness in Plot 3 ($p = 0.057$).

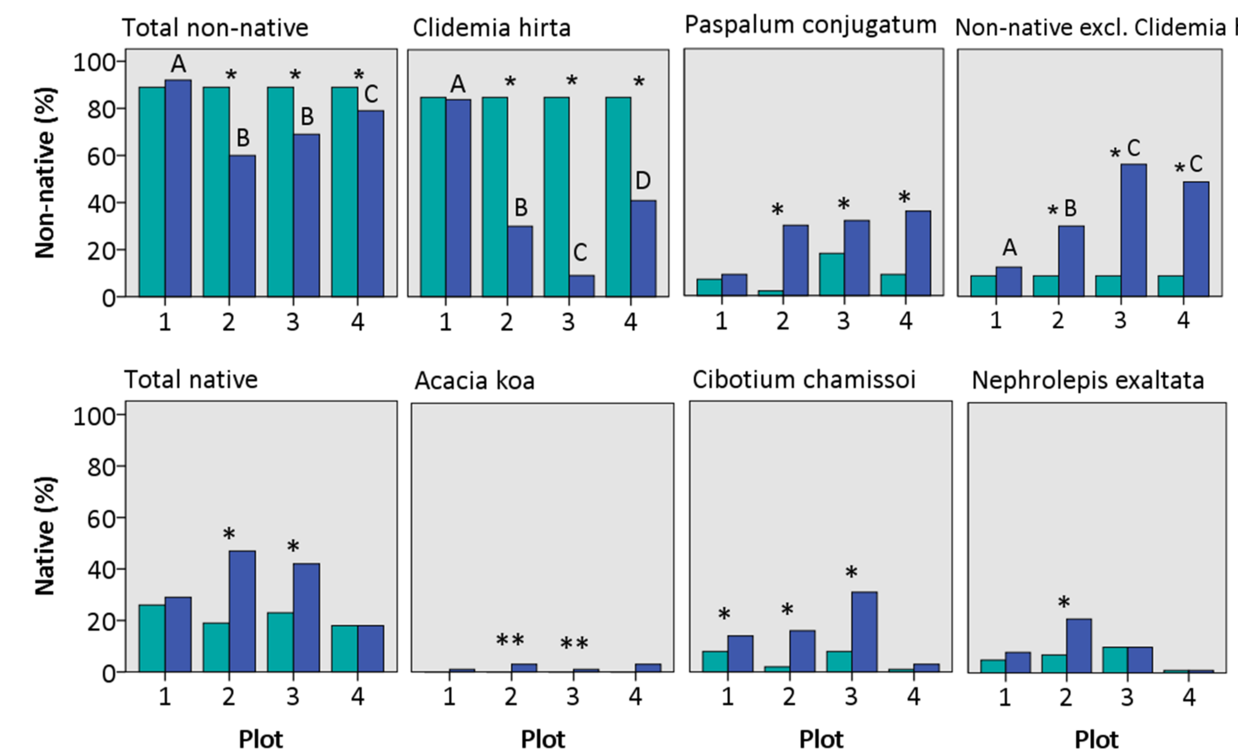

Figure 2. Percent cover of non-native and native understory vegetation at the beginning (before) and end (after) of the trial. *Significant, **marginally significant, change within plots. Letters denote significant difference between plots at the end of the trial.

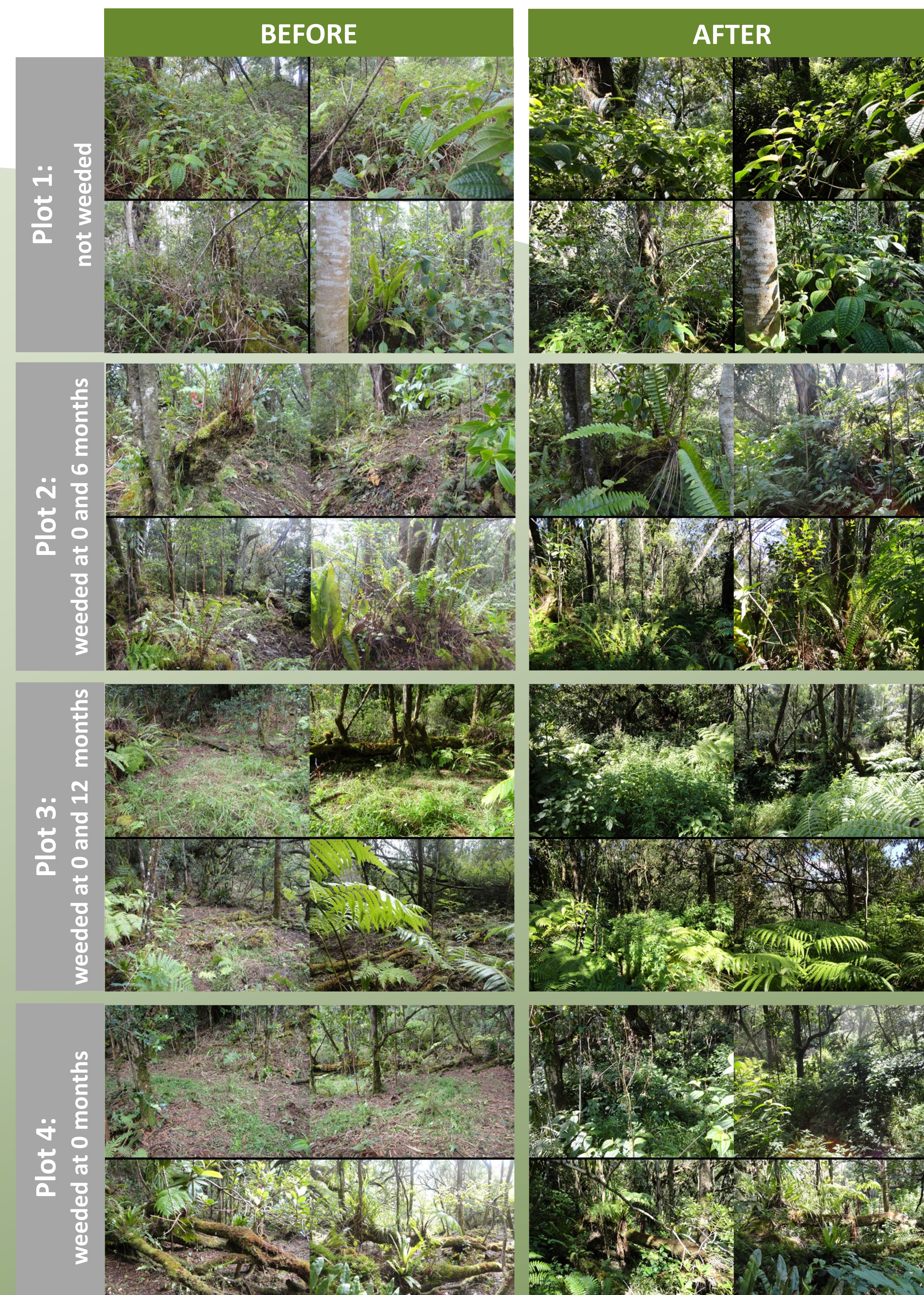

Figure 3. Photopoints of plots at the beginning and end of the trial, with images taken from the north, east, south and west corners (shown counterclockwise from top right image) of each plot.

Maturation time: Among the tagged *C. hirta*, one individual was mature by 12 months, and 43% of the remaining live plants were mature by 18 months. Many of the immature plants remained small, and were beneath dense *C. chamossoi* cover. A treefall occurred between months 12 and 18, and created a light gap that may have prompted *C. hirta* growth and maturation. At the end of the trial, all plots had mature *C. hirta*, including Plot 3, which was weeded only 6 months earlier.

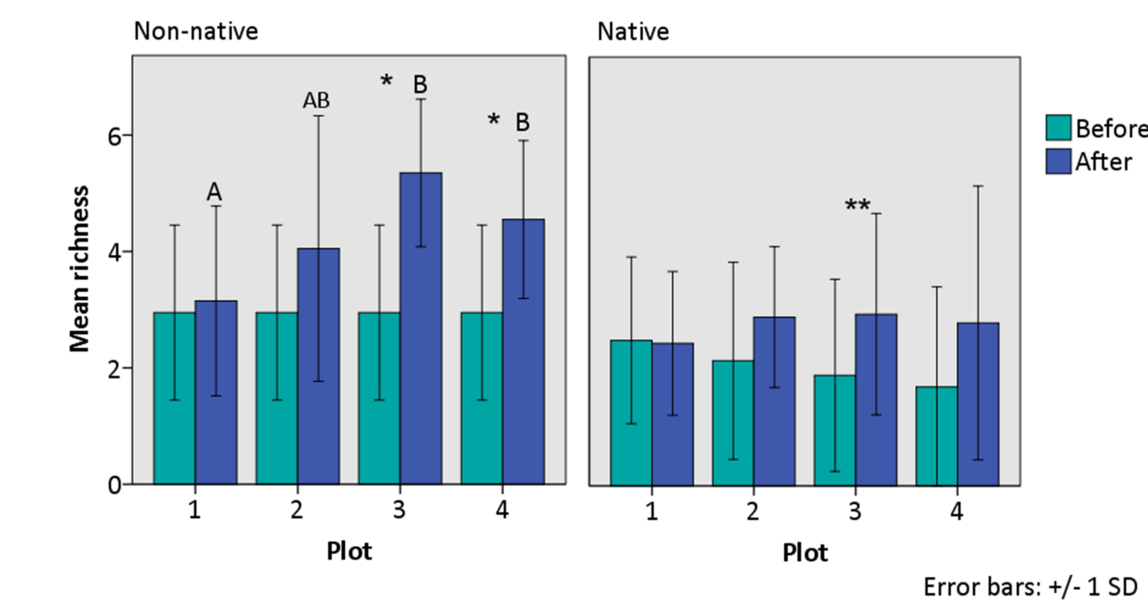

Figure 4. Mean non-native and native species richness at the beginning and end of the trial. *Significant, **marginally significant, change within plots. Letters denote significant difference between plots at the end of the trial.

