Technical Report
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Botanical Survey and Vegetation Analysis, Waiʻele, Hawaiʻi

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Presented are the results of a botanical survey conducted on the east side of Hawaii Island, with a comprehensive overview of the site's floral diversity. Our study identified a total of 103 vascular plant taxa. The flora comprises 73 naturalized taxa, 19 native taxa and 11 Polynesian-introduced taxa. Among the findings was the endemic endangered species *Ischaemum byrone* and the Polynesian introduced *Piper methysticum*. The site's vegetation abundance was measured using relevé plots, and analyzed for clustering. We categorized the vegetation into three major types: *Scaevola-Heliotropium Shrubland, Hibiscus-Paederia Shrubland,* and *Mangifera-Thelypteris-Oplismenus Forest*.

The island of Hawai‘i, known for its rich and diverse ecosystems and also its rates of extinction, presents a unique opportunity for botanical research. The east side of Hawai‘i Island, in particular, boasts a range of ecological zones that are home to a variety of plant taxa, some of which are found nowhere else on Earth. Beyond Hawai‘i's wealth of endemic plant diversity, Indigenous communities possess a profound connection with their ancestral lands, often encompassing centuries of accumulated knowledge and sustainable land management practices. Just before contact, the Kanaka Maoli (Indigenous Hawaiians) had developed an immense number of varieties of crops (Table 1), most of which have been lost, and many more are rare, or threatened (Kagawa-Viviani *et al.* 2018).

This technical report documents the findings of a botanical survey aimed at cataloging the vegetation and assessing the presence of rare and endangered taxa on two parcels recently acquired through the Public Access, Open Space, and Natural Resources Conservation Commission (PONC) for perpetual preservation by the County of Hawai‘i within this region. The survey's objectives were not only to enrich the scientific understanding of the area's flora but also to inform future conservation and management efforts.

The significance of this survey extends beyond academic interest; it is a critical step towards preserving Hawai‘i's natural heritage. The objectives are as follows:

1. to identify and map the major vegetation types
2. to determine the occurrence of threatened and/or endangered taxa
3. to determine the occurrence of Hawaiian cultivars
4. to provide data sufficient to facilitate future management

These goals were pursued with awareness of the delicate balance that exists within island ecosystems and the threats posed by both invasive species and the interruption of Indigenous land management practices.

Our methodological approach was designed to be as thorough and minimally invasive as possible. It included a review of existing literature, consultations with persons familiar with the area, and extensive fieldwork conducted over several months.

Crop	No. Hawaiian Varieties	No. Remaining	Remaining (%)
Kalo *Colocasia esculenta*	300-400	~60	15-20%
‘Uala *Ipomoea batatas*	~250	unknown	-
Mai‘a *Musa* spp.	40	-	-
‘Awa *Piper methysticum*	35	13	37%
Kō *Saccharum officinarum*	50	-	-
‘Uhi *Dioscorea* spp.	9	-	-
‘Ulu *Artocarpus altilis*	1	-	-
Niu *Cocos nucifera*	2	-	-

Table 1: Hawaiian crops with number of varieties documented and currently known. Numbers from Kagawa-Viviani et al. 2018.

The survey was conducted within the context of a changing global climate and increasing ecological pressures. The findings presented in this report are intended to serve as a baseline for future studies and as a guide for conservation strategies. By providing a snapshot of the current state of the site's flora, we hope to contribute to the ongoing efforts to protect and preserve the unique plant life and indigenous practices that contribute to the identity and ecological integrity of the island.

Materials & Methods

Study Area

This study was based on the east side of Hawai‘i Island, in the ahupua‘a (region) of Halepua‘a in the moku (district) of Puna. The boundary of the study corresponds to the property line of Hawai‘i State TMK 3-1-4-3-003 and 3-1-4-3-037. The encompassed area totals 66.9 hectares (165.3 acres) and extends from 53 m.a.s.l. to the ocean. Locally, the area is known as Wai‘ele.

The surrounding area is a landscape matrix composed of private homes, *Casuarina* forests, papaya plantations, and bare lava flows. Just inland of Wai‘ele is the Halepua‘a section of the Nānāwale Forest Reserve, which contains sections of hala (*Pandanus tectorius*) and ‘ōhi‘a (*Metrosideros polymorpha*) native forest studied by Clarke *et al.* (1979).

