OAHU ARMY NATURAL RESOURCES PROGRAM
MONITORING PROGRAM

MAKAHA ECOSYSTEM RESTORATION PRE- AND POST-CLEARING VEGETATION MONITORING

INTRODUCTION

Vegetation monitoring occurred at the "Giant Ohia" ecosystem restoration site at Makaha prior to and six months following completion of initial clearing efforts. The site encompasses approximately 0.4 acres (Figure 1) in an area generally comprised of mixed native and non-native vegetation in the understory and canopy. Restoration efforts included weeding non-native canopy and understory vegetation between August 10 and September 22, 2016, followed by seed sowing of native taxa (*Pipturis albidus*) and quarterly maintenance understory weeding. Weeding efforts were accomplished using the "clip and drip" method with chainsaws and hand saws. All weeded material was placed into large piles to leave open room for plantings, with the exception of many of the larger trees (> 7 inch diameter), which were girdled and left standing to prevent damage to surrounding native vegetation by felling and removal. Point intercept and photopoint vegetation monitoring was conducted to document change in vegetation cover, with a long term goal of obtaining < 10% non-native and > 80% native canopy cover, and < 25% non-native and > 50% native understory cover. Goals were set based on what was deemed achievable for native cover and maintainable for non-native cover at this restoration site.

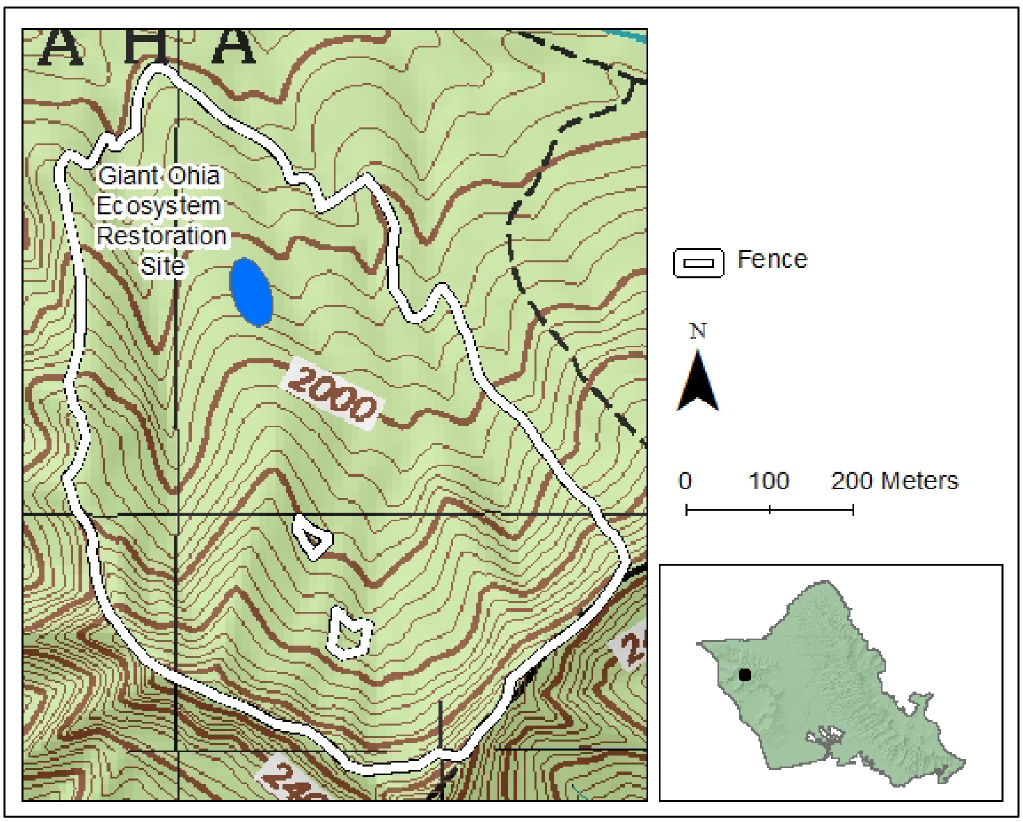

Figure 1. Location of Giant Ohia ecosystem restoration site at Makaha I MU.