Canopy openness: There was no significant change in canopy openness among the weeded plots, yet, there were significant differences among plots at the end of the trial ($p < 0.001$) (Fig. 5). Plot 2 was more open than all other plots, while Plot 4 was the least open.

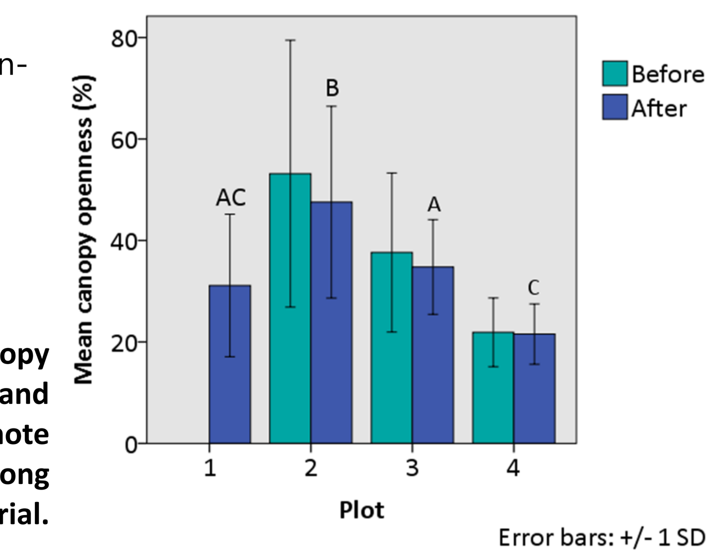

Figure 5. Mean percent canopy openness at the beginning and end of the trial. Letters denote significant differences among plots at the end of the trial.

SUMMARY AND RECOMMENDATIONS

Understory cover: Weeding *C. hirta*-dominated understory at Lower Opaeula produces reduced *C. hirta* cover paired with an increase in native cover after 18 months if initial weeding is followed by additional weeding 6 or 12 months later. However, substantial increased cover of non-native weeds other than *C. hirta* occurred, particularly the alien grass *P. conjugatum*. The plot weeded only once had very poor results after 18 months, with no change in native cover, and a resurgence of non-native cover to nearly as high as it was prior to weeding. ***Re-weeding (including grass control) should occur within 6 to 12 months, in order to allow native cover to expand, and prevent weed cover from returning to near prior levels.***

Species richness: Increased weed species richness resulted from a 12 to 18 month delay in re-weeding. As native species richness did not change substantially, the increase in native cover that occurred in the plots weeded twice was largely an expansion of species already present. ***Because C. hirta-dominated areas are partially replaced by other weed taxa, care should be taken to ensure that more problematic weeds do not become established.***

Maturation time: Though the minimum time for *C. hirta* maturation from the small immature stage was 12 to 18 months in the seedling plot, the presence of mature plants in a plot weeded only 6 month prior to the end of the trial suggests that the minimum time to maturation is < 6 months, and may be influenced by light availability. ***If there is an impetus to deplete the* C. hirta *seed bank, weeding should occur more frequently than 6 months, particularly in areas with greater light availability. Additionally, weeding must be ongoing, as* C. hirta *forms a long lived seed bank (Brooks and Setter, 2012). However, such a high frequency of weeding will limit the total area that is feasible to weed. Additionally, there will likely be a continual influx of* C. hirta *seeds from the surrounding areas. Depletion of the* C. hirta *seed bank is likely an impractical endeavor.***

Canopy openness: Differences in understory change among plots may have been influenced by differences in light availability, as canopy openness differed among plots. ***Clearcutting non-native canopy in this area is not advised, unless there are resources to follow up and prevent* C. hirta *from becoming established.***

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Brooks, S. J., and S. D. Setter. 2012. Soil seed bank longevity information for weed eradication target species. *Pak. J. Weed Sci. Res.*, 18: 73-83.

Frazer, G. W., C. D. Canham, and K. P. Lertzman. 1999. Gap Light Analyzer (GLA), Version 2.0: Imaging software to extract canopy structure and gap light transmission indices from true-colour fisheye photographs, users manual and program documentation. Copyright © 1999: Simon Fraser University, Burnaby, British Columbia, and the Institute of Ecosystem Studies, Millbrook, New York.

Efficacy of Undiluted Herbicide Injections on Tropical Woody Tree Species in Hawaii

Julia Gustine Lee and Jane Beachy: Oahu Army Natural Resources Program • James Leary: University of Hawaii at Manoa

Abstract: Hawaii hosts a wide array of non-native, woody trees, that are considered to be invasive pests which threaten the integrity of delicate native ecosystems and adversely impact watershed health. The Oahu Army Natural Resource Program (OANRP) is tasked with conducting habitat restoration to support endangered species protection, and to this end conducts hundreds of hours of weed removal annually. OANRP's default control method uses a 20% dilution of a triclopyr product in biodiesel, applied with or without cuts to the basal area of woody tree weeds. Anecdotally, this technique is mostly successful at killing target species, but applications are un-calibrated; high doses may mask mediocre results. To identify more efficient and effective control techniques for invasive trees, trials were installed on Oahu in 2010 to examine the efficacy of low doses of four active ingredients (imazapyr, aminopyralid, glyphosate, and triclopyr). The treatment technique, Incision Point Application (IPA), involves making discrete, regularly spaced cuts around the trunk of a tree, and applying a measured amount of undiluted herbicide to each cut. Treated trees were monitored for up to two years. Performance was measured by recording defoliation and cambium health over time. Surprisingly, triclopyr was the least effective product tested. Imazapyr exhibited the greatest success, providing the most effective control across the greatest number of species. Using the results of these trials, OANRP has begun controlling canopy weeds across large acreages.

Background: The Incision Point Application (IPA) method is a calibrated, clean, and efficient field technique for administering lethal herbicide doses directly to the exposed vascular systems of invasive woody species. The IPA technique is a refinement of the more traditional "frill cut" or "hack-n-squirt" basal application methods by minimizing the cutting action to small incisions around the base of the tree at equidistant points, less than a complete girdle. It also precisely delivers known amounts of herbicide to each incision. This technique utilizes a small, sharp implement (e.g. a hatchet) for making the incision and either a veterinary draw-off syringe or calibrated dropper (Fig.1) for metering the herbicide. Knowing the most effective herbicides for each target species optimizes the IPA technique with the smallest lethal dose, allowing applicators to carry less weight into the field and leave the smallest chemical footprint in the environment.

Methods:

Treatment:

- Label 16 or 20 trees of relatively uniform circumference and measure and record each trunk circumference at 50cm from soil surface.
- Sort tree numbers by circumference size from smallest to largest and group into blocks of 4 starting with the smallest. Randomly assign one of the four herbicide treatments to each of the trees per block. Label trees with assigned herbicide.
- Use 'matrix of tree circumference with matching incision treatments' (Leary, 2010) to determine cuts per tree for each trial (based on size range of trial trees).
- Make cuts at equidistant points around the base of the trunk, approximately 20-50cm above the soil surface. All trees in a trial receive the same number of cuts. Administer 0.5 ml of herbicide concentrate to each cut.

Monitoring:

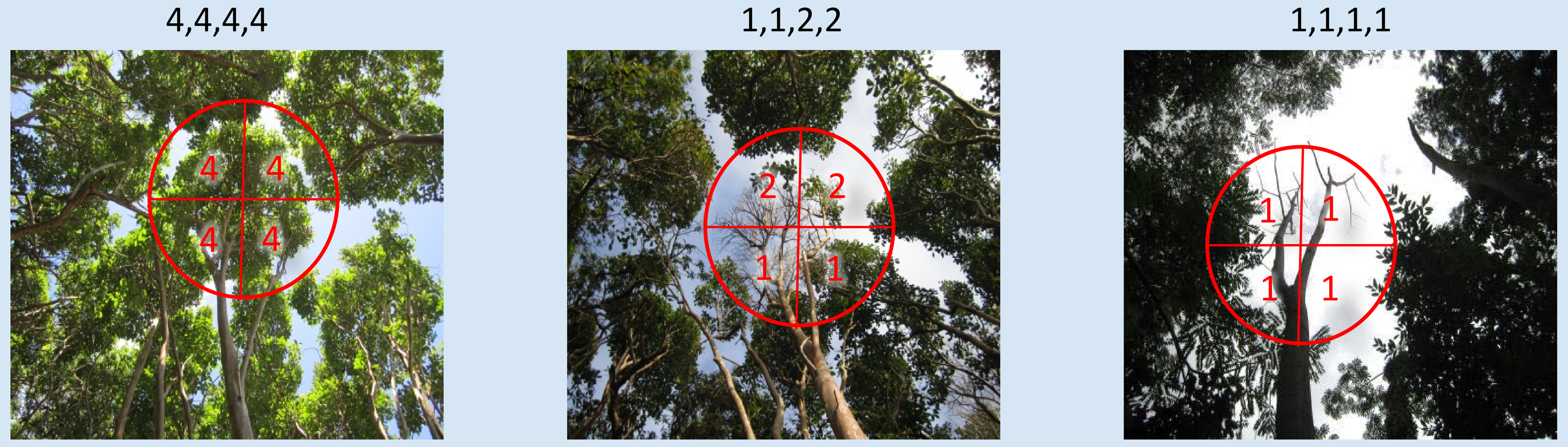
- Record canopy defoliation ratings every 90-100 days for up to 3 years.
- Visually subdivide leaf canopy into four equal quadrants. These designations can be arbitrary and different for each tree.
- Visually rank each quadrant 1-4 for level of defoliation for a total of four rank values for each tree unit (Fig. 2). 100% defoliation and ultimately complete cambium death (checking for dead tissue), were used as measures of efficacy.

