OAHU ARMY NATURAL RESOURCES PROGRAM
MONITORING PROGRAM

# VEGETATION MONITORING AT MANUWAI MANAGEMENT UNIT, 2016

## INTRODUCTION

Vegetation monitoring was conducted at Manuwai Management Unit (MU) in February and March of 2016 in association with MIP/OIP requirements for long term monitoring of vegetation composition and change over time (OANRP 2008) (Figure 1). The primary objective of MU monitoring is to assess if the percent cover of non-native plant species is less than 50% across the MU, or is decreasing towards that threshold requirement. The secondary objective is to assess if native cover is greater than 50% across the MU, or is increasing towards that threshold recommendation. Manuwai MU vegetation monitoring occurs on a five-year interval, and took place once previously (OANRP 2011). Previous monitoring indicated that none of the cover goals were met. The MU consist of two fenced subunits, both of which were completed in 2011.

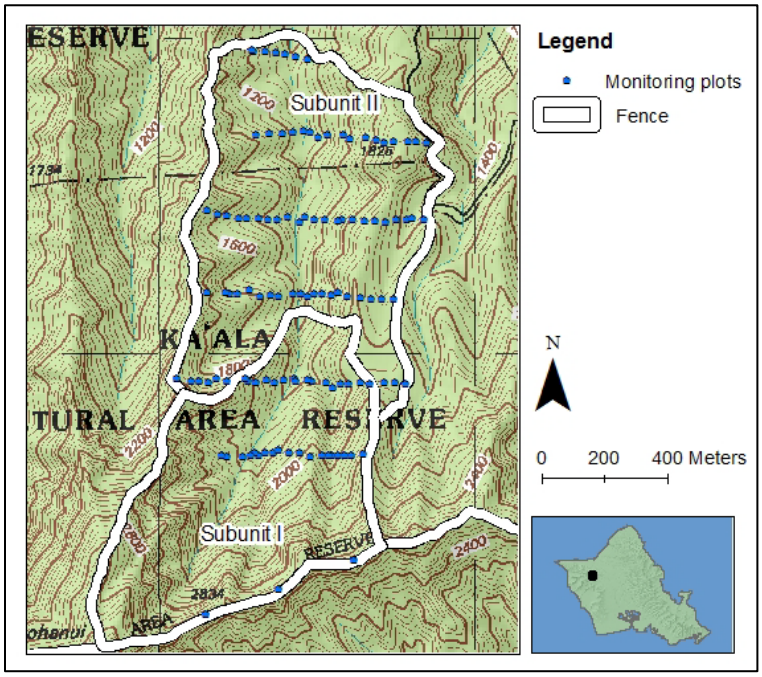


Figure 1. Manuwai MU vegetation monitoring plot locations.

## METHODS

In February and March of 2016, 114 plots were monitored. Plots measuring 5 x 10 m were generally located every 40 m along transects. Transects were located in accessible areas (much of the higher elevations in Subunit I are too steep to access), spaced approximately 250 meters (m) apart. Monitoring of these same plots was completed once previously in 2011 (OANRP 2011). During the prior monitoring, 232 plots were monitored, with plots located every 20 m. Post-hoc power analysis of the prior monitoring data determined that the minimum sample size necessary for meeting the sampling objectives

was 81 plots (OANRP, 2011). Consequently, the number of plots monitored in 2016 was reduced by half, with every other plot along transects arbitrarily discontinued. During the course of monitoring, two additional plots were not monitored. One plot was determined to be too dangerous for monitoring, and a second could not be relocated. Among the 114 plots monitored in 2016, three were determined to be too dangerous to access, and should be discontinued.

Understory [occurring from 0 – 2 m above ground level (AGL), including low branches from canopy species] and canopy (occurring > 2 m AGL, including epiphytes) vegetation was recorded by percent cover for all non-native and native species present. Summary percent cover by vegetation type (shrub, fern, grass/sedge) in the understory, overall summary percent cover of non-native and native vegetation in the understory and canopy, and bare ground (non-vegetated < 25 cm AGL), were also documented. Percent cover categories were recorded in 10% intervals between 10 and 100%, and on finer intervals (0-1%, 1-5%, and 5-10%) between 0 and 10% cover. Understory recruitment (defined as seedlings or saplings < 2 m AGL) data for tree species was recorded in 2016, but not documented previously. Monitoring results were compared with data from 2011. Based on MIP recommendations, $\alpha = 0.05$ was used for significance determinations, and only cover changes $\geq 10\%$ were recognized. Additional methodology information is detailed in Monitoring Protocol 1.2.1 (OANRP 2008). All analyses were performed in IBM SPSS Statistics Version 24. These included Wilcoxon signed-rank tests for cover data, paired t tests for species richness data, and McNemar's test for frequency data.

## RESULTS

### Understory and canopy cover categories

Management objectives of having < 50% non-native understory and canopy and > 50% native understory and canopy cover were not met in 2016 (Table 1). Native understory and canopy percent cover were low (3.0% and 15% median values, respectively). Non-native understory cover was moderately high, and non-native canopy cover was high (65% and 85% median values, respectively). There were several significant[1] changes in percent cover of vegetation from previous monitoring results. However, only a few of these met the 10% standard for recognized change in cover. These included 10% increases in cover for total non-native understory and non-native canopy, as well as a 40% decrease in bare ground (Figure 2). Caution should be applied in interpreting the results of change in bare ground, as the method for this measurement was not as clearly defined in 2011, and as such was less repeatable. In 2016, low native understory percent cover, and high non-native understory and canopy cover occurred nearly consistently throughout the MU (Figure 3). Locations of low to high native canopy cover were patchily distributed across the MU. Locations where beneficial and worsening cover changes occurred were patchily distributed (Figure 4).

[1]**Notes for readers less familiar with statistics:** Statistical significance is determined by p-values. P-values indicate to what extent the results support a hypothesis (the lower the number, the stronger the support for the hypothesis). In this study, the hypotheses would be that there are changes occurring in percent cover, frequency, and species richness. In this study, p-values less than 0.05 were significant. P-values only slightly greater than 0.05 were denoted as marginally significant, meaning that while not technically significant, they are worthy of note, e.g., perhaps a change is occurring, but at a gradual rate that may only become apparent in future monitoring, should that pattern continue. In some instances, there may be significant p-values despite no change in median values, if change occurred in the distribution of data, e.g., percent cover may range from 15 to 35 with a median of 25 one year, then the next year have a range of 15 to 95 but still have a median of only 25.

Table 1. Percent cover of native and non-native vegetation categories in the canopy and understory at Manuwai MU from 2011 to 2016. Median values are represented (n = 114). Categories specifically addressed in management objectives are shaded. Statistically significant values for categories that meet the 10% standard for recognized change in cover are in boldface (Wilcoxon signed-rank test). Arrows indicate increase (↑) or decrease (↓) in cover.

| | 2011 | 2016 | p | Z | Management objective currently met? |
|---|---|---|---|---|---|
| **Understory** | | | | | |
| Native shrubs | 3.00 | 3.00 | < 0.001 ↓ | -6.033 | |
| Native ferns | 0.25 | 0.50 | 0.005 ↑ | -2.816 | |
| Native grasses | 0.00 | 0.00 | 0.002 ↓ | -3.112 | |
| Total native understory | 7.50 | 3.00 | < 0.001 ↓ | -4.750 | No |
| Non-native shrubs | 25.00 | 25.00 | 0.267 | -1.109 | |
| Non-native ferns | 3.00 | 7.50 | < 0.001 ↑ | -5.008 | |
| Non-native grasses | 0.00 | 0.50 | 0.001 ↑ | -3.392 | |
| Total non-native understory | 55.00 | 65.00 | **0.006** ↑ | -2.773 | No, and getting worse |
| Bare ground | 85.00 | 45.00 | **< 0.001** ↓ | -7.133 | |
| **Canopy** | | | | | |
| Native canopy | 15.00 | 15.00 | 0.250 | -1.151 | No |
| Non-native canopy | 75.00 | 85.00 | **0.001** ↑ | -3.294 | No, and getting worse |
| Total canopy | 95.00 | 95.00 | 0.168 | -1.377 | |

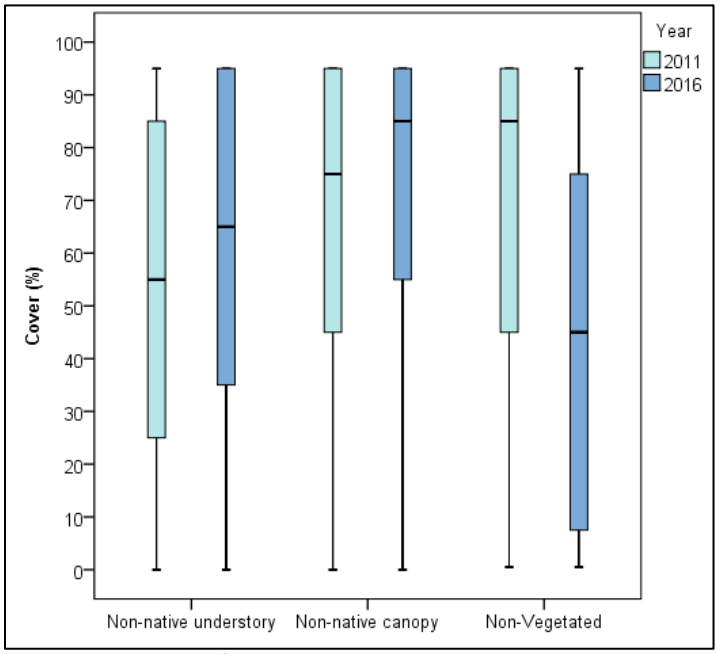


Figure 2. Boxplots[2] for vegetation categories with significant change in percent cover that meet 10% standard for recognized change in cover between years 2011 and 2016 in Manuwai MU.