METHODS

Point intercept monitoring was conducted on August 3, 2016 and March 16, 2017 to assess changes in percent cover of native and non-native taxa in the understory and canopy. All species "hit" at points along transects were recorded for understory and canopy vegetation. A 5 millimeter diameter, 6 foot tall pole was used to determine "hits" in the understory, to include live vegetation less than 2m above ground level (AGL) that touched the pole (including leaves, branches and trunks) along an outstretched measuring tape at regular intervals. A laser pointer held against the pole was used to determine laser "hits" in the canopy (above 2 mAGL) at these same intercept points, where the point fell within the perimeter of a tree's canopy. Locations where no vegetation was intercepted was recorded as non-vegetated. Locations of transects and sampled points were not permanent. Approximately 500 (or more) points were planned based on a priori analysis of a sample size necessary to detect a 10% change with a power of 0.90 using G* Power Version 3.1.9.2. Point intercepts were located every 0.5 m along 11 transects spaced 5 m apart with 630 total point intercepts in August 2016, and along 9 transects spaced 6 m apart with 547 total point intercepts in March 2017. Approximations of percent cover were obtained from the proportion of "hits" among all intercepts. Because infrequent and/or low cover taxa are less likely to be accounted for using point intercept monitoring, a list was made of all taxa anecdotally observed during the course of monitoring. Analysis included Pearson's chi-square tests of change in cover over time using IBM SPSS Version 24. Only absolute cover changes > 10% were analyzed to mitigate the probability of detecting a change when none exists (Type I error), and $\alpha = 0.05$ was used for significance determinations. Prediction maps[1] of taxa occurrence were created using Geostatistical Analyst, ArcGIS 10.3.

Photopoint monitoring was conducted on August 2, 2016, October 3, 2016, and March 20, 2017, to provide representative visual documentation of vegetation change. Four permanent photopoints were established throughout the site, marked with flagged and tagged PVC poles. Photographs were taken in each cardinal direction at each photopoint.

RESULTS

Canopy: Prior to weed clearing, the Giant Ohia site consisted of 88% non-native canopy cover, dominated by *Psidium cattleianum*, largely intermixed with 67% native canopy cover, primarily *Psydrax odorata*, *Acacia koa*, and *Metrosideros polymorpha* (Tables 1 and 2, and Figures 2 through 7). Less than 1% of the area lacked canopy cover. Weed clearing significantly reduced non-native canopy cover to 7%, and *P. cattleianum* from 86% to 3%, and increased non-canopied area to 23%.

Understory: Before clearing, the understory included 30% non-native cover, also dominated by *P. cattleianum*, partially intermixed with 21% native cover, primarily *Alyxia stellata* and *P. odorata*. More than half (53%) of the understory was non-vegetated. Similarly, clearing resulted in a significant decrease in non-native cover to < 1%, as well as *P. cattleianum* from 29% to < 1%, and an increase in non- vegetated area to 79%.

Species composition: During point intercept monitoring, sixteen native and eight non-native taxa were recorded in either the canopy or understory pre-clearing, while fourteen native and five non-native taxa were identified in either the canopy or understory six months post-clearing. An additional six taxa were observed but not intercepted during monitoring pre-clearing, (three native and one non-native), while nineteen were observed but not intercepted six months post-clearing (six native and thirteen non-native) (Table 3). Species composition changes included thirteen (77% non-native) taxa newly observed post-clearing during either point intercept monitoring or anecdotal observations, and six (83% native) taxa observed pre-clearing during either point intercept monitoring or anecdotal observations but not identified post-clearing, in either the canopy or understory (Table 4). One additional non-native taxon not observed on either of the monitoring dates (*Ageratina riparia*) was controlled during maintenance weeding.

Table 1. Native, non-native, and non-vegetated percent cover before and six months following weed removal at the Giant Ohia restoration site, Makaha. P-values derived from Pearson's chi-square test (asymptotic significance). Only taxon groupings with an absolute cover change of > 10% were analyzed. Positive values for cover change denote increased cover, while negative values indicate decreased cover.