Figure 1: Species herbicide trial equipment

Figure 2: Canopy defoliation rating system:

1- 100% defoliation (no intact leaves, unless fully necrotic and desiccated)
2- >50% defoliation (even if a single leaf is present in the canopy, up to 99% defoliation)
3- <50% defoliation (mostly intact canopy with observable defoliation and/or necrosis)
4- 0% defoliation (no observable defoliation)

no defoliation 4,4,4,4 | partial defoliation 1,1,2,2 | complete defoliation 1,1,1,1

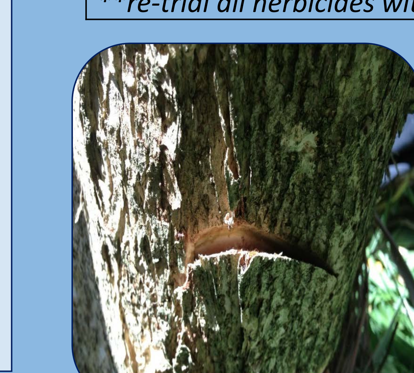


References:
(Leary, 2013: A Practitioner's Guide for Testing Herbicide Efficacy with the IPA Technique on Invasive Woody Plant Species), http://www.ctahr.hawaii.edu/oc/freepubs/pdf/WC-11.pdf:

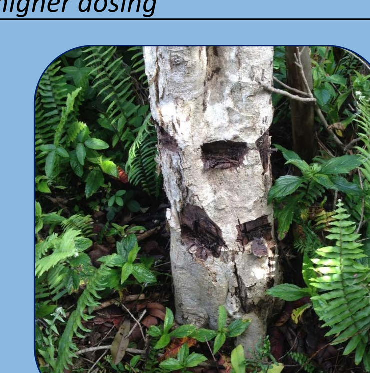
Results: Aminopyralid and Imazapyr had superior performance compared to Glyphosate and Triclopyr (Fig. 3). For all species where an herbicide was identified as effective, one (or in some cases both) of these two active ingredients was either the most, or second most effective. It was not uncommon to observe apparently ineffective treatments after 100 days, but that ranked as effective at 200-300 days after treatment. No herbicide was effective enough to recommend for: *Acacia confusa*, *Citharexylum caudatum* or *Syzygium cumini*. In the case of *Syzygium cumini,* results from two separate trials were inconsistent, and death was only observed in the smallest of trees. There was no effect for *Corymbia citriodora* at the dose given during the trial. Effective cut spacing for most species was between 15 and 25 cm.

Figure 3: Active Ingredient (A.I.) efficacy summary. Triclopyr= TCP (red), Glyphosate=GLY (beige), Aminopyralid= AMP (brown), Imazapyr=IMZ (green). Results are for days after treatment given in column 2. Best performing herbicide for each species is bolded, and second best is in italics. Recommended cut spacing was made by dividing the circumference of the largest tree(s) effectively controlled by the number of cuts administered in that species trial.

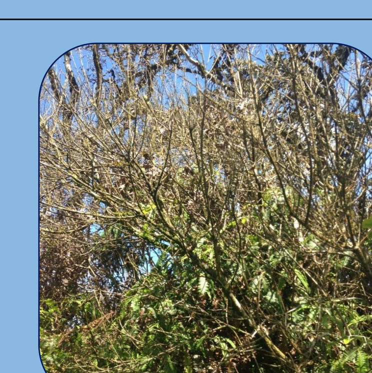
Species	Days after treatment	TCP # 100% defoliated/ # dead	GLY # 100% defoliated/ # dead	AMP # 100% defoliated/ # dead	IMZ # 100% defoliated/ # dead	Recommended Treatment: Herbicide	Recommended Treatment: Cut spacing (0.5ml/cut)
Acacia confusa (n=16)* Fabaceae	916	0/0	0/0	2/0	0/0		
Fraxinus uhdei (n=20) Oleaceae	305	0/0	0/0	2/1	3/2	**IMZ** *AMP*	**15cm-20cm** *15cm*
Araucaria columnaris (n=20) Araurcariaceae	640	0/0	1/0	5/1	2/2	**AMP** *IMZ*	**15cm** *15cm*
Ardisia elliptica (n=20) Myrsinaceae	481	0/0	0/0	1/0	5/5	**IMZ**	**15-20cm**
Callitris columellaris (n=20) Cupressaceae	430	0/0	2/unk	2/unk	0/0	**GLY** *AMP*	**15cm** *15cm*
Casuarina glauca (n=20) Casuarinaceae	430	2/2	0/0	2/2	0/0	**AMP** *TCP*	**10cm** *10cm*
Citharexylum caudatum (n=20)* Verbenaceae	333	0/0	0/0	0/0	1/0		
Coffea arabica (n=20) Rubiaceae	640	1/0	0/0	1/0	5/4	**IMZ**	**25cm**
Cordia alliodora (n=20) Boraginaceae	669	2/0	0/0	1/0	2/0	**IMZ**	**15-20cm**
Corymbia citriodora (n=20) ** Myrtaceae	343	0/0	0/0	0/0	0/0		
Cryptomeria japonica (n=20) Cupressaceae	580	0/0	5/5	5/5	0/0	**AMP** *GLY*	**20cm** *20cm*
Elaeocarpus grandis (n=20) Elaeocarpaceae	454	0/0	0/0	0/0	3/2	**IMZ**	**20cm**
Fraxinus uhdei (n=20) Oleaceae	640	2/1	0/0	1/0	5/4	**IMZ**	**15-20cm**
Grevillea robusta (n=16) Proteaceae	785	4/4	n/a	4/4	4/3	**AMP** **TCP** *IMZ*	**25cm** **25cm** *20cm*
Heliocarpus popayenensis (n=20) Tiliaceae	305	1/0	1/0	2/2	4/4	IMZ **AMP**	20cm **20cm**
Leptospermum scoparium (n=20) Myrtaceae	453	0/0	5/4	1/1	5/5	**IMZ** *GLY*	**25cm** *20cm*
Leucaena leucocephala (n=16) Fabaceae	513	0/0	0/0	4/4	0/0	**AMP**	**20cm**
Melaleuca quinquenervia (n=20) Myrtaceae	453	0/0	1/1	4/4	5/5	**IMZ** *AMP*	**25cm** *10cm*
Morella faya (n=20) Myricaceae	580	1/0	2/2	5/4	5/4	**IMZ** *AMP*	**15-20cm** *15-20cm*
Pimenta dioica (n=20) Myrtaceae	641	0/0	0/0	3/3	5/4	**IMZ** *AMP*	**15-20cm** *15-20cm*
Psidium guajava (n=20) Myrtaceae	563	1/1	2/0	1/0	4/2	**IMZ**	**25cm**
Schefflera actinophylla (n=16) Araliaceae	435	0/0	4/4	4/4	4/4	**GLY** **IMZ** **AMP**	**10-15cm** **10-15cm** **10-15cm**
Schinus terebinthifolius (n=16) Anacardiaceae	559	1/0	1/0	4/3	4/3	**IMZ** **AMP**	**5-10cm** **5-10cm**
Spathodea campanulata (n=16) Bignoniaceae	531	0/0	0/0	1/1	4/3	**IMZ**	**20cm**
Syzygium cumini (n=20) **	481	1/1	0/0	0/0	1/0		
Syzygium cumini (n=16) ** Myrtaceae	443	0/0	0/0	0/0	1/1		
Toona ciliata (n=16) Meliaceae	916	4/3	0/0	1/0	4/4	**IMZ** *TCP*	**15cm** *15cm*
Trema orientalis (n=20) Ulmaceae	461	1/1	2/2	4/4	4/4	**IMZ** *AMP*	**15-20cm** *15-20cm*
Total species adequately controlled with active ingredient		**3**	**4**	**15**	**20**		
**re-trial with best herbicide to determine dosing*							
***re-trial all herbicides with higher dosing*							