[2]**Additional notes for readers less familiar with statistics**: Boxplots show the range of data values for a given variable, analogous to a squashed bell curve turned on its side. The shaded boxes depict 50% of the data values, and the horizontal line inside the shaded box represents the median value. In this report, very high or low values relative to the shaded box are indicated by circles (1.5 to 3 times the length of the shaded box) and asterisks (> 3 times the length of the shaded box), while the lines extending above and below the shaded box depict the range in values for all remaining data. Circles and asterisks that appear to be in boldface indicate multiple data points for the same values.

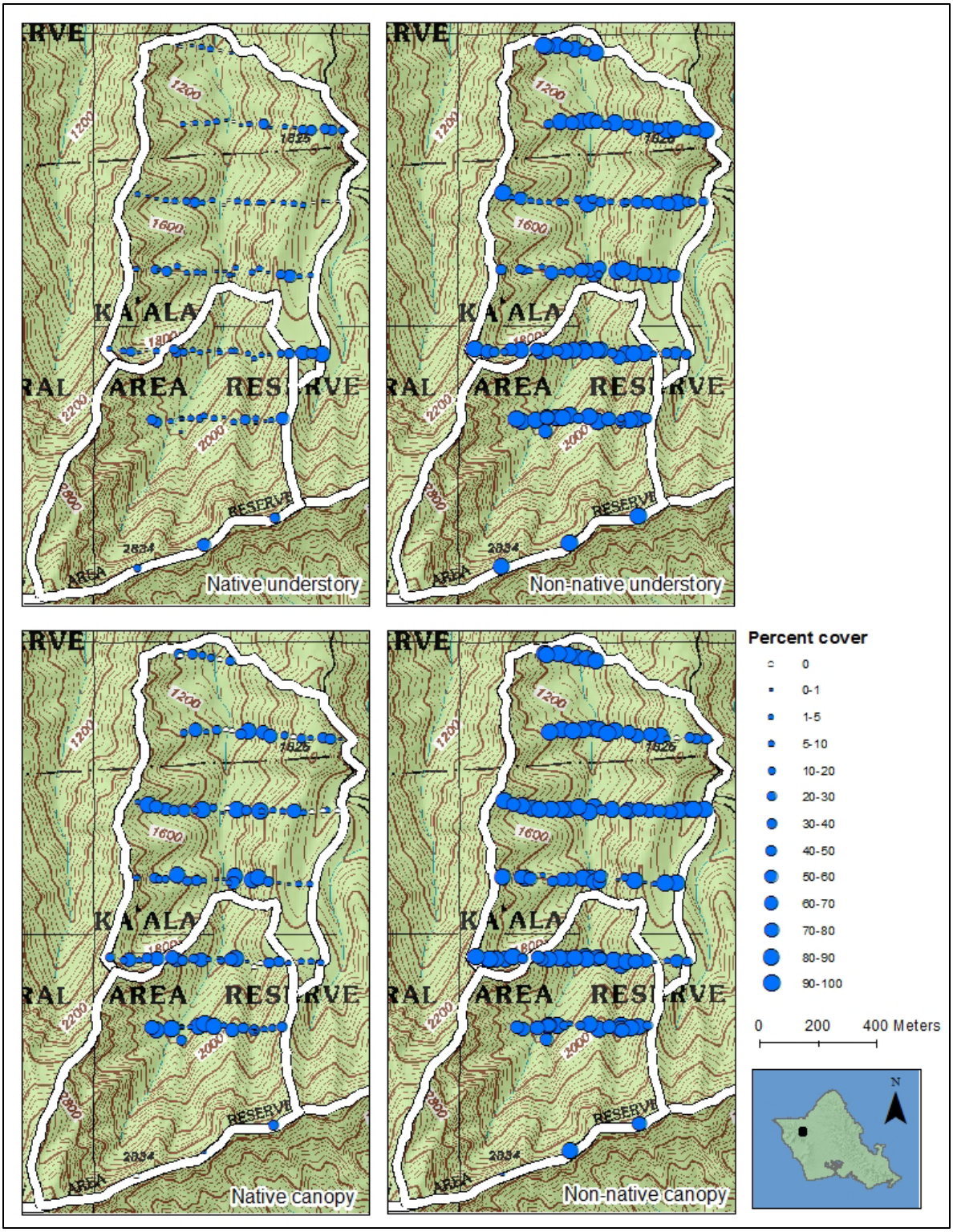


Figure 3. Locations of low to high percent cover of native and non-native understory and canopy vegetation among monitored plots at Manuwai MU in 2016. Larger circles denote higher percent cover, while smaller circles represent lower cover.

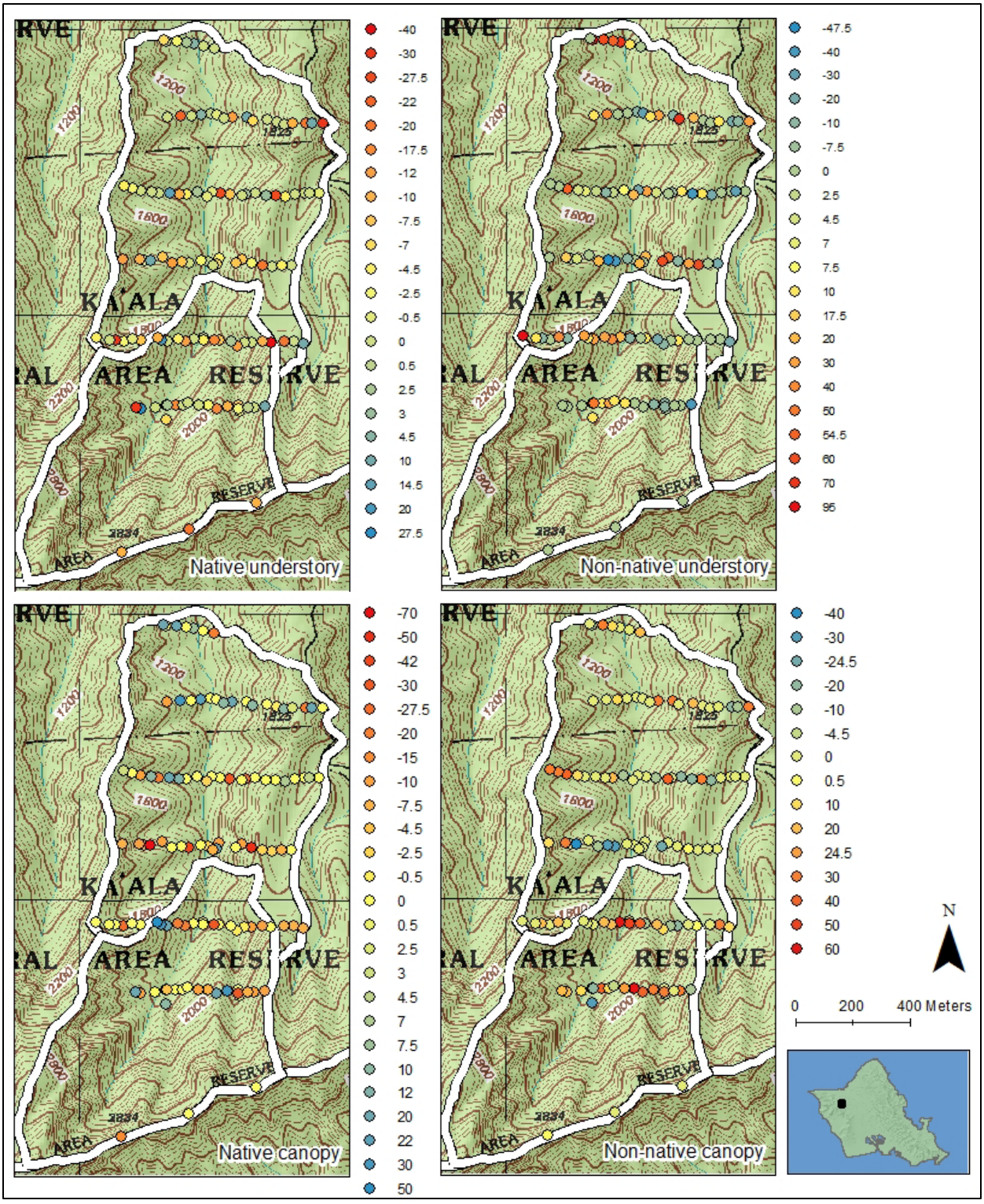


Figure 4. Locations of change in native and non-native percent cover for the understory and canopy vegetation in monitored plots in Manuwai MU between 2011 and 2016. Color gradients are inverted for native and non-native vegetation, such that blue indicates beneficial change, red depicts worsening conditions. Cover change of 0 indicates there was no change in percent cover.