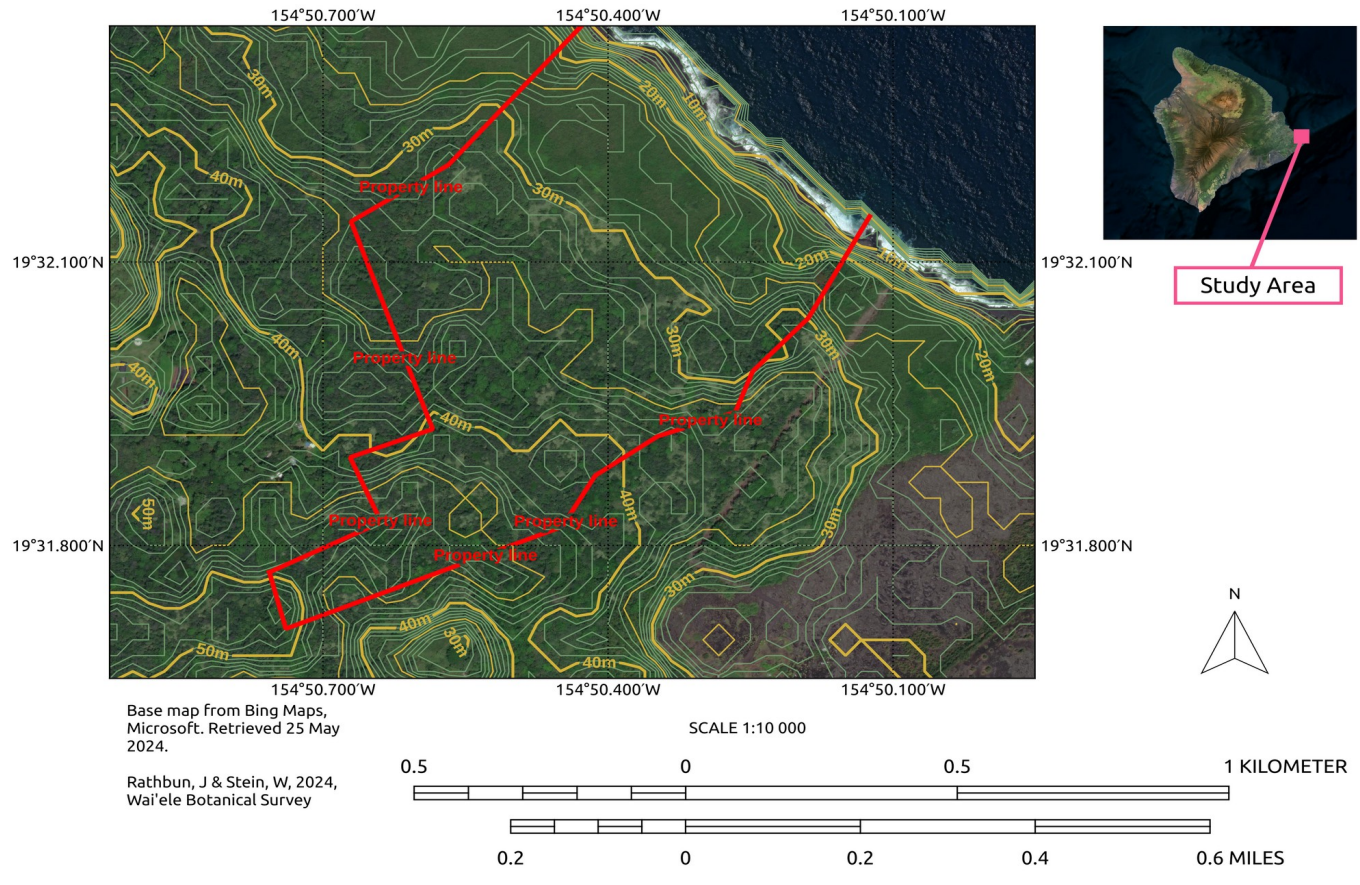


Figure 1: Study area with boundaries indicated as "Property line" and 5m elevation contours.

The climate is moist mesic (Price *et al.* 2012) with a mean annual precipitation of 2500 mm (98 inches) (Giambelluca *et al.* 2013). Summers tend to be dryer, though dry periods may occur at any time of year. East-northeast trade winds predominate, and they blow onshore for much of the year. Occasionally, generally during the winter, the area is subject to southerly to south-westerly Kona winds that are sometimes strong and quite dry.