Ideal IPA hatchet cut



12 cuts in *S. cumini* trial, however only 1 of 20 trees died after 481 days

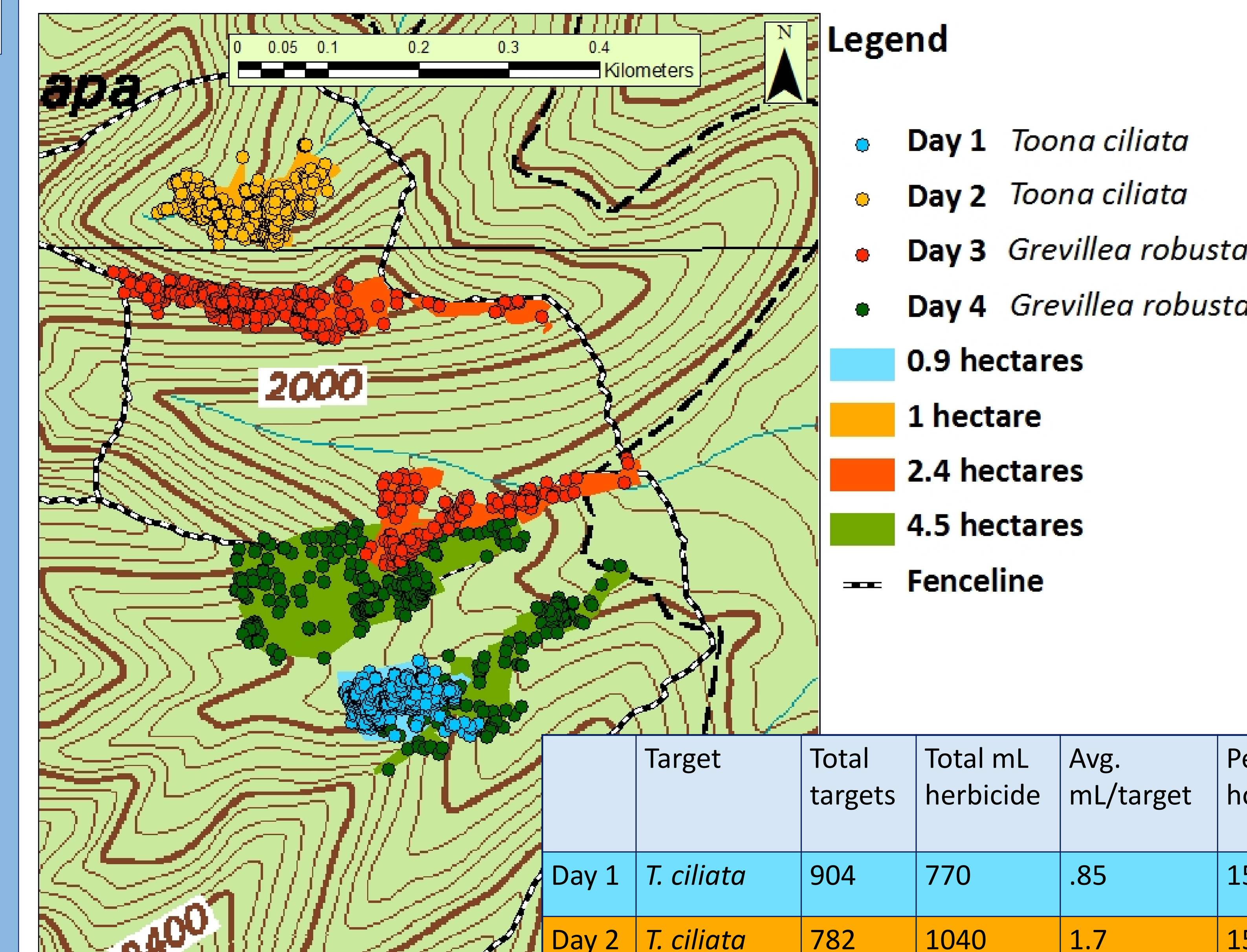


Surrounding native understory and canopy of treated tree remain in good health

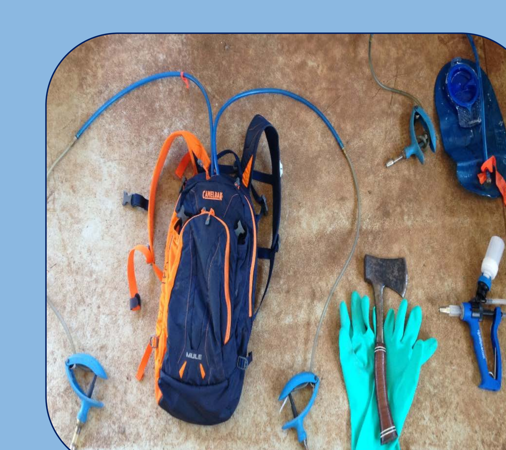
Callusing and aerial roots in response to triclopyr treatment

IPA operational control: OANRP now uses the IPA technique operationally for control of *Toona ciliata* and *Grevillea robusta* across large portions of managed areas. As an example, Figure 4 illustrates four individual days of control efforts for these two targets within a fenced management unit. Area controlled is highly influenced by target density. Quantities of herbicide used per target are remarkably low.

Figure 4: IPA Operational treatment example, Kaluaa, Oahu



	Target	Total targets	Total mL herbicide	Avg. mL/target	Person hours
Day 1	*T. ciliata*	904	770	.85	15
Day 2	*T. ciliata*	782	1040	1.7	15
Day 3	*G. robusta*	450	1460	3.2	20
Day 4	*G. robusta*	373	825	2.2	21



Above photos: Operational gear continues to evolve as tools are field tested.

Above photo: Defoliated *G. robusta* (right) next to a healthy *Acacia koa* (left). Aminopyralid is known for efficacy on Fabaceae, and therefore nearly all area treated on day 4 (Fig. 4) was monitored for non-target effects to *A. koa*, a native hardwood Fabaceae. No non-target effects were observed to *A. koa*, however a single *Alyxia stellata* wraped around a treated *G. robusta* died.

Above photo: Slope with defoliated *G. robusta.* The speed of control with IPA allows for greater landscape weed management.

Conclusions:

- IPA offers a measured, clean, cost effective, and efficient field technique for administering lethal doses to invasive woody species.
- Conducting IPA herbicide species trials, although a somewhat long-term (ideally 2 years) commitment, are an important step in determining effective herbicide and dose rate for effective control of target species throughout the Hawaiian islands.
- Imazpyr and Aminopyralid are two herbicides that field managers should consider stocking in their herbicide supply for control with the IPA method.

Acknowledgements: Thank you to the following land managers and owners for their support with these trials: Amanda Hardman and the State of Hawaii NARS division, Laurant Pool and Waimea Valley and Paul Zweng in Waikane Valley.

Restoring *Psidium cattleianum* dominated forest in the Waiʻanae Mountains, Hawaiʻi

Jane Beachy, Julia Gustine Lee and Michelle Akamine
Oʻahu Army Natural Resources Program, Pacific Cooperative Studies Unit and USAG-HI Directorate of Public Works, Environmental Division, Schofield Barracks

Abstract: Diverse mesic forests in the northern Waiʻanae Mountains of Oʻahu support a vibrant mix of endangered species. Unfortunately, much of this forest is heavily invaded by *Psidium cattleianum*, an exotic tropical tree hailing from South America. The invasive characteristics of *P. cattleianum* are well documented, as is the threat it poses to native taxa. The Oahu Army Natural Resource Program (OANRP) conducted an informal trial investigating strategies for removal of *P. cattleianum* monocultures ($100m^2$) which suggested clear-cutting and chipping slash efficiently controlled the invasive tree while allowing re-colonization by native plants. Based on this, in 2010 and 2012 OANRP removed 0.9 ha of dense *P. cattleianum* from Kahanāhaiki Gulch with the goal of reducing alien vegetation cover, increasing native vegetation cover and diversity, and connecting surrounding native forest patches. This project included flying a chipper into the site to grind up large slash piles. Clearing work was done by full-time staff in 2010, and by a combination of full-time and temporary staff in 2012. As feasible, initial clearing was timed to coincide with the senescence of the *P. cattleianum* seed bank, 3-6 months post fruiting, to minimize seedling germination. Volunteers conducted much of the follow-up weed control. Encouragingly, the native tree *Acacia koa* recruited heavily into the site. One opportunistic restoration outplanting was conducted of *Canavalia galeata*. Extensive hand-broadcast of a fast growing native herb, *Bidens torta*, was performed. Photopoints were used to document the dramatic changes at the site. Plots comparing the areas cleared in 2010 and 2012 indicate that while both native vegetation cover and species richness dropped one month after clearing, after five years, both recovered and greatly exceeded pre-clearing levels, while *P. cattleianum* cover remained low. While this aggressive strategy had high initial costs, with a moderate level of follow-up, native forest reclaimed the area.

Project Description:

The Kahanāhaiki Management Unit (MU), located in the northern Waiʻanae Mountains, is home to a variety of endangered plants, one endangered tree snail, and some high-value stands of mesic forest. OANRP manages Kahanāhaiki, with the goal of protecting rare taxa and improving habitat. The MU is fenced free of ungulates and rats are suppressed throughout via a rodent trap grid. Like much of Oʻahu's mesic forest, Kahanāhaiki is infested with non-native plants. While initial efforts focused weeding around native forest patches, vegetation monitoring conducted in 2009 indicated that non-native taxa comprised more than 50% cover across the MU. More aggressive efforts were needed to push non-native cover below the 50% threshold and meet restoration goals. To that end, staff built on informal trials conducted in 2002 which indicated that clearing stands of *Psidium cattleianum* could trigger vigorous growth of the native hardwood tree *Acacia koa*.


Acacia koa

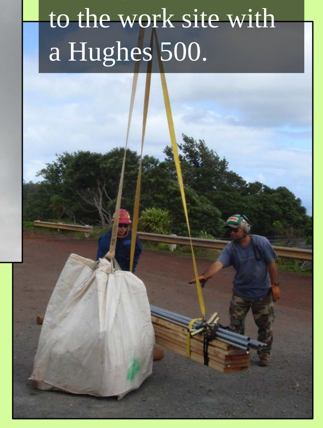

P. cattleianum with green, immature fruit. Controlling trees before fruit matures red is ideal.

Psidium cattleianum (strawberry guava, waiawi), forms dense monocultures, grows quickly, has allelopathic properties, forms deep shade, and has tasty, bird-dispersed fruit (HPWRA, 2012). Few native species thrive in *P. cattleianum* stands, and it is not appropriate or preferred habitat for rare taxa. It is the dominant weed in Kahanāhaiki. Seeds remain viable in the soil for less than three months (Uowolo and Denslow, 2008). This suggests that if control is timed before fruiting periods in summer and winter, recruitment from seed can be minimized. *P. cattleianum* is susceptible to triclopyr (Garlon 4) applied to basal bark (< 3" diameter), girdled trunks, and cut stumps.