**Species richness**

During monitoring in 2016, 132 species were recorded in the understory (50% native taxa), and 58 were identified in the canopy (62% native). Most species present in the canopy were also represented in the understory, with the exception of three native species (*Antidesma platyphyllum*, *Cyanea angustifolia*, *Erythrina sandwicensis*, and *Polyscias sandwicensis*). Locations of high and low species richness for the native and non-native understory and canopy were primarily patchily distributed across the MU, though higher native understory and canopy richness occurred more frequently in the southern portions of the MU (Figure 5). Species richness differed significantly between the years monitored, with an increase in both non-native understory and canopy taxa within plots (Table 2). No detectable change occurred in species richness among plots in the native understory or canopy. The significant increase in non-native understory and canopy richness among plots was paired with an increase in overall diversity for the MU. Overall native understory and canopy diversity for the MU decreased slightly. Twenty-one new species (61.9% non-native) were found in plots in 2016, while 15 species (73.3% native) were recorded in 2011 but not observed in 2016 (Table 3). The presence or absence of species may be due in part to human error such as misidentification, observer bias regarding plot boundaries or amount of time spent searching, or accidental non-recording. The occurrence within plots of short-lived, less common species is expected to vary over time. All of the species that were not present in 2016 were uncommon in previous years, with frequencies less than 2%.

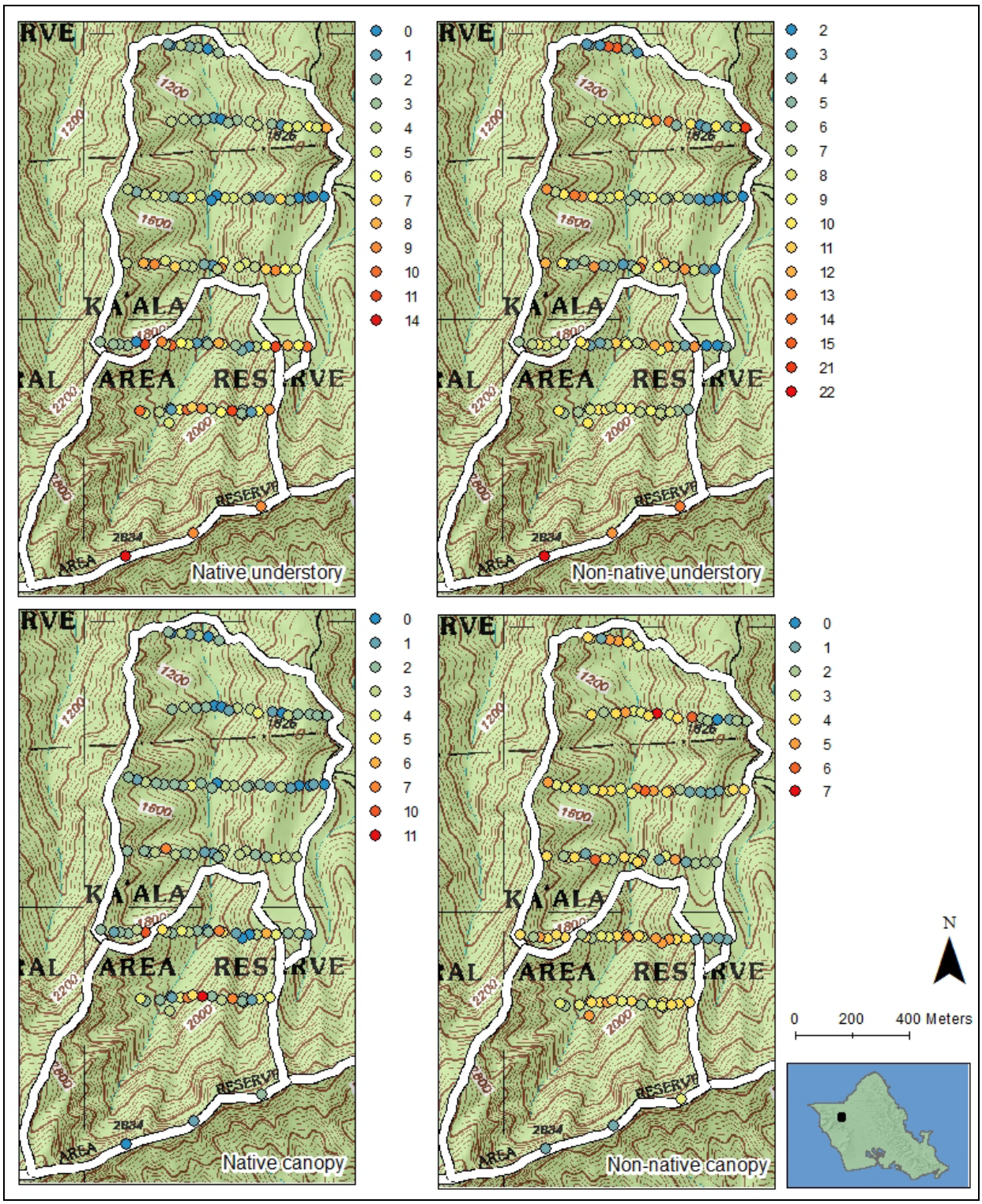


Figure 5. Locations of low to high species richness among plots in the native and non-native understory and canopy in Manuwai MU, 2016. Color gradients of blue to red indicate low to high values, respectively, of the number of species occurring in plots (i.e., blue indicates low diversity, while red indicates relatively higher diversity).

Table 2. Manuwai MU understory and canopy species richness. Mean species richness per plot during vegetation monitoring is shown by year, with the total number of species recorded among all plots in parenthesis (n = 114). P-values obtained from paired t tests. Statistically significant values are in boldface. Arrows indicate increase (↑) or decrease (↓) in richness.

| | 2011 | 2016 | p | t |
|---|---|---|---|---|
| Native understory | 4.49 (69) | 4.46 (66) | 0.837 | -0.207 |
| Non-native understory | 6.72 (56) | 8.02 (66) | < **0.001** ↑ | 5.602 |
| Native canopy | 2.50 (37) | 2.46 (36) | 0.699 | -0.387 |
| Non-native canopy | 2.89 (19) | 3.29 (22) | < **0.001** ↑ | 3.881 |

Table 3. Newly recorded, and no longer present, species from 2016 Manuwai MU monitoring, in the understory and/or canopy. Native taxa are in boldface.

| New species recorded in 2016 | Species found in plots in 2011 but not recorded in 2016 |
|---|---|
| *Angiopteris evecta* | ***Coprosma longifolia*** |
| ***Antidesma platyphyllum*** | ***Crepidomanes minutum*** |
| *Ardisia elliptica* | *Cuphea carthagenesis* |
| ***Caesalpinia bonduc*** | *Digitaria insularis* |
| *Castilleja arvensis* | ***Dryopteris sandwicensis*** |
| *Cenchrus polystachios* | ***Gynochthodes trimera*** |
| *Centaurium erythraea* | ***Kadua affinis*** |
| ***Charpentiera ovata*** | ***Myrsine sandwicensis*** |
| *Crassocephalum crepidoides* | ***Peperomia membranacea*** |
| *Cyclosorus dentatus* | ***Phyllostegia parviflora* var. *lydgatei*** |
| *Desmodium incanum* | ***Plectranthus parviflorus*** |
| *Erechtites valerianifolia* | ***Rauvolfia sandwicensis*** |
| ***Erythrina sandwicensis*** | *Sida rhombifolia* |
| *Lophospermum erubescens* | ***Strongylodon ruber*** |
| *Nephrolepis brownii* | *Trema orientalis* |
| ***Phyllanthus distichus*** | |
| ***Pilea peploides*** | |
| ***Psychotria mariniana*** | |
| Pteridaceae indet. | |
| *Pterolepis glomerata* | |
| ***Sida fallax*** | |

**Species frequency**

Non-native species that occurred most frequently in plots (present in more than half the plots) in the understory included *Psidium cattleianum, Clidemia hirta, Blechnum appendiculatum,* and *Toona ciliata,* while those most commonly occurring in the canopy were *P. cattleianum* and *T. ciliata* (Table 4). The most frequent native species (in at least a quarter of the plots) included *Diospyros sandwicensis, Psydrax odorata, Alyxia stellata, Dodonaea viscosa* and *Carex meyenii* in the understory, and *D. sandwicensis* and *P. odorata* in the canopy. Of the 16 rare taxa occurring at Manuwai MU (OANRP 2011), two (*Labordia kaalae* and *Polyscias sandwicensis*) were identified during monitoring in 2016. Analysis of frequency change (McNemar's test) was limited to taxa with at least ten percent change between 2011 and 2016. These included three non-native species in the understory (*Adiantum hispidulum, Clidemia hirta,* and *Passiflora suberosa*) and one non-native species in the canopy (*T. ciliata*), all of which had significant increases in frequency (Table 5).