The lava substrate that underlies Waiʻele is a relatively smooth and flat pāhoehoe that has been dated AD 1200-1550 (Sherrod *et al.* 2021). We did not encounter any lava tube systems within the survey area. A layer of black muck soil averaging more than 20 cm thick has accumulated on top of the pāhoehoe. This organic soil has been supplemented by a considerable quantity of fine cinder sand probably deposited from the 1960 Kapoho eruption and/or earlier eruptions from the nearby east rift of the Kīlauea Volcano. The soil thins out toward the rocky shore. Low cliffs line most of the shore, which are, in places, fronted by boulder beaches. Rock walls and other stone structures are ubiquitous throughout Waiʻele, evidence that the area has been used by humans in the past.

Flora Sampling

We reviewed the available literature on the site and its adjoining areas. This was complemented by discussions with local experts, community members and other individuals familiar with the terrain. Fieldwork was conducted from November 2023 to June 2024.

Transects and plots were located in the *QGIS* desktop application (QGIS Development Team 2024), following a period of ground familiarization. The field team utilized this GIS data in the *QField* phone app and GPS, for real-time data collection and editing. Our survey efforts were intensified in regions reported to harbor rare plants by the area's community, selected via aerial photos, and/or identified in our preliminary site walk. Aerial photography was also studied to delineate tentative vegetation types. Presence/absence data were developed via transect sampling. Abundance data were collected via twenty-two 10 m x 10 m quadrats. Twelve initial quadrats in groups of four were laid out along 40 m transects to evaluate species accumulation curves, vegetation diversity indices and other preliminary data (Mueller-Dombois & Ellenberg 1974). The first four plots were the inland plots laid just north of the property line, and may be used as a control in analyzing the effectiveness of management decisions. The subsequent plots were laid out at random using the "random points in polygons" tool in *QGIS* and located *in situ* with a GPS smartphone app. Within each plot, each species was assigned an ordinal cover value and height class according to a modified Braun-Blanquet coverscale (Mueller-Dombois & Ellenberg 1974).

Taxa were identified to species, or subspecies, *in situ*, with unidentified specimens collected for subsequent determination. When significant characters such as flowers or fruits were not available, plants were identified to the lowest level possible, or given a cf. taxa designation. Names were validated against *Plants of the World Online* (POWO 2024) and flora lists published for Hawaiʻi (Imada 2012, Imada 2019, Herbst & Staples 2005).

Notable taxa were mapped using GIS tools. As *Ischaemum byrone* is well documented from surrounding areas, we refrained from collecting vouchers to minimize impact on the study area and its small population.

Data Analysis

In identifying and mapping the various vegetation communities, we aimed to quantify the difference between plots. To accomplish this, we utilized a suite of analytical tools. Various dissimilarity indices for samples were calculated and the results compared using the package *vegan* (Okansen *et al.* 2024) in R 4.1.2 (R Core Team