In 2010, staff identified a large stand of *P. cattleianum* in the southern, mostly flat end of the MU. Patches of native forest bordered the site and some mature *A. koa* persisted within the *P. cattleianum* stand. At the time, no rare taxa were known from within site. Staff began clear-cutting the *P. cattleianum* with chainsaws. To minimize the volume of slash created, a wood-chipper was flown into the work site. The chipper, Bandit model 65 XP, weighs 2,850 lbs, and was flown into place by a contracted Huey helicopter ($3,000/hr). In the 2002 trial, a small, lightweight chipper was used; while it was easy to transport, the small chipper required staff to spend large amounts of time cutting slash small enough to fit the hopper, and was simply not efficient in the field.



Left and above: Flying the chipper into Kahanāhaiki .


Other gear was flown to the work site with a Hughes 500.


Working at the project site. When not in use, the chipper was covered with a protective tent.


The chipper easily handled 6" diameter trunks.

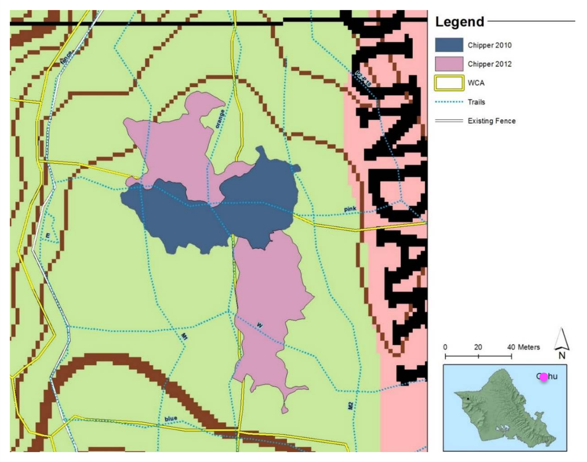

By placing boards under the wheels, staff could move the chipper around the site.

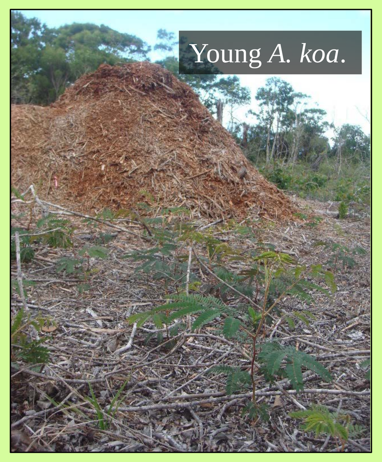
Sometimes a 'come-along' winch was needed as well.

During clearing work, staff discovered the endangered tree snail, *Achatinella mustelina*, on a tree in the site. Work halted due to the threat of accidentally chipping snails or creating an inhospitably hot environment. Staff developed a protocol to follow in future to avoid potential *A. mustelina* impacts, including conducting both night and daytime snail surveys.


Achatinella mustelina

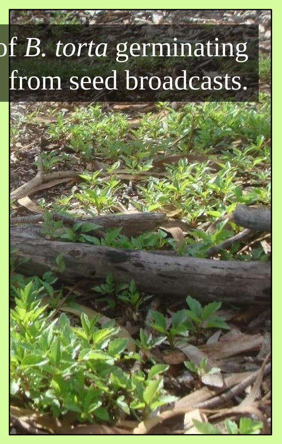

Decomposing chips release heat; to minimize the risk of fire, many small piles of chips were made.




Young *A. koa*.

Hundreds of *A. koa* germinated across the work site, prior to any other colonizers. To provide cover across the area, staff broadcast locally collected *Bidens torta* seed. Previous trials indicated such broadcasts effectively created robust stands of the perennial shrub.


Bidens torta


Carpets of *B. torta* germinating from seed broadcasts.

Project Phase	Duration	Effort (person hours)	Area Cleared (ha)
2010 Clearing	2 months	456	0.36
2012 Clearing	5 months	519	0.54
All Clearing (sum)	7 months	975	0.90
Re-treatment and follow up weed control	5 years	1,027	-

In 2012, staff continued clearing work at the site. While permanent staff conducted all clearing work in 2010, in 2012 at least half the work was carried out by temporary staff. Between 2010 and 2015, follow-up weed control and site maintenance was carried out by both staff and volunteers. More time was spent on follow-up work than initial clearing.


Aerial view of the work site, late 2010


Volunteers provided critical assistance by conducting follow-up weed control.


Many *P. cattleianum* stumps resprouted, likely because they escaped herbicide treatment, or were treated too long after they were cut. They were re-treated as part of maintenance work.

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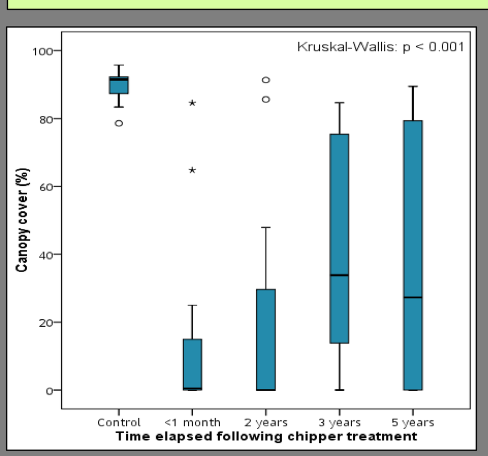
Vegetation Monitoring Methodology:

Monitoring of understory and canopy vegetation following *P. cattleianum* clearcutting was conducted in 2012 and 2015. During monitoring, all native and non-native species present in the understory and canopy in 1x3m plots were recorded. Hemispheric photographs of the canopy were taken from the middle of each plot, with canopy cover measured using Gap Light Analyzer (GLA), Version 2.0 software (Frazer et al. 1999). Native and non-native understory percent cover was categorically recorded in 1x1m plots as 0-25, 25-50, 50-75, or 75-100%. Canopy cover, native and non-native understory cover, and species richness were analyzed using Kruskal-Wallis tests. Species frequencies were analyzed using chi-square and Fisher's exact tests. Analyses were performed in IBM SPSS Statistics Version 20.

Percent Cover

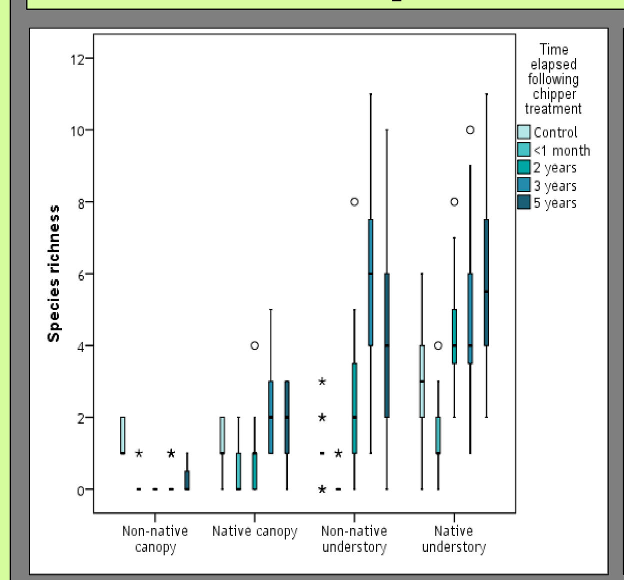


Left: total canopy cover over time. Prior to chipping, the area was densely canopied and dominated by non-native taxa. Immediately following clearing, the canopy was largely open. After 2 years, canopy cover remained low and was predominantly native. After 3-5 years, the canopy continued to refill primarily with native taxa.

Right: understory cover over time. Similar to canopy cover, non-native vegetation dominated prior to chipping, but decreased immediately after chipping ($p < 0.001$), and stayed low for 5 years. Native vegetation cover increased ($p < 0.001$) by 2 years after chipping.

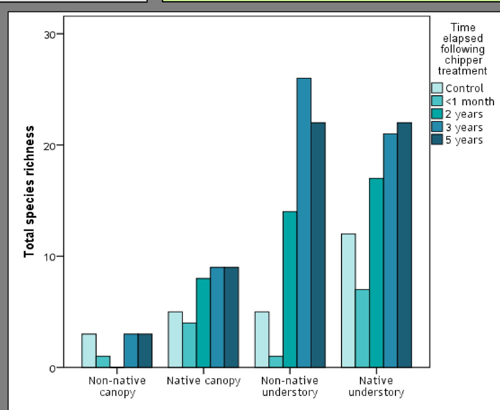
Time elapsed after chipping	Non-native understory	Native understory
Control	75-100%	0-25%
< 1 month	0-25%	0-25%
2 years	0-25%	25-50%
3 years	25-50%	25-50%
5 years	0-25%	25-50%

Species Richness

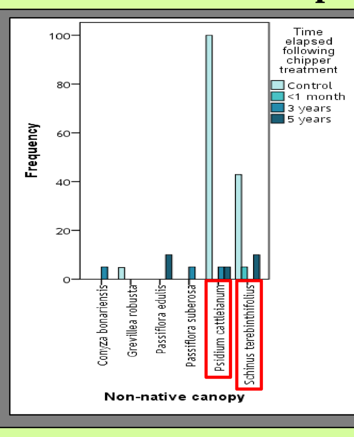


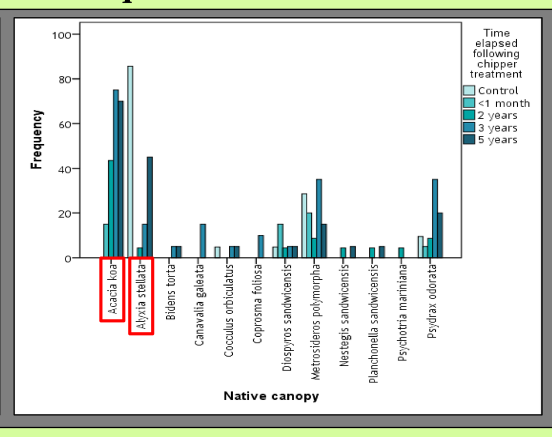
Left: species richness among plots in chipped areas over time. Median species richness changed significantly ($p < 0.001$ each) over time in all categories. Non-native understory richness increased after 2 years, while native understory richness initially declined (primarily due to the decline of *A. stellata* immediately following chipping), and later increasing by 2-5 years post-chipping.