Table 4. Species frequency among plots (percent of plots in which a given species occurs) during 2016 Manuwai MU monitoring (n= 114), in order of most to least frequent. Native species are in bold print. *Rare taxa. **Target weed taxa.

| Taxon | Freq. | Taxon | Freq. | Taxon | Freq. | Taxon | Freq. |
|---|---|---|---|---|---|---|---|
| Understory | | | | | | | |
| *Psidium cattleianum* | 85.1 | *Conyza bonariensis* | 9.6 | *Melia azedarach*** | 3.5 | *Ardisia elliptica* | 0.9 |
| *Clidemia hirta* | 78.9 | *Rubus rosifolius* | 9.6 | *Paspalum conjugatum* | 3.5 | ***Asplenium nidus*** | 0.9 |
| *Blechnum appendiculatum* | 76.3 | ***Wikstroemia oahuensis*** | 9.6 | ***Psilotum nudum*** | 3.5 | ***Bobea elatior*** | 0.9 |
| *Toona ciliata*** | 57.0 | ***Dianella sandwicensis*** | 8.8 | ***Pteridium aquilinum*** | 3.5 | ***Caesalpinia bonduc*** | 0.9 |
| ***Diospyros sandwicensis*** | 50.0 | *Oxalis corniculata* | 8.8 | ***Scaevola gaudichaudiana*** | 3.5 | *Castilleja arvensis* | 0.9 |
| *Schinus terebinthifolius* | 42.1 | *Passiflora edulis* | 8.8 | *Setaria parviflora* | 3.5 | *Cenchrus longisetus* | 0.9 |
| ***Psydrax odorata*** | 40.4 | *Aleurites moluccana* | 7.9 | *Buddleja asiatica* | 2.6 | *Centaurium erythraea* | 0.9 |
| *Adiantum hispidulum* | 37.7 | ***Lepisorus thunbergianus*** | 7.9 | *Chamaecrista nictitans* | 2.6 | ***Charpentiera ovata*** | 0.9 |
| *Cyclosorus parasiticus* | 37.7 | *Spathodea campanulata*** | 7.9 | ***Chrysodracon halapepe*** | 2.6 | ***Coprosma foliosa*** | 0.9 |
| *Syzygium cumini*** | 34.2 | ***Bidens torta*** | 7.0 | *Cyclosorus dentatus* | 2.6 | *Crassocephalum crepidoides* | 0.9 |
| *Oplismenus hirtellus* | 30.7 | *Leucaena leucocephala* | 7.0 | ***Cyperus hypochlorus* var. *hypochlorus*** | 2.6 | *Cyanthillium cinereum* | 0.9 |
| ***Alyxia stellata*** | 28.1 | ***Pipturis albidus*** | 6.1 | *Mesosphaerum pectinatum* | 2.6 | *Desmodium incanum* | 0.9 |
| ***Dodonaea viscosa*** | 27.2 | ***Sphenomeris chinensis*** | 6.1 | *Oxalis corymbosa* | 2.6 | ***Dicranopteris linearis*** | 0.9 |
| ***Carex meyenii*** | 25.4 | *Youngia japonica* | 6.1 | *Phlebodium aureum* | 2.6 | *Emilia sonchifolia* | 0.9 |
| ***Carex wahuensis*** | 23.7 | *Andropogon virginicus* | 5.3 | ***Pisonia brunoniana*** | 2.6 | *Erechtites valerianifolia* | 0.9 |
| *Lantana camara* | 23.7 | *Begonia hirtella* | 5.3 | *Triumfetta semitriloba*** | 2.6 | ***Freycinetia arborea*** | 0.9 |
| ***Microlepia strigosa*** | 22.8 | ***Kadua acuminata*** | 5.3 | *Ageratum conyzoides* | 1.8 | ***Labordia kaalae**** | 0.9 |
| *Grevillea robusta* | 20.2 | ***Nephrolepis exaltata* subsp. *hawaiiensis*** | 5.3 | *Cenchrus polystachios* | 1.8 | *Lophospermum erubescens* | 0.9 |
| *Passiflora suberosa* | 18.4 | *Stachytarpheta australis* | 5.3 | ***Charpentiera obovata*** | 1.8 | ***Lythrum maritimum*** | 0.9 |
| *Ageratina riparia* | 17.5 | *Ageratina adenophora* | 4.4 | ***Elaphoglossum paleaceum*** | 1.8 | ***Microlepia speluncae*** | 0.9 |
| ***Sapindus oahuensis*** | 15.8 | *Cheilanthes viridis* | 4.4 | ***Eragrostis grandis*** | 1.8 | *Nephrolepis brownii* | 0.9 |
| ***Diospyros hillebrandii*** | 14.9 | ***Cocculus orbiculatus*** | 4.4 | ***Kadua cordata*** | 1.8 | ***Paspalum scrobiculatum*** | 0.9 |
| *Coffea arabica* | 14.0 | *Cupressus lusitanica* | 4.4 | *Melinis repens* | 1.8 | ***Phyllanthus distichus*** | 0.9 |
| ***Metrosideros polymorpha*** | 14.0 | ***Doryopteris decipiens*** | 4.4 | ***Metrosideros tremuloides*** | 1.8 | ***Pisonia sandwicensis*** | 0.9 |
| *Urochloa maxima*** | 14.0 | ***Eugenia reinwardtiana*** | 4.4 | ***Osteomeles anthyllidifolia*** | 1.8 | ***Pittosporum confertiflorum*** | 0.9 |
| ***Leptecophylla tameiameiae*** | 13.2 | ***Nestegis sandwicensis*** | 4.4 | ***Peperomia tetraphylla*** | 1.8 | *Pluchea carolinensis* | 0.9 |
| *Psidium guajava* | 13.2 | ***Peperomia blanda*** | 4.4 | ***Pilea peploides*** | 1.8 | Pteridaceae indet. | 0.9 |
| *Adiantum radianum* | 12.3 | ***Psychotria hathewayi*** | 4.4 | ***Planchonella sandwicensis*** | 1.8 | *Pterolepis glomerata*** | 0.9 |
| ***Doodia kunthiana*** | 12.3 | *Schefflera actinophylla*** | 4.4 | *Plantago lanceolata* | 1.8 | ***Santalum freycinetianum*** | 0.9 |
| *Kalanchoe pinnata* | 12.3 | ***Acacia koa*** | 3.5 | ***Psychotria mariniana*** | 1.8 | ***Scaevola gaudichaudii*** | 0.9 |
| *Melinis minutiflora* | 12.3 | ***Canavalia galeata*** | 3.5 | *Acacia confusa*** | 0.9 | ***Sida fallax*** | 0.9 |
| ***Selaginella arbuscula*** | 12.3 | *Deparia petersenii* | 3.5 | *Angiopteris evecta* | 0.9 | ***Tectaria gaudichaudii*** | 0.9 |
| *Cordyline fruticosa* | 10.5 | ***Euphorbia multiformis*** | 3.5 | ***Antidesma pulvinatum*** | 0.9 | ***Waltheria indica*** | 0.9 |

Table 4, continued.

| Taxon | Freq. | Taxon | Freq. | Taxon | Freq. | Taxon | Freq. |
|---|---|---|---|---|---|---|---|
| Canopy | | | | | | | |
| *Psidium cattleianum* | 71.9 | *Coffea arabica* | 7.0 | *Phlebodium aureum* | 2.6 | ***Asplenium nidus*** | 0.9 |
| *Toona ciliata*** | 59.6 | ***Leptecophylla tameiameiae*** | 7.0 | ***Pipturis albidus*** | 2.6 | ***Cyanea angustifolia*** | 0.9 |
| ***Diospyros sandwicensis*** | 55.3 | ***Wikstroemia oahuensis*** | 7.0 | ***Pisonia sandwicensis*** | 2.6 | ***Dicranopteris linearis*** | 0.9 |
| *Syzygium cumini*** | 53.5 | *Passiflora edulis* | 6.1 | *Urochloa maxima*** | 2.6 | ***Erythrina sandwicensis*** | 0.9 |
| ***Psydrax odorata*** | 42.1 | ***Planchonella sandwicensis*** | 6.1 | *Ageratina adenophora* | 1.8 | ***Kadua acuminata*** | 0.9 |
| *Schinus terebinthifolius* | 36.8 | *Spathodea campanulata*** | 6.1 | ***Canavalia galeata*** | 1.8 | ***Labordia* sp.** | 0.9 |
| *Aleurites moluccana* | 30.7 | ***Psychotria hathewayi*** | 5.3 | ***Eugenia reinwardtiana*** | 1.8 | *Lophospermum erubescens* | 0.9 |
| *Grevillea robusta* | 23.7 | *Clidemia hirta* | 4.4 | ***Pisonia brunoniana*** | 1.8 | *Melia azedarach*** | 0.9 |
| ***Dodonaea viscosa*** | 21.1 | ***Lepisorus thunbergianus*** | 3.5 | ***Pittosporum confertiflorum*** | 1.8 | ***Osteomeles anthyllidifolia*** | 0.9 |
| ***Metrosideros polymorpha*** | 17.5 | ***Nestegis sandwicensis*** | 3.5 | ***Psychotria mariniana*** | 1.8 | ***Peperomia tetraphylla*** | 0.9 |
| ***Diospyros hillebrandii*** | 14.0 | ***Acacia koa*** | 2.6 | ***Santalum freycinetianum*** | 1.8 | *Pluchea carolinensis* | 0.9 |
| ***Sapindus oahuensis*** | 13.2 | ***Bobea elatior*** | 2.6 | *Acacia confusa*** | 0.9 | ***Polyscias sandwicensis**** | 0.9 |
| ***Alyxia stellata*** | 12.3 | *Cupressus lusitanica* | 2.6 | ***Antidesma platyphyllum*** | 0.9 | ***Psilotum nudum*** | 0.9 |
| *Psidium guajava* | 9.6 | *Lantana camara* | 2.6 | ***Antidesma pulvinatum*** | 0.9 | *Schefflera actinophylla*** | 0.9 |
| ***Chrysodracon halapepe*** | 7.0 | *Passiflora suberosa* | 2.6 | | | | |