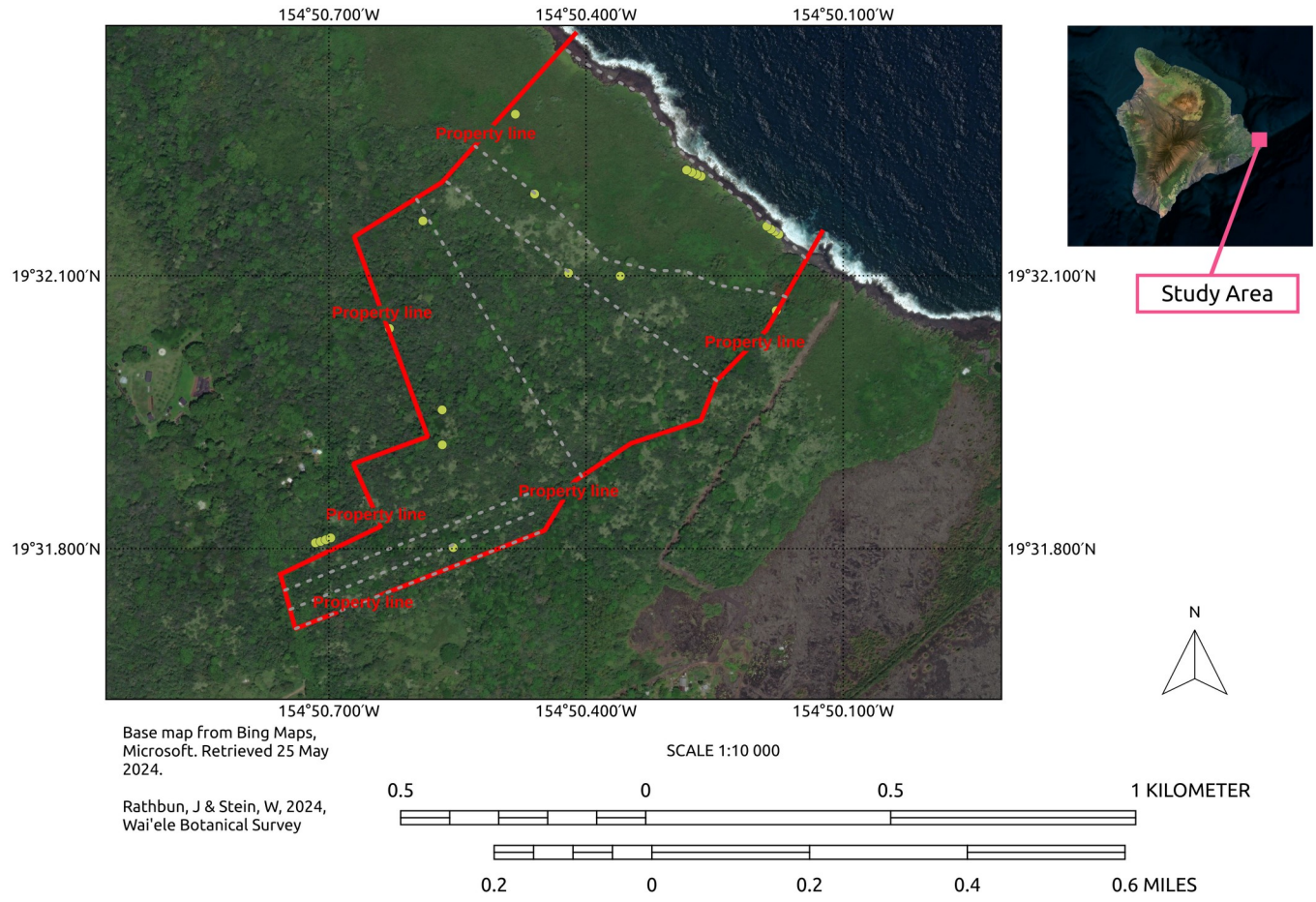


Figure 2: Vegetation Analysis Plots and Transects

2021). Clustering between samples was analyzed according to various clustering criterion. Optimal group number was verified according to the Calinski-Harabasz (1974) criterion. Non-metric multidimensional scaling ordination with Bray-Curtis distance was used to further evaluate clustering in the vegetation. The Shannon-Weiner diversity index (Hill 1973) was calculated for each plot for insights into how vegetation diversity differed across the site.

Results

Vascular Plants

The study identified a total of 103 vascular plant taxa across 48 families. The naturalized flora comprises 73 taxa or 70.8% of the total species richness, with 52 dicots, 11 monocots and 10 ferns. Native flora are represented by 19 taxa or 18.4%, including 3 endemic taxa and one endemic hybrid taxon, *Nephrolepis* × *medlerae*, resulting from naturalized *N. brownii* crossed with indigenous *N. exaltata*. Polynesian introductions are represented by 11 taxa or 10.6%, which constitute roughly half of the original canoe plants brought to Hawai‘i. Of the 48 families represented, more than half (58%) of the vascular plant diversity is represented by only 13 (27%) families. The three most diverse families are Fabaceae and Polypodiaceae with 7 taxa, and Aspleniaceae with 6 taxa.

Of the 18 native taxa recorded, only 4 are endemic, meaning they occur only in the Hawaiian Archipelago: *Pipturus albidus*, *Thelypteris hudsoniana*, *Ischaemum byrone*, and the hybrid *Nephrolepis × medlerae*. The remaining taxa are indigenous, i.e. occuring naturally in the Hawaiian Archipelago, but also elsewhere in the world.