Right: total species observed among all plots in chipped areas over time. Initially, diversity declined for all categories. From 2-5 years, all categories became more diverse except for the non-native canopy, which rebounded only to its original level.

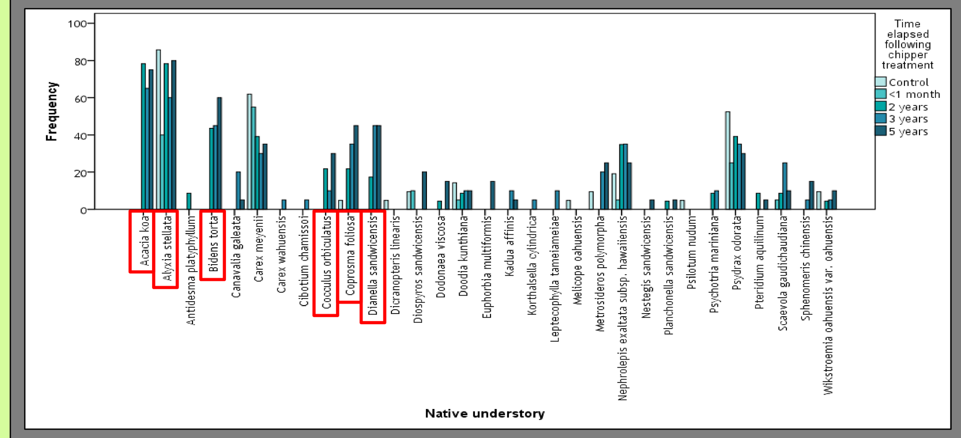


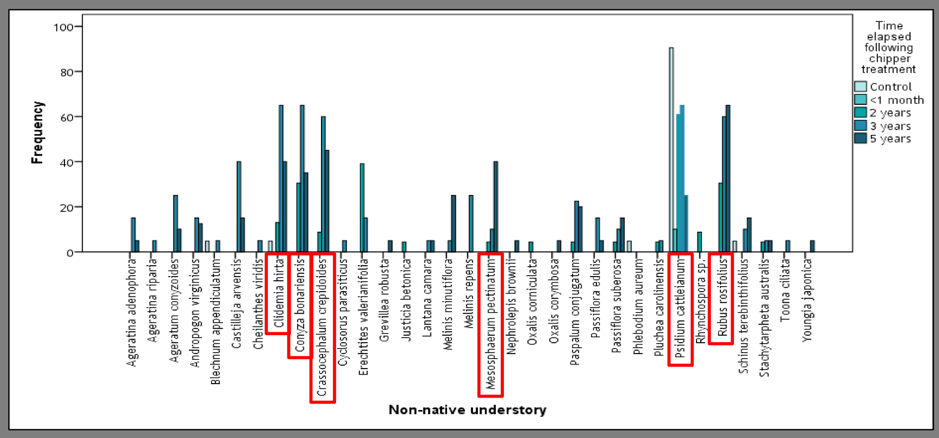
Species Frequencies





Above: Non-native (left) and native (right) taxon frequencies in the canopy among plots over time. Notable non-native taxa changes include reductions in *P. cattleianum* (100 to 5%, $p < 0.001$) and *S. terebinthifolius* (43 to 10%, $p = 0.018$). Interesting native taxa changes include increases in *A. koa* (0 to 70%, $p < 0.001$) and fluctuations in *A. stellata* which experienced a net decline (86 to 45%, $p = 0.006$). However, *A. stellata* rebounded significantly ($p = 0.001$) between < 1 month, when no plants were noted, and 5 years post-chipping.





Native Taxa	Frequency Change	P value
Acacia koa	0 to 75%	< 0.001
Bidens torta	0 to 60%	< 0.001
Cocculus orbiculatus	0 to 30%	0.009
Coprosma foliosa	5 to 45%	0.004
Dianella sandwicensis	0 to 45%	< 0.001
Alyxia stellata	86 to 80%	-

Above: Native (left) and non-native (right) taxon frequencies in the understory among plots over time. Notable changes are highlighted in the tables to either side. While removing *P. cattleianum* created large light gaps, allowing for the proliferation of a variety of other weeds, it also allowed for the recovery of a host of native plants. Many of the weeds colonizing the project area are short-lived and sun-loving (for example, *C. bonariensis*) and are expected to decline as canopy cover increases. Other weeds, such as *C. hirta*, thrive in shade and will require continued follow-up. The native taxa found in the site, span a variety of growth forms and light preferences. Interestingly, *A. stellata* frequency first decreased to 0, before recovering almost to original levels. The dramatic increase in *A. koa* is key to the recovery of the area.

Non-native Taxa	Frequency Change	P value
Clidemia hirta	5 to 40%	0.009
Conya bonariensis	0 to 35%	0.004
Crassocephalum crepidioides	0 to 45%	< 0.001
Mesosphaerum pectinatum	0 to 40%	0.001
Rubus rosifolius	0 to 65%	< 0.001
Psidium cattleianum	90 to 25%	< 0.001

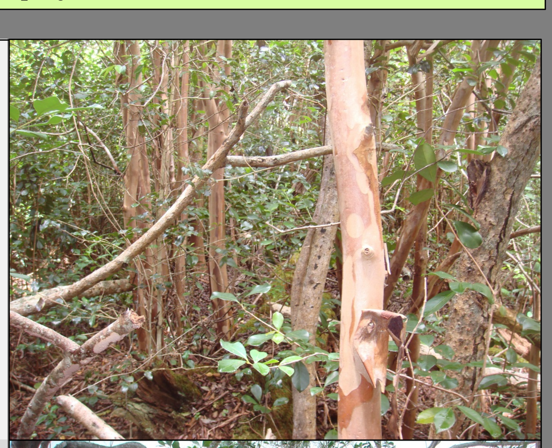
Photopoint Methodology:

Flagged and tagged PVC poles were installed throughout the proposed work site. Photos were taken from the poles in the four cardinal directions. A compass and print-outs of the September 2010 set of photopoints aided staff in lining up each photo. Unfortunately camera type, focal length, and precise angle varied over the years due to changes in observers. The photopoint series below showcase the dramatic changes seen at the project site.

2010 June
Prior to clearing. All clearing completed here in June and July.

Few native plants are visible in this stand of *P. cattleianum*.

The entire project area was covered in a dense stand of *P. cattleianum*, typical of this photo. A variety of size classes are present, although most trees ranged from 5-15 cm in diameter.



2010 Sept.
2 months post-clearing

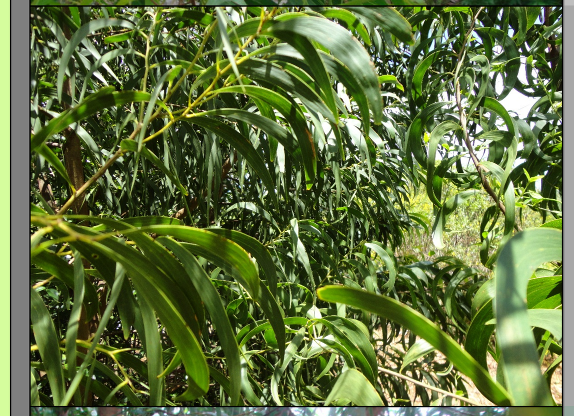
While most vegetation was chipped, large limbs and trunks were stacked into piles. Leafy branches comprised the greatest volume of slash, and were the highest priority for chipping. Volunteers used some limbs and chips to line access trails.

Piles of chips cover most of the cleared area. Staff limited the size of chip piles to reduce the likelihood of compost fires. Re-sprouting *P. cattleianum* stumps are visible in the foreground. Note the spindly *Psydrax odorata* tree uncovered during clearing in the center of the photo.

2011 July
12 months post-clearing

On the right side of the photo, large *B. torta* shrubs cover much of the open ground. In the fore-ground, a fast growing *A. koa*, has already reached 1 m in height. In the background, note the stand of mature *A. koa* uncovered during clearing.

Large *B. torta* plants colonize open ground, excluding deep chip piles. *Alyxia stellata* vines appear to be recovering in the foreground, after being trampled during initial clearing.



2012 July
24 months post-clearing

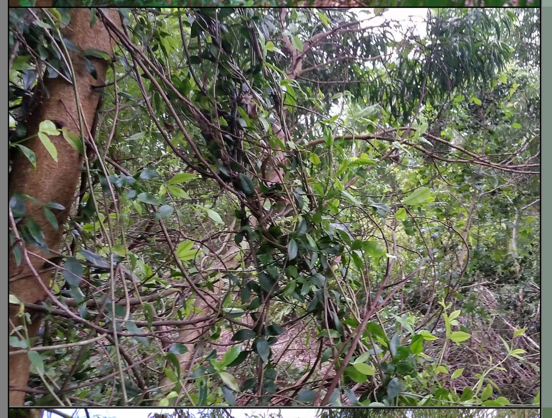
Within two years, *A. koa* saplings have obscured the view from this photopoint. These trees are between 1.5 – 2.5 m tall.

Native understory plants filled in much of the open area. Note the *A. koa* saplings in the background, yellow flowers of *B. torta* in the mid-ground, and the tangle of *A. stellata* in the foreground.

2013 April
33 months post-clearing

While many of the hundreds of *A. koa* recruits did not survive, the trees visible here thrived, and just three years after clearing form a canopy. Note the twining vine *A. stellata* climbing through the *A. koa* branches on the left side of the photo.