	Pre-clearing	Post-clearing	p	X^2	Absolute cover change	Management goals currently met?
Understory						
Non-native	29.84	0.73	0.000	181.74	-29.11	Yes
Native	20.79	20.29				No
Non-vegetated	52.86	78.98	0.000	87.79	26.12	
Canopy						
Non-native	88.25	7.13	0.000	770.84	-81.12	Yes
Native	67.14	74.41				No
Non-vegetated	0.48	22.85	0.000	151.24	22.37	

Table 2. Species cover before and six months following weed removal at the Giant Ohia restoration site, Makaha. Native taxa in boldface. Positive values for cover change denote increased cover, while negative values indicate decreased cover. P-values derived from Pearson Chi-square (asymptotic significance) test. Only taxa with > 10% absolute cover change were analyzed.

Taxon	Pre-clearing	Post-clearing	Cover change	p	X^2
Understory					
Acacia koa	0.16	3.29	3.13		
Alyxia stellata	11.27	7.86	-3.41		
Bobea elatior	0.16	0.00	-0.16		
Carex wahuensis	0.48	0.55	0.07		
Clidemia hirta	0.16	0.00	-0.16		
Coffea arabica	0.16	0.00	-0.16		
Coprosma foliosa	0.79	0.00	-0.79		
Cordyline fruticosa	0.32	0.37	0.05		
Crassocephalum crepidoides	0.00	0.18	0.18		
Diospyros sandwicensis	0.32	0.37	0.05		
Dodonaea viscosa	0.00	0.18	0.18		
Doodia kunthiana	0.32	0.37	0.05		
Euphorbia multiformis	0.00	0.18	0.18		
Kadua affinis	0.32	0.00	-0.32		
Lepisorus thunbergianus	0.00	0.18	0.18		
***Melicope* sp.**	0.16	0.00	-0.16		
Metrosideros polymorpha	0.00	0.91	0.91		
Microlepia strigosa	0.79	0.91	0.12		
Psidium cattleianum	28.73	0.18	-28.55	0.000	182.53
Psychotria mariniana	0.16	0.00	-0.16		
Psydrax odorata	7.62	6.58	-1.04		
Schinus terebinthifolius	0.16	0.00	-0.16		
Syzygium cumini	0.32	0.00	-0.32		
Canopy					
Acacia koa	30.32	31.81	1.49		
Aleurites moluccana	0.48	0.00	-0.48		
Alyxia stellata	9.05	5.30	-3.75		
Bobea elatior	2.06	1.46	-0.60		
Cocculus orbiculatus	0.16	0.00	-0.16		
Cordyline fruticosa	0.16	0.00	-0.16		
Diospyros sandwicensis	6.35	4.75	-1.60		
Dodonaea viscosa	0.63	1.46	0.83		
Grevillea robusta	1.27	0.00	-1.27		
Kadua affinis	0.48	0.00	-0.48		
Metrosideros polymorpha	13.33	21.21	7.88		
Nestegis sandwicensis	2.86	1.10	-1.76		
Psidium cattleianum	86.03	3.11	-82.92	0.000	807.35
Psychotria mariniana	1.90	1.65	-0.26		
Psydrax odorata	34.60	44.42	9.82		
Schinus terebinthifolius	1.27	2.01	0.74		
Syzygium cumini	2.70	2.01	-0.69		