One-third of the native taxa are represented by epiphytic ferns. Almost another third (5 taxa) are lianas or vines. That corresponds to 61% of the native vegetation richness that lives exclusively or mostly above the forest floor.

Laukahi (*Thelypteris hudsoniana*), was the sole native terrestrial fern encountered, though at times it formed a dominant aspect of the ground cover. Only two individuals of māmaki (*Pipturus albidus*), a shrub, were encountered, surviving at the southeast *Hibiscus-Paederia Shrubland* to *Mangifera-Thelypteris-Oplismenus Forest* boundary.

Hala (*Pandanus tectorius*) is a native tree, and constitutes a significant proportion of the biomass produced at Waiʻele. Several moderately dense hala groves are scattered around the forest, these usually overtopped by taller mango (*Mangifera indica*) and cecropia (*Cecropia obtusifolia*) trees.

The origin status of hau (*Hibiscus tiliaceus*) is uncertain. Whether it arrived to the Hawaiian Islands via sea or with Polynesian voyagers has not yet been conclusively proven (Wagner *et al.* 1999, Herbst & Staples 2005). Nevertheless, it is currently considered indigenous to Hawaiʻi by *The Manual of Flowering Plants to Hawaii* (Wagner *et al.* 1999), the Imada Checklists (2012, 2019), the *Flora of the Hawaiian Islands* (Wagner *et al.* 2023), and *Plants of the World Online* (POWO 2024), and we follow that consensus in this report.

Among the taxa cataloged, *Ischaemum byrone* stands out as it is listed as Endangered under the Endangered Species Act (ESA) (Fish and Wildlife Service 2019). It is the only rare native taxon cataloged. A few individuals of this endangered species grow along the immediate shoreline within the *Scaevola-Heliotropium Shrubland*.

In addition to the native taxa, the survey identified 11 taxa that are Polynesian introductions, reflecting Kanaka Maoli land-use and cultivation. Plants brought to and/or developed in the Hawaiian Islands in ancient times form a conspicuous part of the flora of Waiʻele today, including extensive stands of kukui (*Aleurites moluccana*), ʻulu (breadfruit; *Artocarpus altilis*), ʻōhiʻa ʻai (*Szygium malaccense*), noni (*Morinda citrifolia*), kī (ti; *Cordyline fruticosa*), and niu (coconut; coconut palm; *Cocos nucifera*). ʻUlu sap "was commonly used throughout Polynesia and Fiji for caulking canoes and as an adhesive," and several trees in Waiʻele bore successive horizontal scarring indicative of sap harvesting (Whistler 2009). Several coconut palms were tall and appeared quite old. Their provenance deserves further investigation. As well as these, a single, small patch of ʻawa (*Piper methysticum*) was recorded.

Lebot *et al.* (1999) formalized 13 ʻawa varieties. According to Table 1 from Lebot *et al.*, "Morphological description of the germplasm collection," the ʻawa found corresponds closest to cultivar (cv.) *Waʻa Waʻa* or cv. *Molokaʻi.* An ʻawa expert (anon., pers. comm.) identified the ʻawa as cv. *Nene,* which Lebot *et al.* synonymize with cv. *Ava Lea,* a Samoan genotype, and to which the plant's morphology also closely agrees.

The extent of the Kanaka Maoli crops was not limited to the property boundaries. The forest extended along the road north and to the west of the acquired parcels, and a large population lies to the south and east, including more kukui-dominant vegetation, and large stands of ʻulu and ʻōhiʻa ʻai.