The *P. odorata* is notably fuller, perhaps due to increased light, decreased competition, or reduced alleleopathic effects. Much of the background is completely filled with *A. koa* saplings. Tall *B. torta* shrubs dominate the mid-ground.



2014 Dec.
53 months post-clearing

Prior to clearing, *A. stellata* was the most common native species in the canopy. Unsurprisingly, *A. stellata* levels dropped greatly post-clearing, but as is evident in this photo, the vine rebounded vigorously over time.

The understory has completely filled in four years after clearing. While short-lived *B. torta* is still present, other native species now thrive in the site. A canopy of *A. koa* is visible in the background.

2015 July
60 months post-clearing

Very encouraging results are visible after five years. Not only has *A. koa* formed a canopy, but native plants have also colonized the understory. Large patches of *Nephrolepis exaltata* subsp. *hawaiiensis* stretch across the ground.

The change evident in this photopoint series is dramatic. Despite the drastic techniques used, native vegetation reclaimed the project site. Regular follow-up weeding was critical to preventing the proliferation of understory weeds during this time.

Conclusions:

- Restoration of *P. cattleianum* stands through aggressive weed control (clearcutting and chipping) can be highly effective.
- Native Hawaiian mesic forest can be very resilient. Within 5 years, both understory and canopy coverage reached approximately 50% vegetative cover.
- Seed broadcast of the short-lived perennial shrub *Bidens torta* was successful in creating large beds of this taxon within 2 years. Establishing a native ground cover likely reduced weed invasion.
- Outplanting is not necessary for restoration, although it may speed the process further.
- Follow-up weed control is critical to project success, and must be sustained for at least 5 years after initial clearing.
- The size of the project area should be based on the estimated area staff can commit to conducting follow-up weed control in, rather than the size of the area which can be clearcut in a given season.

Targeted Surveys Provide Opportunities to Assess Threats to Managed Areas

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Abstract: Surveys can be the first line of defense in detecting invasive plant species. Effort spent searching targeted areas can provide numerous novel specimens that can be assessed for management action. The Oahu Army Natural Resources Program (OANRP) uses inventory surveys to identify potential new threats to endangered species Management Units (MUs) and to detect and prevent the spread of weeds on Army Training Ranges. These inventories are a low-tech method of detection that have provided valuable results. Each year OANRP surveys approximately 325 km along Army Training Range and MU access roads, 50 helicopter landing zones, 7 high-use field sites (such as campsites), and 15 highly trafficked trails (Fig. 1). With identification assistance from the Bishop Museum and the Oahu Early Detection program (OED), OANRP has documented 29 new island records for O'ahu, 9 new State of Hawaii records, and 13 new records of naturalizing taxa since 2004. Not all new species result in management actions, but early detection provides the opportunity to decide if a particular taxon requires action before it becomes a significant threat to resources in managed areas. The threats posed by new finds are assessed with the use of the Hawaii Weed Risk Assessment (HWRA) program, collection and naturalization data from Bishop Museum, the Smithsonian National Museum of Natural Botany Department, and expert botanical field knowledge. New taxa are assessed and management actions are determined using a management decision matrix.

Background and Methods: Early detection is critical in allowing managers maximum flexibility in addressing incipient or novel invasive weed populations. Once a weed reaches a certain threshold infestation size, they can become too large to effectively control, particularly with limited staff time. OANRP conduct surveys at potential locations of introduction and spread on OANRP managed areas (Fig. 1). The surveys help to address Army requirements to minimize the threat of alien species introductions resulting from range maintenance, construction and training activities within and adjacent to landing zones, trails, and roadsides, as well as to address potential weed spread into areas of native forest managed for rare taxa. Information about the current distribution of a species, its invasiveness, and location are all used to determine an appropriate management response.

On each survey, staff record all non-native taxa observed within the defined survey area (Fig. 2). Survey data are entered into the OANRP Database and the following reports can be generated to assist with taxa assessments: 1) new taxa observed on a survey, 2) a list of surveys for which a particular taxa is present, 3) the date a taxa is first observed on any given survey, and 4) a list of taxa observed on previous survey dates. For species difficult to identify, specimens are sent to Bishop Museum for identification (Fig. 3).

Figure 2: Example survey field form

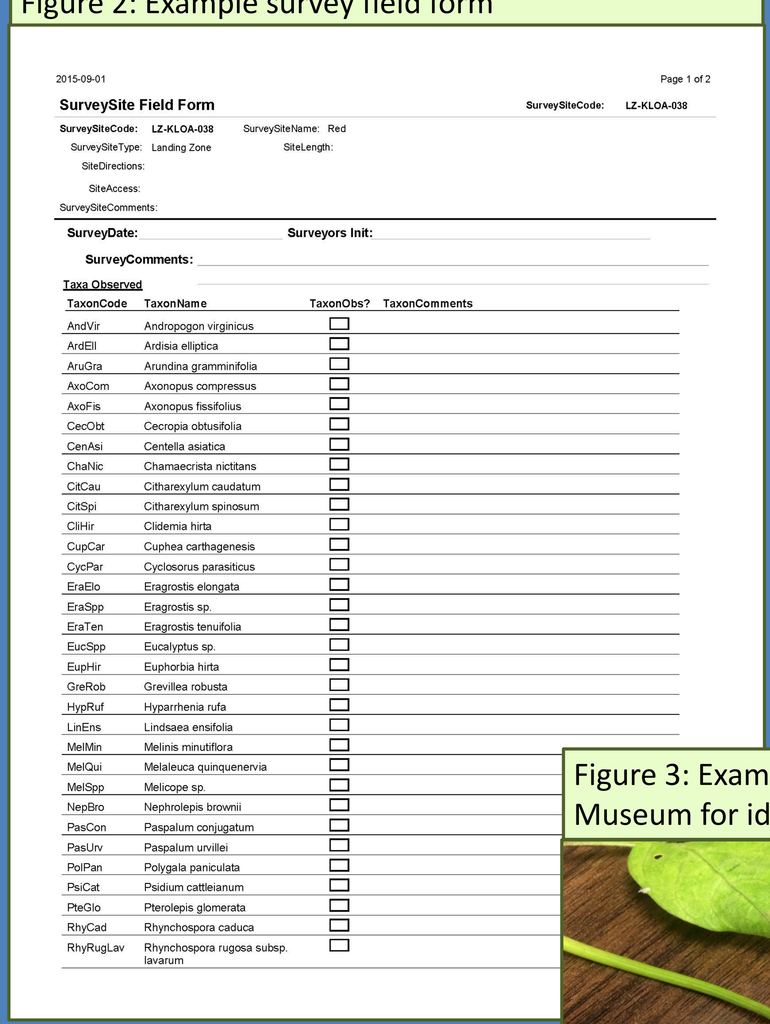


Figure 1: Map of all weed surveys. Surveys are conducted at different intervals and therefore not all surveys shown are completed each year.

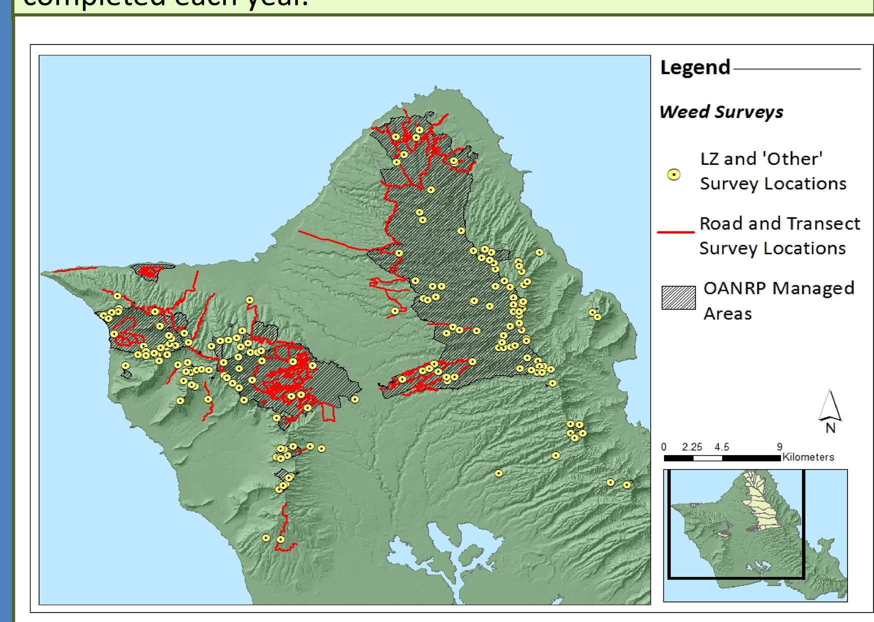
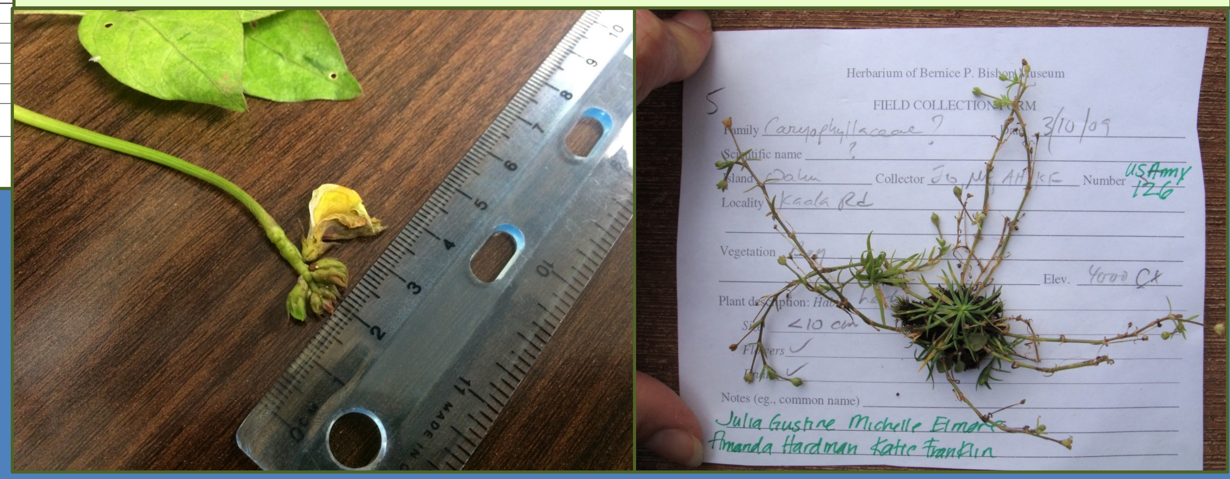


Figure 3: Examples of unknown species and submission form sent to OED staff at Bishop Museum for identification. OANRP photograph submissions for reference.