Table 5. Species frequency change at Manuwai MU between 2011 and 2016. Only taxa with at least 10% change in frequency were analyzed. Frequency values represent the proportion of plots in which species are present (n = 114). Native species are in boldface. P-values obtained from McNemar's test (exact significance). Arrows indicate increase (↑) or decrease (↓) in frequency.

| Species | Frequency 2011 | Frequency 2016 | % change | p |
|---|---|---|---|---|
| Understory | | | | |
| *Adiantum hispidulum* | 25.4 | 37.7 | 12 | <0.001 ↑ |
| *Clidemia hirta* | 66.7 | 78.9 | 12 | 0.001 ↑ |
| *Passiflora suberosa* | 6.1 | 18.4 | 12 | 0.004 ↑ |
| Canopy | | | | |
| *Toona ciliata* | 48.2 | 59.6 | 11 | 0.002 ↑ |

**Species cover**

Species with frequencies > 0.20 (present in at least 23 plots) in 2011 and/or 2016 were subjected to analysis of cover change (Wilcoxon signed-rank test). Fine scale cover categories between 0 and 10% were lumped into a single value to minimize the influence of very small differences on the analysis. Significant increases in percent cover occurred for four non-native understory species (*A. hispidulum, B. appendiculatum, C. hirta,* and *Oplismenus hirtellus,* and one non-native canopy species (*P. cattleianum*) (Table 6 and Figure 6). Decreases in percent cover occurred for one species in the non-native understory (*P. cattleianum)*, two species in the native understory (*A. stellata* and *P. odorata*), one non-native species in the canopy (*Grevillea robusta*), and one native species in the canopy (*D. sandwicensis*) (Figure 7). The median change in percent cover was 0.0% for all species (as most taxa were absent from more than half of the plots during both years, most plots maintained 0% cover).

Table 6. Percent cover change of native and non-native species in the canopy and understory at Manuwai from 2011 to 2016. Only species with frequencies greater than 0.20 (present in at least 23 plots) in 2016 were analyzed. Native taxa and statistically significant values are in boldface (Wilcoxon signed-rank test, n = 114). Arrows indicate increase (↑) or decrease (↓) in cover.

| Species | Median cover change | p | Z |
|---|---|---|---|
| Understory | | | |
| *Adiantum hispidulum* | 0.00 | **< 0.001**↑ | -3.94 |
| ***Alyxia stellata*** | 0.00 | **0.034**↓ | -2.12 |
| *Blechnum appendiculatum* | 0.00 | **< 0.001**↑ | -4.49 |
| ***Carex meyenii*** | 0.00 | 0.127 | -1.53 |
| ***Carex wahuensis*** | 0.00 | 1.000 | 0.00 |
| *Clidemia hirta* | 0.00 | **0.006**↑ | -2.77 |
| *Cyclosorus parasiticus* | 0.00 | 0.125 | -1.53 |
| ***Diospyros sandwicensis*** | 0.00 | 0.315 | -1.01 |
| ***Dodonaea viscosa*** | 0.00 | 0.319 | -1.00 |
| *Grevillea robusta* | 0.00 | 1.000 | 0.00 |
| *Lantana camara* | 0.00 | 0.808 | -0.24 |
| ***Microlepia strigosa*** | 0.00 | 0.438 | -0.78 |
| *Oplismenus hirtellus* | 0.00 | **0.004**↑ | -2.86 |
| *Psidium cattleianum* | 0.00 | **0.017**↓ | -2.38 |
| ***Psydrax odorata*** | 0.00 | **0.007**↓ | -2.70 |
| *Schinus terebinthifolius* | 0.00 | 0.985 | -0.02 |
| *Syzygium cumini* | 0.00 | 0.575 | -0.56 |
| *Toona ciliata* | 0.00 | 0.221 | -1.23 |
| Canopy | | | |
| *Aleurites moluccana* | 0.00 | 0.625 | -0.49 |
| ***Diospyros sandwicensis*** | 0.00 | **0.018**↓ | -2.36 |
| ***Dodonaea viscosa*** | 0.00 | 0.058↑ | -1.90 |
| *Grevillea robusta* | 0.00 | **0.016**↓ | -2.42 |
| *Psidium cattleianum* | 0.00 | **0.004**↑ | -2.87 |
| ***Psydrax odorata*** | 0.00 | 0.391 | -0.86 |
| *Schinus terebinthifolius* | 0.00 | 0.497 | -0.68 |
| *Syzygium cumini* | 0.00 | 0.296 | -1.05 |
| *Toona ciliata* | 0.00 | 0.077↑ | -1.77 |

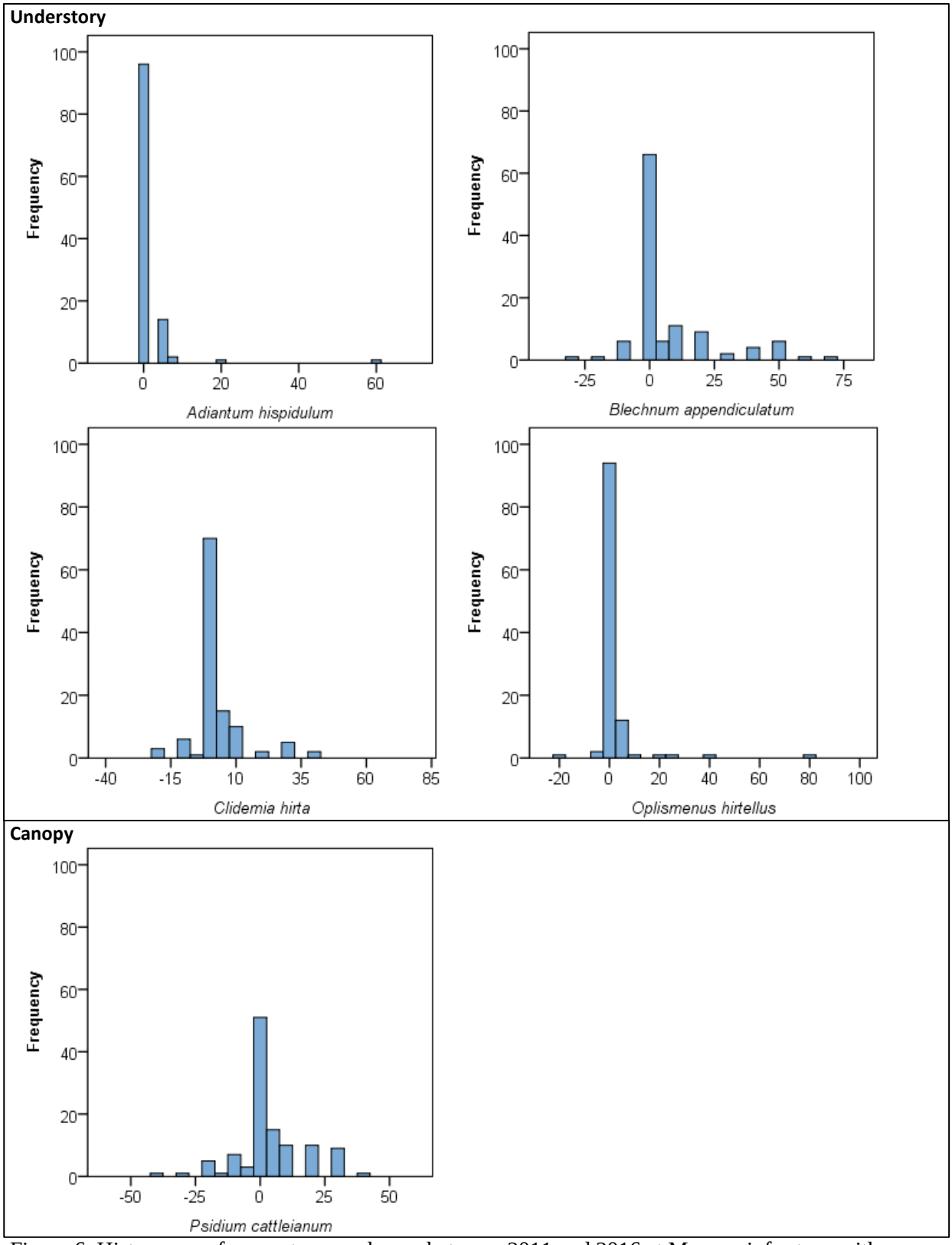


Figure 6. Histograms of percent cover change between 2011 and 2016 at Manuwai, for taxa with significant increases in cover in the understory and canopy. Values > 0 represent increased cover in plots, while those < 0 represent decreased cover. Values equaling 0 represent no change. *Native taxa.