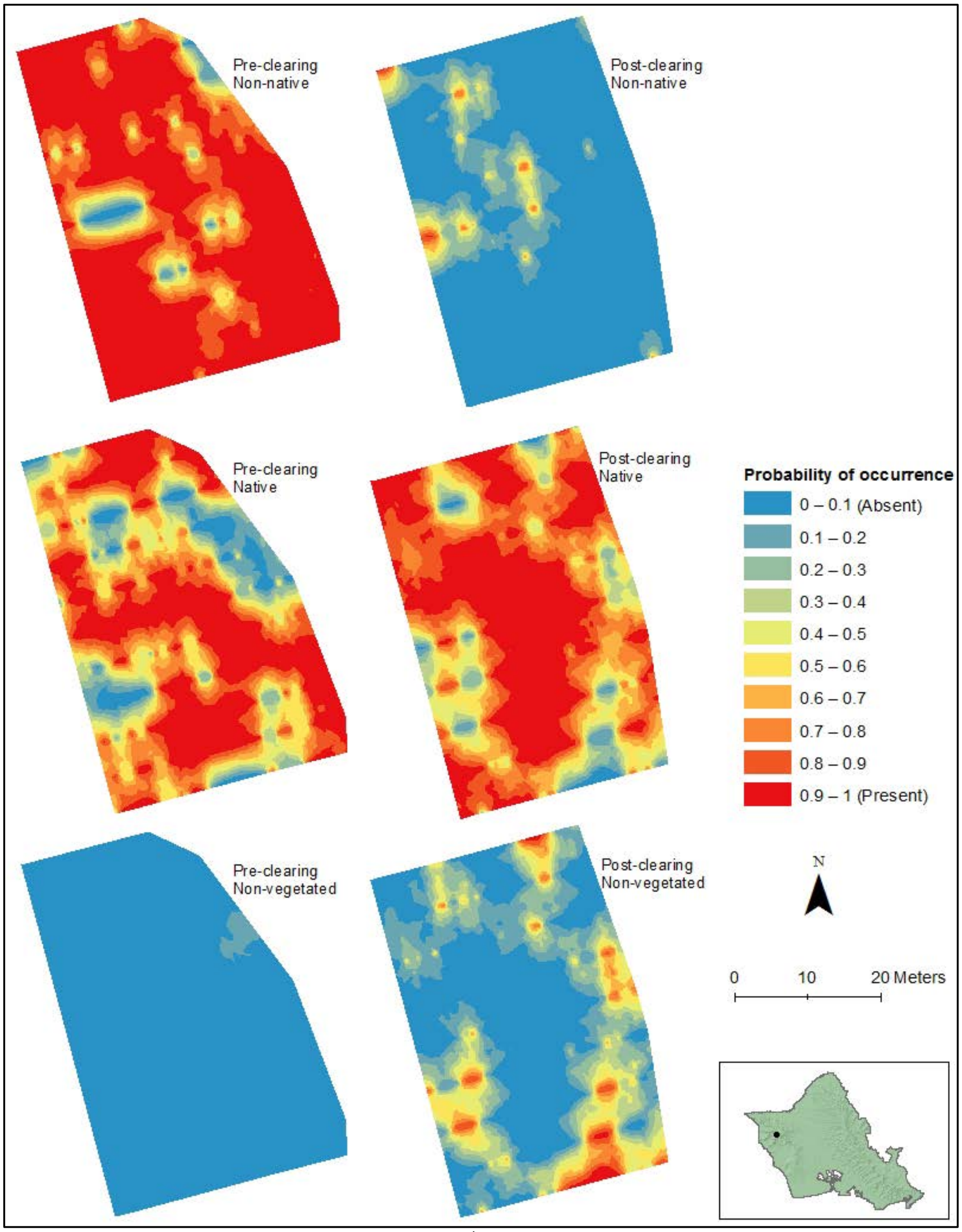

Figure 2. Ordinary kriging predicted locations[1] of canopy taxa prior and six months following weed clearing, showing overall non-native and native cover as well as non-vegetated areas. Probability of occurrence is scaled from zero (contours shown in blue, indicating absence) to one (contours shown in red, indicating presence). Predictions extend to the outer extent of transect locations, thus map shapes differ as a result of small differences in transect locations and lengths pre- and post-clearing.

[1]*Maps created using statistical methods in association with geographic information to show predicted locations of one or more variables, with the probability of occurrence indicated by color coded values. This technique maps probable, not actual, distributions. Known locations are used to predict presence/absence in unsampled locations. When used in association with point intercept data, locations of taxa and taxon groupings with higher cover, particularly those that tend to occur in clusters, may be more accurately predicted. Those with low cover and spotty distributions will have considerably less certainty when mapped.*