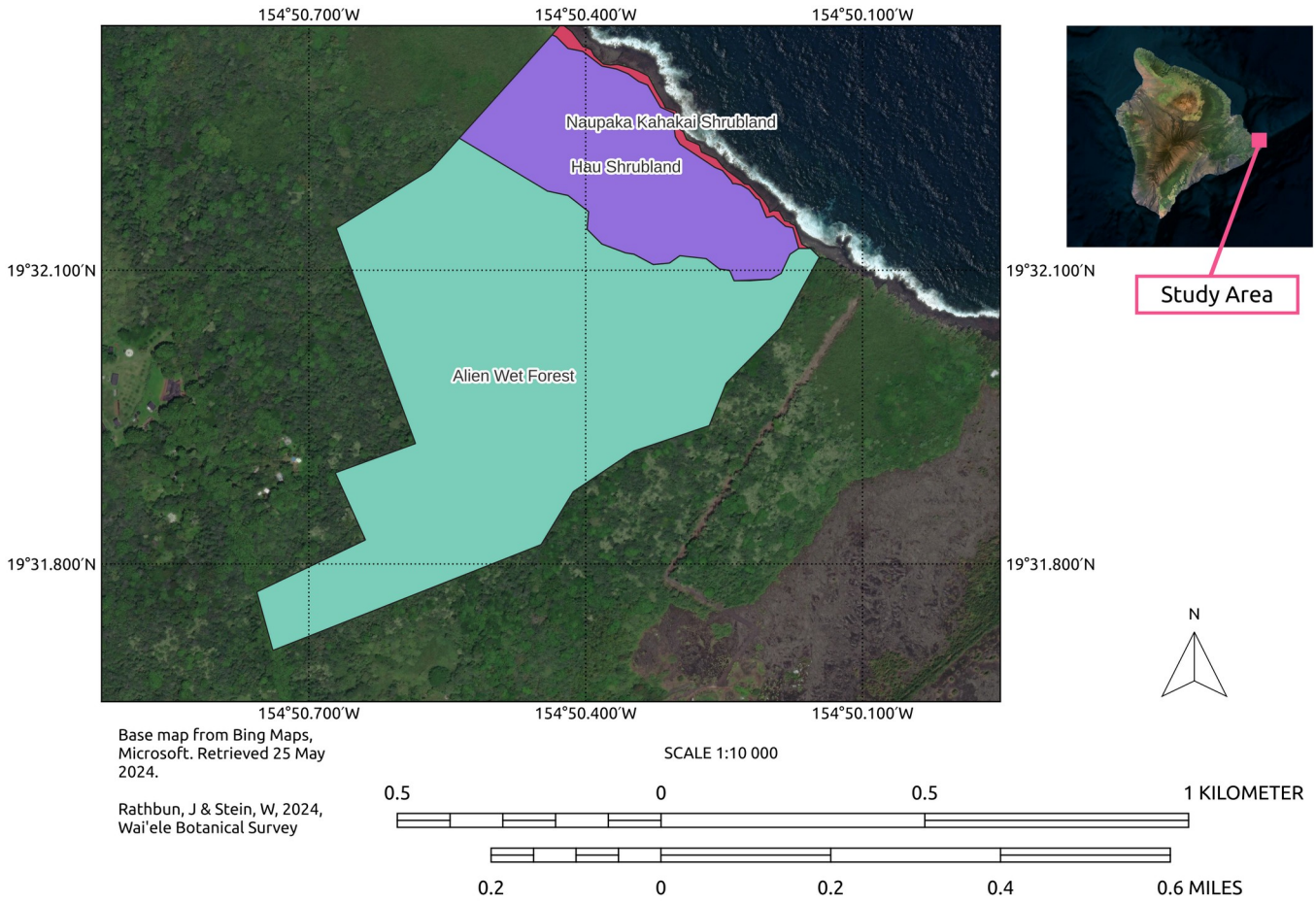


Figure 3: Map of Vegetation Communities

Vegetation Communities

Cluster Analysis & Ordination

Our cluster analysis and ordination support the existence of three vegetative communities. For inland Wai‘ele, the canopy can be diverse, with some areas being largely mango, and others, largely cecropia, or kukui. Our data do not support these canopy types as distinct communities when compared to the differences between the three major communities. The three communities proposed by our analysis have obvious structural differences on the ground, as well as their compositional differences examined by our analysis. We will discuss them at length in their corresponding sections, below.

The Calinski-Harabasz criterion (CHC) was highest for 2 clusters within our plots, indicating 2 clusters as the “optimal” grouping just slightly above 3, with decreasing values for 4, and 5 groups. However, a variety of dissimilarity indices (Chao, Bray-Curtis & Horn–Morisita) all converged on the same 3 clusters. Further, visualizing the Bray-Curtis distance with non-metric multidimensional scaling (NMDS) ordination, showed the three clusters were well-defined.