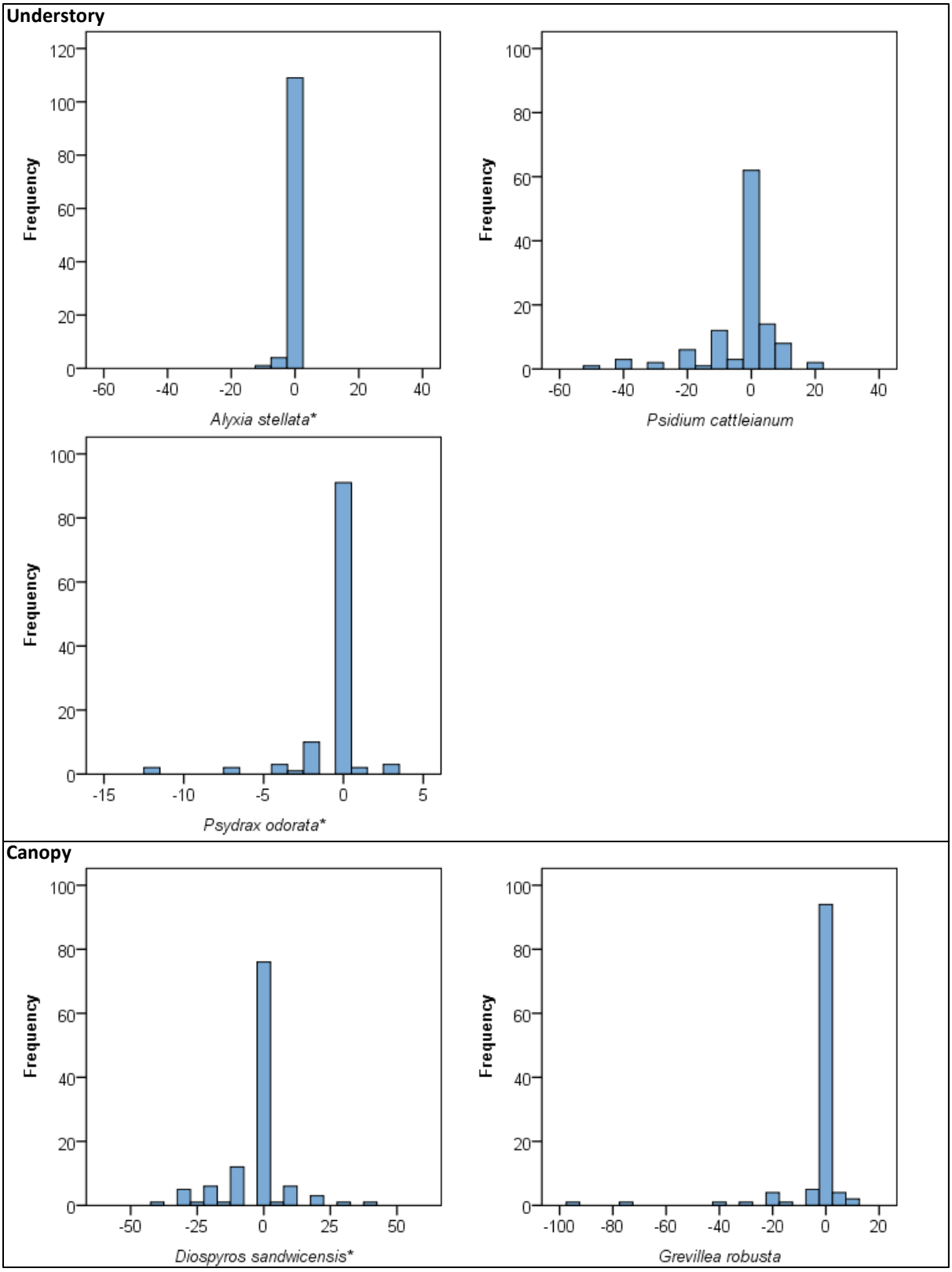


Figure 7. Histograms of percent cover change between 2011 and 2016 at Manuwai, for taxa with significant decreases in cover in the understory and canopy. Values > 0 represent increased cover in plots, while those < 0 represent decreased cover. Values equaling 0 represent no change. *Native taxa.

**Canopy replacement**

Most canopy tree species were found recruiting in the understory (Table 7). *Diospyros sandwicensis* and *P. odorata* were the most commonly recruiting native tree species, while non-native recruiting tree species were primarily *P. cattleianum, T. ciliata, S. terebinthifolius* and *Syzygium cumini*. Native trees with no recruitment in the understory were also relatively infrequent in the canopy (with frequencies < 7%). It should be noted that the age of saplings may vary greatly, from less than one year to decades, in accordance with differing species and individual growth rates, complicating interpretations of presence/absence and change over time with respect to concerns over long term canopy replacement.

Table 7. Summary of canopy tree species recruitment in the understory during 2016 Manuwai MU monitoring, in order of most to least frequent. Frequency represents the percent occurrence of tree species with a maximum height < 2 meters (seedlings to small trees) among plots (n = 148). Native species are in boldface. *Rare taxa. **Target weed taxa.

| Species | Freq. | Species | Freq. | Species | Freq. |
|---|---|---|---|---|---|
| *Psidium cattleianum* | 71.1 | *Aleurites moluccana* | 7.0 | ***Chrysodracon halapepe*** | 1.8 |
| *Toona ciliata*** | 48.2 | *Spathodea campanulata*** | 6.1 | *Cordyline fruticosa* | 1.8 |
| ***Diospyros sandwicensis*** | 34.2 | *Leucaena leucocephala* | 5.3 | *Cupressus lusitanica* | 1.8 |
| *Schinus terebinthifolius* | 28.9 | ***Metrosideros polymorpha*** | 5.3 | ***Nestegis sandwicensis*** | 1.8 |
| ***Psydrax odorata*** | 28.1 | ***Pipturis albidus*** | 5.3 | ***Psychotria mariniana*** | 1.8 |
| *Syzygium cumini*** | 25.4 | ***Wikstroemia oahuensis*** | 5.3 | *Acacia confusa*** | 0.9 |
| ***Dodonaea viscosa*** | 16.7 | *Schefflera actinophylla*** | 4.4 | ***Charpentiera ovata*** | 0.9 |
| *Grevillea robusta* | 14.0 | ***Eugenia reinwardtiana*** | 3.5 | ***Freycinetia arborea*** | 0.9 |
| ***Sapindus oahuensis*** | 13.2 | *Melia azedarach*** | 3.5 | ***Labordia kaalae**** | 0.9 |
| ***Diospyros hillebrandii*** | 11.4 | *Buddleja asiatica* | 2.6 | ***Pisonia brunoniana*** | 0.9 |
| *Coffea arabica* | 8.8 | ***Acacia koa*** | 1.8 | ***Pittosporum confertiflorum*** | 0.9 |
| *Psidium guajava* | 8.8 | ***Charpentiera obovata*** | 1.8 | ***Psychotria hathewayi*** | 0.9 |

**Weed control**

Weed control efforts at Manuwai between the 2011 and 2016 monitoring intervals included approximately 966 person hours. The total amount of effort varied among the fourteen weed control areas (WCA) that encompass the MU, ranging from 0 to 334.25 hours per WCA. Three WCAs were not weeded during that time interval. Between the 2011 and 2016 monitoring intervals, 22.9% of the MU was weeded. The majority of the area weeded is attributable to IPA control (IPA control occurred across 19.5% of the MU, whereas general ecosystem weeding encompassed only 3.7% of the MU). Weed control efforts crossed through 40% of the plots between the 2011 and 2016 monitoring intervals (39% fell within IPA control areas, 3.5% were within areas with general ecosystem weeding) (Figure 8). Due to the prevalence of steep and inaccessible areas, the uppermost elevations received very little weeding, and included only a small number of monitoring plots, thus the higher proportion of plots weeded as compared with the proportion of the MU weeded.

Nine out of the 22 target weed species (taxa of special concern for weed management, including incipient species) for Manuwai MU (OANRP 2011) were identified during monitoring, and at least one target taxa was present in 89% of the monitored plots in either the understory or canopy. These included two widespread target taxa (*T. ciliata* and *S. cumini*), and 7 less common target species (*Acacia confusa, Melia azedarach, Pterolepis glomerata, Schefflera actinophylla, Spathodea campanulata, Triumfetta semitriloba* and *Urochloa maxima*) (Figure 9). Of these, only *T. ciliata* had a high frequency, occurring in 68% of the plots. One new incipient non-native taxa of concern, *Angiopteris evecta*, was identified one plot.