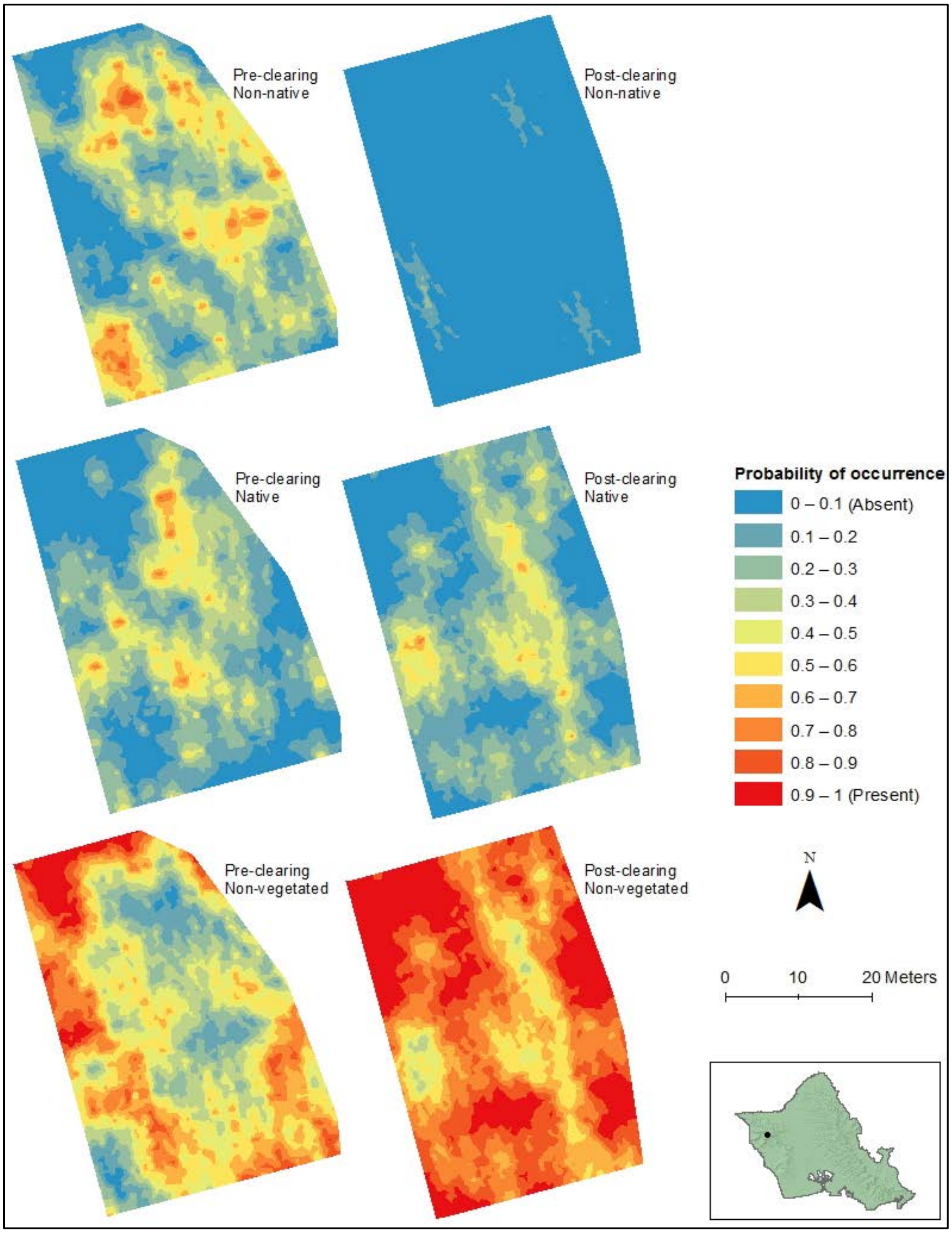

Figure 3. Ordinary kriging predicted locations of understory taxa prior to and six months following weed clearing, showing overall non-native and native cover as well as non-vegetated areas. Probability of occurrence is scaled from zero (contours shown in blue, indicating absence) to one (contours shown in red, indicating presence). Predictions extend to the outer extent of transect locations, thus map shapes differ as a result of small differences in transect locations and lengths pre- and post-clearing.

Pre-clearing *< 1 month post-clearing* *6 months post-clearing*

Figure 4. Photopoint 1 pre-clearing (left column), within one month post-clearing (middle column), and six months post-clearing (right column), with views to the north, east, south, and west, from top to bottom.

Pre-clearing | *< 1 month post-clearing* | *6 months post-clearing*

Figure 5. Photopoint 2 pre-clearing (left column), within one month post-clearing (middle column), and six months post-clearing (right column), with views to the north, east, south, and west, from top to bottom.