The first division splits coastal naupaka-dominant (*Scaevola taccada*) plots (5-12) with more inland plots (13-22), and the second division splits the hau-dominant (*Hibiscus tiliaceus*) plots (18-19) from the rest of the inland plots. The prevalence of these divisions were preserved across various dissimilarity indices. The vegetation dissimilarity between naupaka (5-8) and hala (9-12) plots was lower than most other divisions.

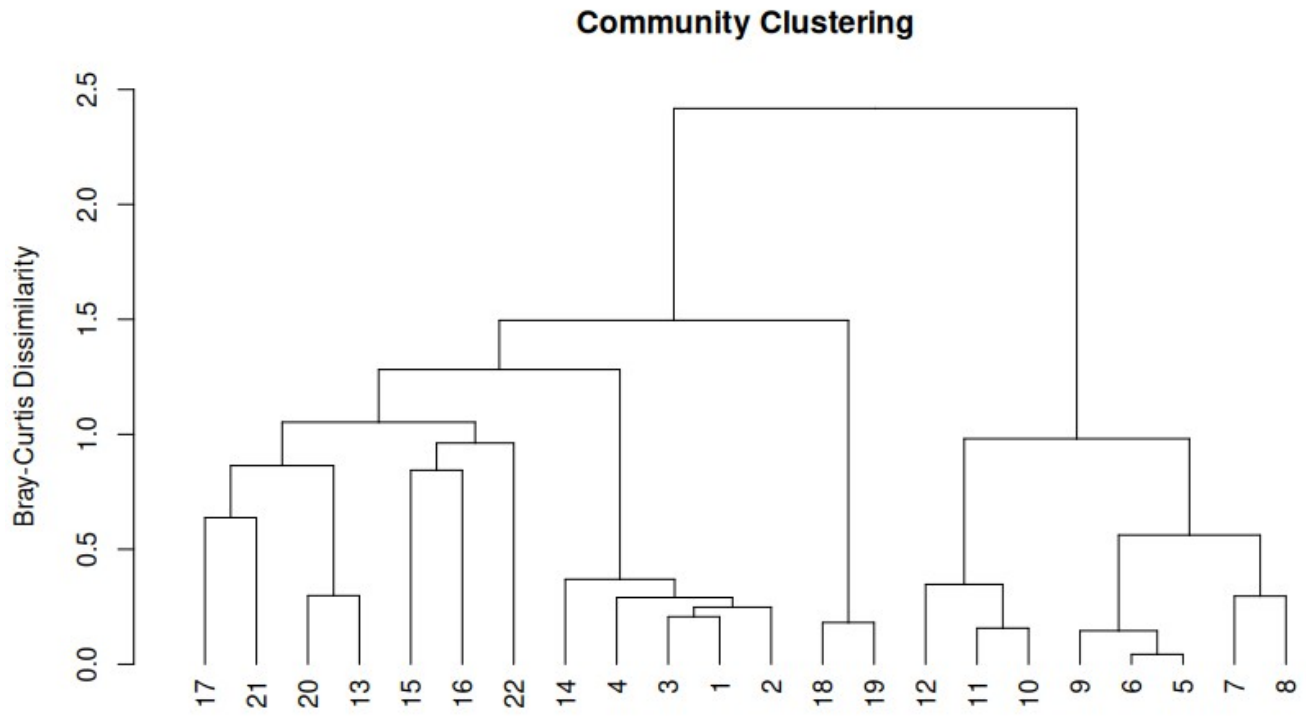


Figure 5: Dendrogram of Vegetation Clusters. No.s 1-22 refer to plot numbers.