Survey Types:

Road: Effort varies for each survey depending on length (up to 2 kilometers) and quality of road (paved vs four wheel drive) and can range from half a day to two days to complete. Roads on Army Training Ranges and high-use OANRP access roads are surveyed annually, and the remaining OANRP access roads are surveyed every other year. On Army Training Ranges, road surveys include all drivable roads as well as training sites that appear to have had use. Ranges may be separated into several surveys to facilitate access and tracking. Each year some roads are too overgrown to drive, or new roads are created. Staff take GPS tracks of all areas surveyed to document annual survey effort and to map new roads.

Camp/Other: These surveys aim to capture any spread of invasive weeds from staff and gear. 'Other' surveys are a catchall for locations of potential contamination and spread such as washrack sediment disposal sites, and sand or gravel stockpiles used to deploy fill across ranges. Surveys of the piles and the surrounding vegetation can give a good idea of which species may be moved to new areas with deployment of materials.

Weed Transect: Most of these surveys are located along corridors of high traffic such as fencelines or staff trails that lead from a trailhead or parking area to an MU.

Landing Zone(LZ): Most OARNP LZs are small and located in remote mountainous locations. Army LZs on the other hand are often large fields across which staff conduct surveys. Army LZs are surveyed annually, and OANRP LZs are surveyed quarterly when used within a given quarter.

Evaluations of new taxa: Each year dozens of new species are found on surveys or observed in new locations during the course of other management actions. These taxa range from being widely naturalized on Oahu to new island or state records. Figure 4 illustrates the process used for determining appropriate OANRP management actions ranging from targeting for eradication to no control. Information about species that are found outside of OANRP managed areas and that may warrant further control or monitoring is shared with relevant landowners and partners so that they may assess management priorities. Basic information about individual taxa considered as part of the decision matrix includes: known distribution of taxa, invasiveness (use HWRA for determination), and location found. Additionally, potential control partners, availability of effective control methods, type of location (terrain, accessibility), resources/funding, etc., are also important inputs in deciding how to manage a new invasive species but are often more difficult to evaluate.

Figure 5 shows the process of assessing management actions with examples of species that were found during surveys or incidentally. The list also highlights that assessments and management responses are challenging as taxa information is sometimes incomplete, resources for control may be unavailable, and management responsibility may be best suited to another agency.

Figure 4: Management Decision Matrix

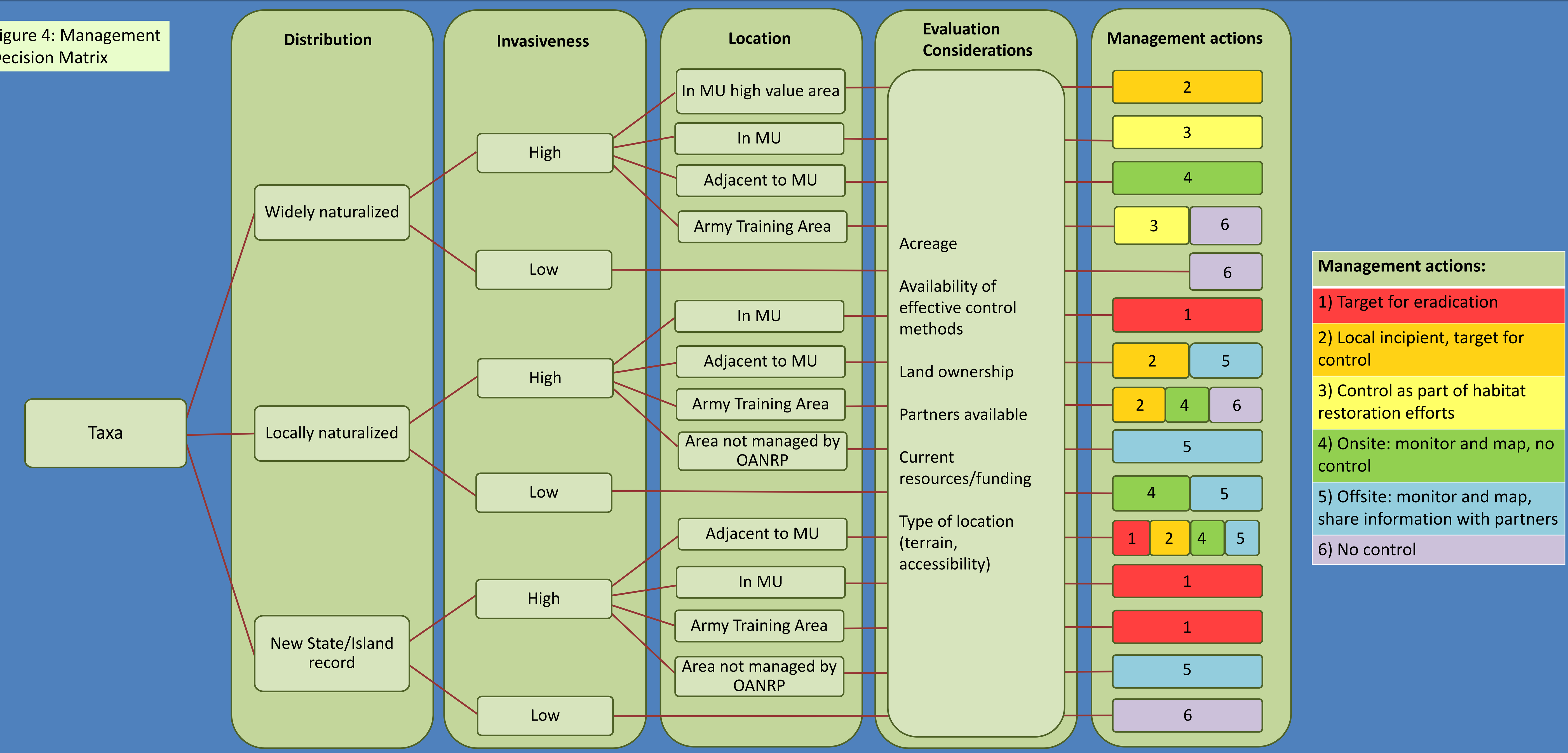


Figure 5: OANRP examples of working species through the decision matrix

Species	Common name	Distribution	Invasiveness	Location	Evaluation considerations	Management actions
Albizia adianthifolia (Fabaceae)	Flat Crown	New State Record	Not thoroughly researched by OANRP staff although observed naturalizing on range	On Army Training Range	Only known from Training Range, but recently observed 2km from core. Appears to behave similarly to *F. moluccana*.	Onsite: Monitor and map naturalizing individuals; if resources and time available for control, should target prioritized plants (4)
Cenchrus setaceus (Poaceae)	Fountain Grass	Locally naturalized	Highly	Adjacent to MU and degraded training area	Grass in a fire prone area on leeward side of island. Seedbank <1 yr; eradicable	Target for eradication (1)
Chromolaena odorata (Asteraceae)	Devil Weed	New State Record	High. Well documented as highly invasive worldwide	In high-use areas of Army Training Range	Likely military introduction therefore OANRP commitment to control. Infestation covers large area, so important to have good strategy.	Target for eradication (1)
Dietes iridioides (Iridaceae)	African Iris	Widely naturalized	Unknown	Inside MU	Small patch near native forest	Local incipient, target for control (2)
Dovyalis hebycarpa (Flacourtiaceae)	Ceylon gooseberry	Locally naturalized	Highly	On Army Training Range	Need to monitor	Onsite: monitor and map, no control (4)
Nephrolepis brownii (Dryopteridaceae)	Rough Sword Fern	Widely naturalized	Highly	Inside MU	Invades disturbed/open areas after canopy control and creates thick understory	Control as part of habitat restoration efforts (3)
Olea Europa (Oleacea)	Wild Olive	Locally naturalizing	Highly	Access road; area not managed by OANRP	On access road to MU, but currently a safe distance from trailhead	Offsite: Monitor and map; share information with partner agencies (5)
Petrorhagia velutina (Caryophyllaceae)	Tunica	New Island Record	Unknown; not likely to become ecosystem altering	On Army Training Range	Small, only found in degraded locations	Not a control priority (6)
Senecio madagascariensis (Asteraceae)	Fire Weed	New Island Record	Not a high threat to OANRP managed areas, but is a State noxious agricultural weed	On Army Training Range	Likely introduced by military training; don't want to spread further	Target for eradication (1)

Conclusions:

- Surveys highlight the way that military training and natural resource management practices can result in unintended introductions and movement of weedy species. Strict sanitation protocols are necessary.
- Time spent looking specifically for invasive weed introduction or spread at regular intervals, increases the chance of identifying an infestation early in establishment.
- Even with targeted surveys, invasive taxa may go unnoticed; surveys conducted at regular intervals are therefore important to catch missed species.
- Identification experts and Bishop Museum records are critical in helping to make management decisions.