Pre-clearing *< 1 month post-clearing* *6 months post-clearing*

Figure 6. Photopoint 3 pre-clearing (left column), within one month post-clearing (middle column), and six months post-clearing (right column), with views to the north, east, south, and west, from top to bottom.

Pre-clearing *< 1 month post-clearing* *6 months post-clearing*

Figure 7. Photopoint 4 pre-clearing (left column), within one month post-clearing (middle column), and six months post-clearing (right column), with views to the north, east, south, and west, from top to bottom.

Table 3. Taxa observed, but not intercepted, during monitoring prior to and six months after initial weed clearing in the understory and/or canopy. Native taxa in boldface. *Intercepted during post-clearing monitoring. **Intercepted during pre-clearing monitoring.

Pre-clearing	Post-clearing
Asplenium nidus	***Asplenium caudatum***
Euphorbia multiformis	*Aleurites moluccana***
Lepisorus thunbergianus***	*Blechnum appendiculatum*
Nephrolepis exaltata* subsp. *hawaiiensis	*Clidemia hirta***
Phlebodium aureum	*Coffea arabica***
Planchonella sandwicensis	*Conyza bonariensis*
	Emilia sonchifolia
	Kadua affinis**
	Korthalsella complanata
	***Melicope* sp.** **
	Paspalum conjugatum
	Passiflora edulis
	Phlebodium aureum
	Pipturis albidus
	Psilotum nudum
	Rubus rosifolius
	Spathodea campanulata
	Toona ciliata
	Trema orientalis

Table 4. Species composition changes, showing newly recorded, and no longer identified, taxa from point intercept monitoring and anecdotal observations in the canopy and/or understory six months post-clearing, with percent cover values indicated for intercepted taxa. Native taxa are in boldface.

Taxa recorded pre-clearing but not post-clearing	Cover	New taxa recorded post-clearing	Cover
Asplenium nidus		***Asplenium caudatum***	
Cocculus orbiculatus	0.16	*Blechnum appendiculatum*	
Coprosma foliosa	0.79	*Conyza bonariensis*	
Grevillea robusta	1.27	*Crassocephalum crepidoides*	0.18
Nephrolepis exaltata* subsp. *hawaiiensis		*Emilia sonchifolia*	
Planchonella sandwicensis		***Korthalsella complanata***	
		Paspalum conjugatum	
		Passiflora edulis	
		Pipturis albidus	
		Rubus rosifolius	
		Spathodea campanulata	
		Toona ciliata	
		Trema orientalis	

DISCUSSION

Weed removal and maintenance successfully altered vegetation at the Giant Ohia restoration site at Makaha such that management goals for non-native cover were met for the canopy, and far surpassed for the understory. Though goals were not met for native canopy or understory, it is anticipated that those changes will occur gradually over time, particularly in the canopy, and that progress toward those objectives will be made by one year following clearing, at least in the understory.

While the significant reduction in non-native cover in the canopy and understory was anticipated (namely resulting from significant reductions in *P. cattleianum* dominated canopy and understory), there was also concern that weeding actions would result in an initial reduction in native cover due to the destructive nature of clearing such a large volume of non-native trees, particularly for native vines in the canopy, and native understory taxa in general. Such was the case during restoration efforts at the Kahanahaiki “chipper site,” where *A. stellata* frequency dropped from 86% to 0% in the canopy and from 86% to 40% in the understory within one month following clearing (but rebounded to 45% in the canopy and 80% in the understory after five years), as so much of it was growing on and around non-native trees removed using chainsaws (OANRP 2016). Many *P. cattleianum* trees were girdled and left standing at the Giant Ohia site, and trunks and branches of dead trees remained standing six months post-weeding. This likely mitigated damage to native vegetation, as not all trees were felled and dragged off site. The low initial cover values for *A. stellata* in the canopy and understory at this site also likely minimized the impact to that species. Likewise, no change occurred in overall native understory cover.