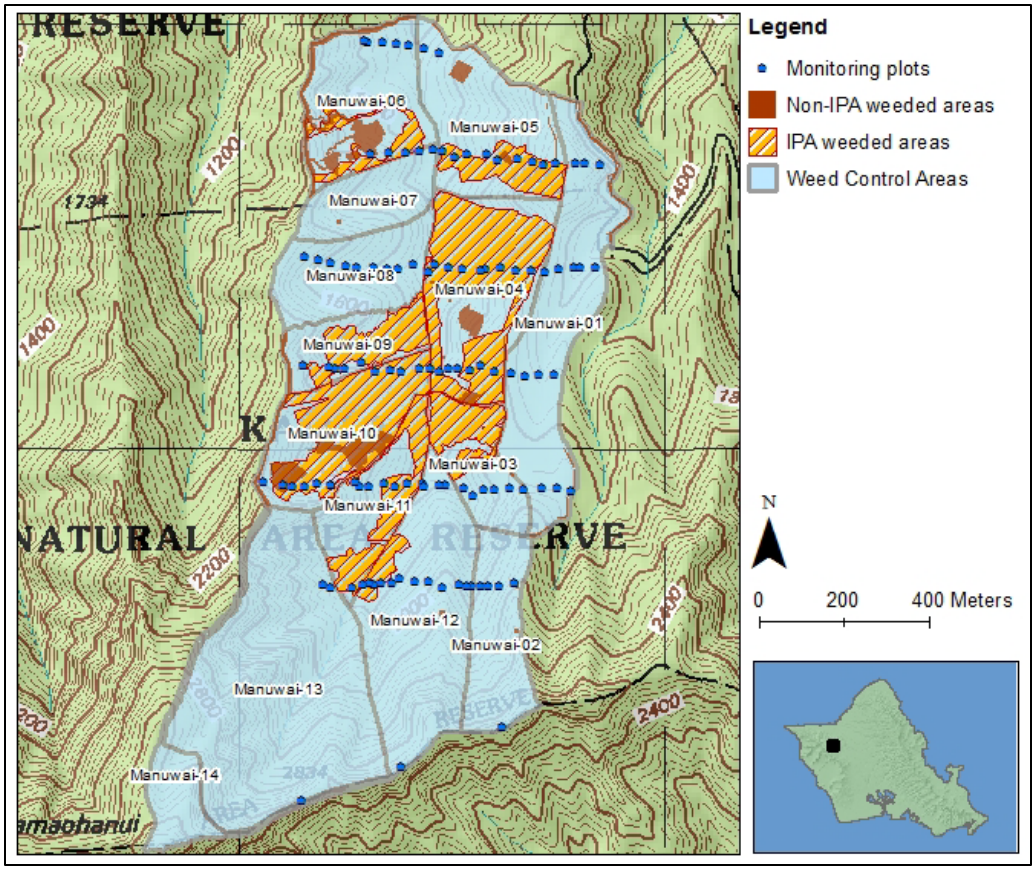


Figure 8. Locations of vegetation monitoring plots at Manuwai MU in relation to weed control areas (WCA) and areas weeded (showing locations with or without IPA control) between the 2011 and 2016 monitoring intervals.

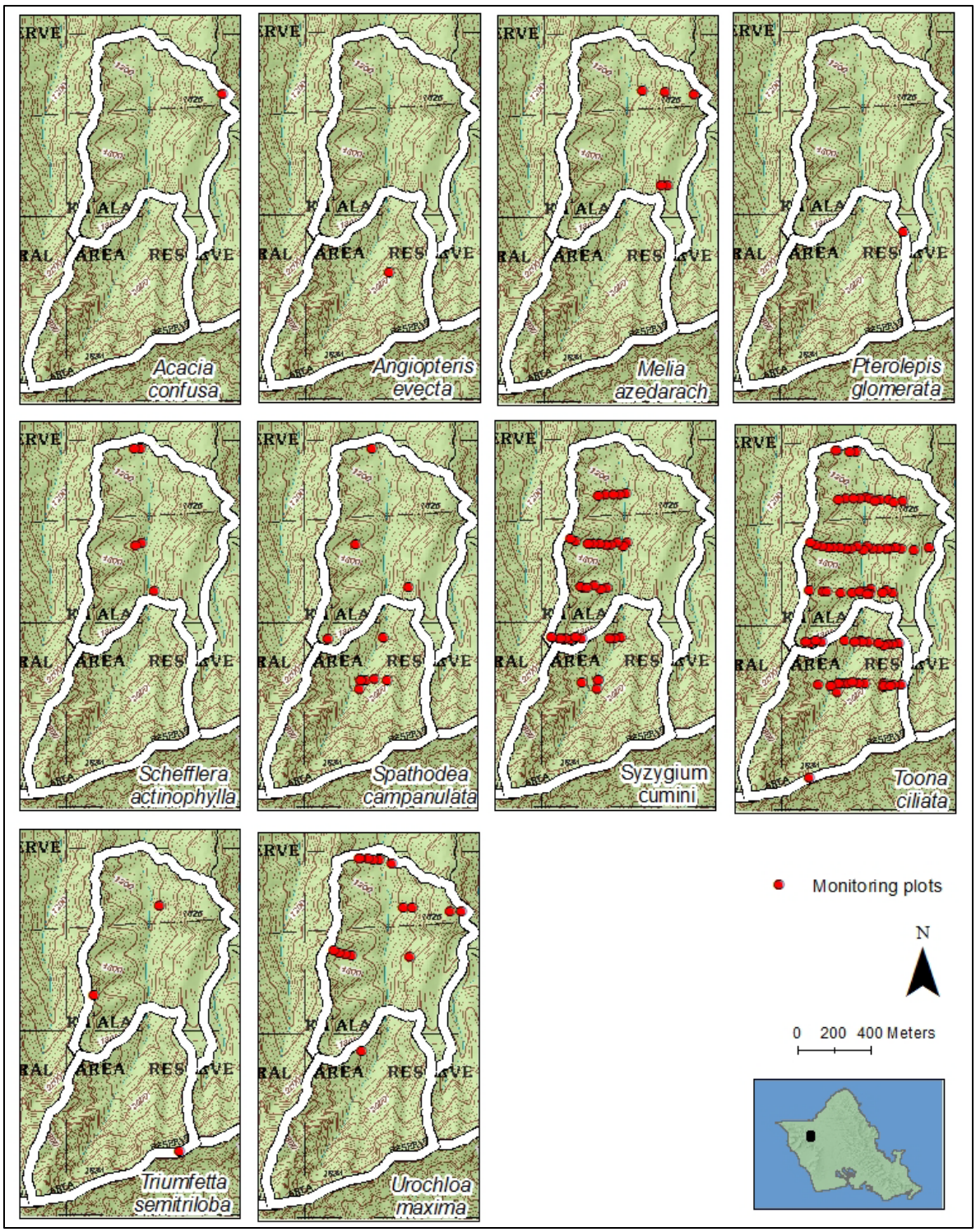


Figure 9. Locations of target taxa and new incipient taxa (*Angiopteris evecta*) in the understory and/or canopy among plots in Manuwai MU in 2016.

In order to discern the impacts of weeding efforts, vegetation percent cover was further scrutinized to examine change in weeded (n = 46) vs. unweeded (n = 68) plots for the native and non-native understory and canopy, as well as canopy *T. ciliata* and *G. robusta*, which were primary IPA target taxa. There was a significant decline in native understory cover both in weeded and unweeded plots (Table 8 and Figure 10). Understory weed cover increased significantly in weeded plots, but not in unweeded plots. There was a significant increase in non-native canopy cover in unweeded plots, but not in weeded plots. No significant change occurred in native canopy cover in either weeded or unweeded plots. There was a significant reduction in *G. robusta* canopy cover among weeded plots but not in unweeded plots. Canopy cover of *T. ciliata* increased significantly in unweeded plots, but there was no difference in weeded plots.