Though the native canopy cover estimate was slightly higher six months post-clearing as compared with pre-clearing, it did not meet the 10% absolute cover change prerequisite for analysis that mitigates the potential for Type 1 errors. The increased cover estimate is primarily attributed to slight increases in estimated cover for *M. polymorpha* and *P. odorata* canopy. Increased cover over such a short amount of time, especially for slow-growing species like *M. polymorpha* and *P. odorata*, was unexpected. The canopy was so dense with *P. cattleianum* during pre-clearing monitoring, such that it was very difficult at times to see all layers of canopy vegetation, and *P. odorata* in particular could have been easily missed. Also, as the transects were not permanent, the post-clearing ones may by chance have encountered more natives as compared with pre-clearing. Slightly different results are expected with non-permanent sampling. As such, the apparent increase could be a result of human error from obstructed canopy, and/or random sampling differences. Alternatively, a small amount of increased cover could have genuinely resulted via native trees flushing out in association with seasonality (post-clearing monitoring occurred in the winter, whereas pre-clearing data was collected in the summer), and/or growth following release from competition with non-native trees for resources. Future monitoring, which will occur only around the month of September, may give a better indication of the validity of this change, if cover continues to increase over time.

Weed ingress was expected to occur rapidly in response to increased light levels following alien canopy removal, however the ingress was slower than expected. The relatively high native canopy cover may facilitate maintenance of weeds in the understory to low levels, precluding weedy incursions in expansive light gaps which could otherwise occur following the removal of dense *P. cattleianum* canopy. As some non-native trees were girdled rather than felled, this also likely promoted a gradual change in light levels, preventing flushes of weeds in response to sudden light availability.

Change in native understory cover is expected to occur gradually over the next several years. Seed sowing efforts may result in measurable changes in the understory by one to two years, as *P. albidus* was observed anecdotally post-clearing, though it had only been sown in the preceding quarter.

The canopy now has a patchy distribution of small open areas. A number of new *A. koa* seedlings were anecdotally observed in sunnier areas (but less so in canopied areas), however these newly open areas may also be more prone to weed incursion, and may be targeted for outplanting or seed sowing of native taxa that respond well to higher light levels (e.g., *P. albidus*, *Bidens torta*). The understory also has considerably more open area below native canopy, which may become colonized by shade tolerant native and non-native species, and additional restoration of shade tolerant native taxa may be targeted for those non-vegetated understory areas (e.g., *A. stellata*, ferns).

Though a number of new weedy taxa were anecdotally observed while monitoring post-clearing, their presence remained small enough to escape interception during monitoring. The larger number of non-intercepted taxa during the post-clearing monitoring also may be influenced in part by having fewer point intercepts, which slightly reduced the likelihood of interception for taxa with very low cover.

The presence of individual taxa may vary over time, particularly for short-lived species and those present in low numbers at early life stages (when they are most vulnerable to mortality). Small or infrequent taxa not intercepted during monitoring may also be overlooked during anecdotal observations. This may partially explain differences in species composition pre- and post-clearing. However, those changes were more heavily weighted towards increased diversity of non-native taxa, and to a lesser extent towards slightly reduced native diversity, suggesting an influx of diverse new weedy taxa, and the possible loss of a few native taxa, following clearing efforts. All taxa potentially no longer present, as well as those new to the site, had low cover values less than 2%, or were only anecdotally observed.

The small proportion of non-native cover remaining in the canopy indicates that a small number of non-native trees still need to be weeded. Observational notes indicated that there were a few trees that were inadvertently missed, and a few larger girdled trees were not completely defoliated. Mortality following girdling may take several months, and larger trees in particular may require a second round of treatment. These remaining trees will be cleared or retreated as needed during quarterly weed maintenance.

Future monitoring is planned for one, two and five years post-clearing during the month of September to track short term change in association with vegetation restoration. Subsequent long term monitoring plans will be evaluated after five years. Quarterly maintenance weeding is planned, as well as outplanting and seed sowing of native taxa, to enhance restoration efforts. While the bounds of the restoration area may expand over time, monitoring will recur only in previously monitored areas to track change over time from the initial phase of restoration.

REFERENCES

OANRP. 2016. Appendix 3-8 Results of Kahanahaiki chipper site vegetation monitoring five years after initial clearing *in* 2016 Status Report for the Makua and Oahu Implementation Plans.