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

Table 8. Percent cover change in weeded (n = 46) and unweeded (n = 68) plots at Manuwai from 2011 to 2016 for taxon groupings and IPA target taxa. Median values for percent cover in 2011 and 2016 are represented. Statistically significant values are in boldface (Wilcoxon signed-rank test). Arrows indicate increase (↑) or decrease (↓) in cover.

| | Plots outside weeded areas | | | | Plots inside weeded areas | | | |
|---|---|---|---|---|---|---|---|---|
| | Cover (%) | | | | Cover (%) | | | |
| | 2011 | 2016 | p | Z | 2011 | 2016 | p | Z |
| Native understory | 7.5 | 5.3 | **0.002**↓ | -3.041 | 3.0 | 3.0 | **< 0.001**↓ | -3.880 |
| Non-native understory | 55.0 | 65.0 | 0.203 | -1.272 | 45.0 | 65.0 | **0.013**↑ | -2.479 |
| Native canopy | 15.0 | 20.0 | 0.972 | -0.035 | 25.0 | 15.0 | 0.054 | -1.928 |
| Non-native canopy | 70.0 | 85.0 | **0.002**↑ | -3.170 | 85.0 | 95.0 | 0.238 | -1.181 |
| *Grevillea robusta* | 0.0 | 0.0 | 0.436 | -778.000 | 0.0 | 0.0 | **0.015**↓ | -2.426 |
| *Toona ciliata* | 0.0 | 5.0 | **0.007**↑ | -2.680 | 5.0 | 5.0 | 0.674 | -0.421 |

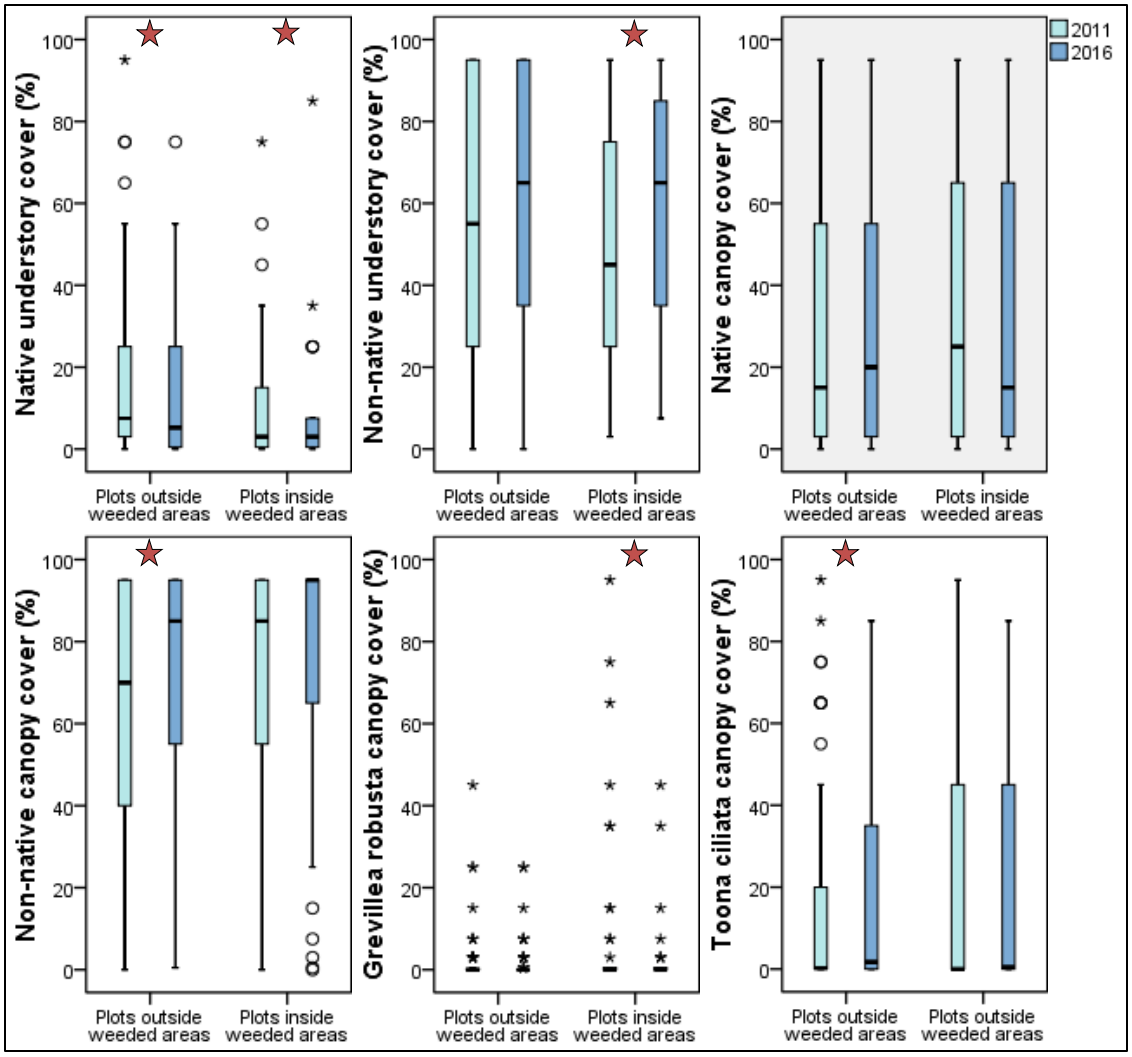

Figure 10. Boxplots of percent cover in plots within (n = 46) vs. outside (n = 68) weeded areas in 2011 and 2016 for taxon groupings and IPA target taxa used in analysis. Stars indicate significant change in cover between 2011 and 2016.

**SUMMARY AND DISCUSSION**

Management objectives were not met for percent cover of native and non-native understory and canopy vegetation for Manuwai MU. There were a number of noteworthy significant differences in the 2016 data as compared with five years prior, including:

- Increase in non-native understory and canopy cover
- Increase in non-native understory and canopy richness
- Increase in frequency for non-native species:
    - *A. hispidulum* (understory)
    - *C. hirta* (understory)
    - *P. suberosa* (understory)
    - *T. ciliata* (canopy)
- Increase in percent cover for non-native species:
    - *A. hispidulum* (understory)

    - *B. appendiculatum* (understory)
    - *C. hirta* (understory)
    - *O. hirtellus* (understory)
    - *P. cattleianum* (canopy)
- Decrease in percent cover for non-native species:
    - *P. cattleianum* (understory)
    - *G. robusta* (canopy)
- Decrease in percent cover for native species:
    - *A. stellata* (understory)
    - *P. odorata* (understory)
    - *D. sandwicensis* (canopy)
- Percent cover change in weeded plots:
    - Decrease in native understory and *G. robusta* (canopy)
    - Increase in non-native understory
- Percent cover change in unweeded plots:
    - Decrease in native understory
    - Increase non-native canopy and *T. ciliata* (canopy)

Most of the vegetation change that occurred between 2011 and 2016 indicated worsening conditions, with increases in non-native cover, richness and frequency, and declines in some native taxon cover. Given the high level of non-native canopy cover in the MU, management goals of < 50% cover may be unrealistic across the MU. Refinement of management goals to apply specifically to prioritized areas (those with greater potential for restoration) within the MU may result in goals that are more likely to be successfully accomplished. Manuwai MU is challenging to manage, given access limitations during inclement weather, and difficulties associated with working in very steep terrain.

Impacts of weeding efforts were primarily attributed to IPA control of *G. robusta* and *T. ciliata*. These efforts were effective for reduction of canopy *G. robusta* within weeded areas. The pervasiveness of *T. ciliata* throughout the MU presents a considerable management challenge. The significant increase in canopy *T. ciliata*, as well as non-native canopy cover in general, in plots outside, but not inside, weeded areas suggest IPA efforts may be preventing canopy cover increases for that taxon and for non-native cover in general within treated areas. *Toona ciliata* frequency increase in the canopy may be explained in part by vertical growth of individuals that were in the understory in 2011, but reached the canopy by 2016. Because IPA efforts focus on larger individuals in efforts to minimize primary seed sources, the continued presence of smaller individuals within the canopy is to be expected. The prevalence of *P. cattleianum* and smaller individuals of the targeted taxa in the lower reaches of the canopy could potentially mask impacts of canopy reduction via IPA. The increase in non-native understory cover in weeded plots may have been a response to the creation of light gaps in the canopy resulting from IPA treatment. The decline in native understory cover in weeded areas had a similar pattern in unweeded areas, and was not likely influenced by IPA efforts.

Natural resource management staff anecdotally observed increased cover of *Urochloa maxima* in Subunit II within the last year, and expressed concerns that IPA control efforts may exacerbate the problem (Figure 11). Though the frequency of this taxon was too low for statistical analyses, it did appear in more plots in 2016 (in 14% of plots) than in 2011 (in 11% of plots), and cover increased in over half of the plots in which it was observed in 2011, while none had reduced cover.

Figure 11. Photograph showing dense *Urochloa maxima* understory cover in a monitoring plot at Manuwai. Natural resource management technician, Christopher Lum, is uncharacteristically frowning.

**RECOMMENDATIONS**

Based on the results of vegetation monitoring, a number of recommendations were made with the goal of making progress towards meeting management objectives:

- designate prioritized areas for management
- refine management goals to focus on prioritized areas
- more aggressive weed control paired with restoration efforts in prioritized areas
- target uncommon weeds when seen (particularly target taxa)
- continue IPA efforts within areas already treated, as *T. ciliata* and *G. robusta* grow to the targeted size/stage, and expand efforts into new areas, including higher elevations with more native cover
- monitoring of understory change in direct association with IPA treatments (via a separate monitoring regime) may be done to better understand it's impact on native and non-native understory cover
- continued discussion and assessment of costs associated with worsening understory conditions resulting from the creation of light gaps associated with large scale IPA canopy removal vs. benefits of controlling IPA target taxa
- aerial spraying of *U. maxima*

## REFERENCES

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

Oahu Army Natural Resource Program. 2011. Chapter 1.2.3 Manuwai Ecosystem Restoration Management Plan *in* 2011 Status Report for the Makua and Oahu Implementation Plans.