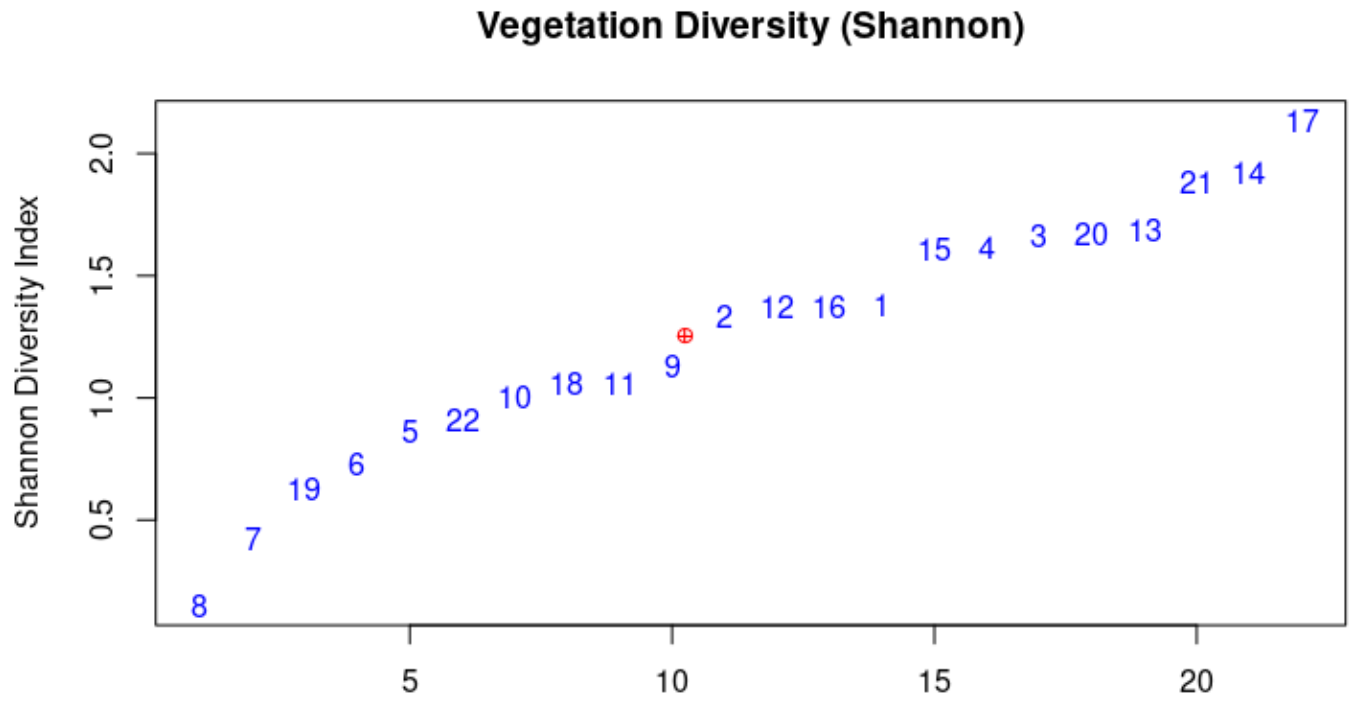


Figure 4: Shannon Diversity Index of plots. Blue numbers are plots, the red circle is the mean diversity.

Our NMDS ordination clarified the differences in clustering between the different dissimilarity indices. Both the hoi-dominant plot (16) and the coconut palm plot (22) were fairly distant from the main group of inland plots, but much closer to the group 1 centroid than the group 2 or group 3.

According to Gagné and Cuddhiy's (1999) vegetation classification for the Hawaiian Islands, our groups most closely follow: *Naupaka Kahakai Shrubland/Hala* Forest, *Hau (Hibiscus) Shrubland.* The forest zone lacks as clear of a designation under their system, following closely *Alien Wet Forest,* but at times resembling their mesic *Kukui (Aleurites) Forest*. Although Wai'ele falls within the 1200 to 3800 mm mesic range, *Alien Wet Forest* follows closely the diversity of naturalized species present at our site. The being said, "*Alien Wet Forest"* is ill-fitting for an area that has a large portion of Hawaiian crops, but accommodates the zone's quantity of naturalized species.

Our indicator species analysis (ISA), showed that group 1 is indicated by *Mangifera indica, Oplismenus hirtellus, Thelypteris parasitica* ($p < 0.01$), *Nephrolepis blanda* and *Aleurites moluccana* ($p <= 0.05$), group 2 is indicated by *Scaevola taccada* and *Heliotropium foertherianum* ($p < 0.01$), and group 3 is indicated by *Hibiscus tiliaceus, Paederia scandens* and *Morinda citrifolia* ($p <= 0.05$).

Vegetation diversity, via the Shannon-Weiner diversity index, was lowest for naupaka-dominant (5-8) plots with a hau (19) plot and the coconut palm (22) plot being about comparable. The second hau (18) plot scored above the naupaka plots and below the hala (9-12) plots. Plots 17 & 14 were scored as the most diverse, but the inland plots were characterized by a generally higher diversity than the other groups.

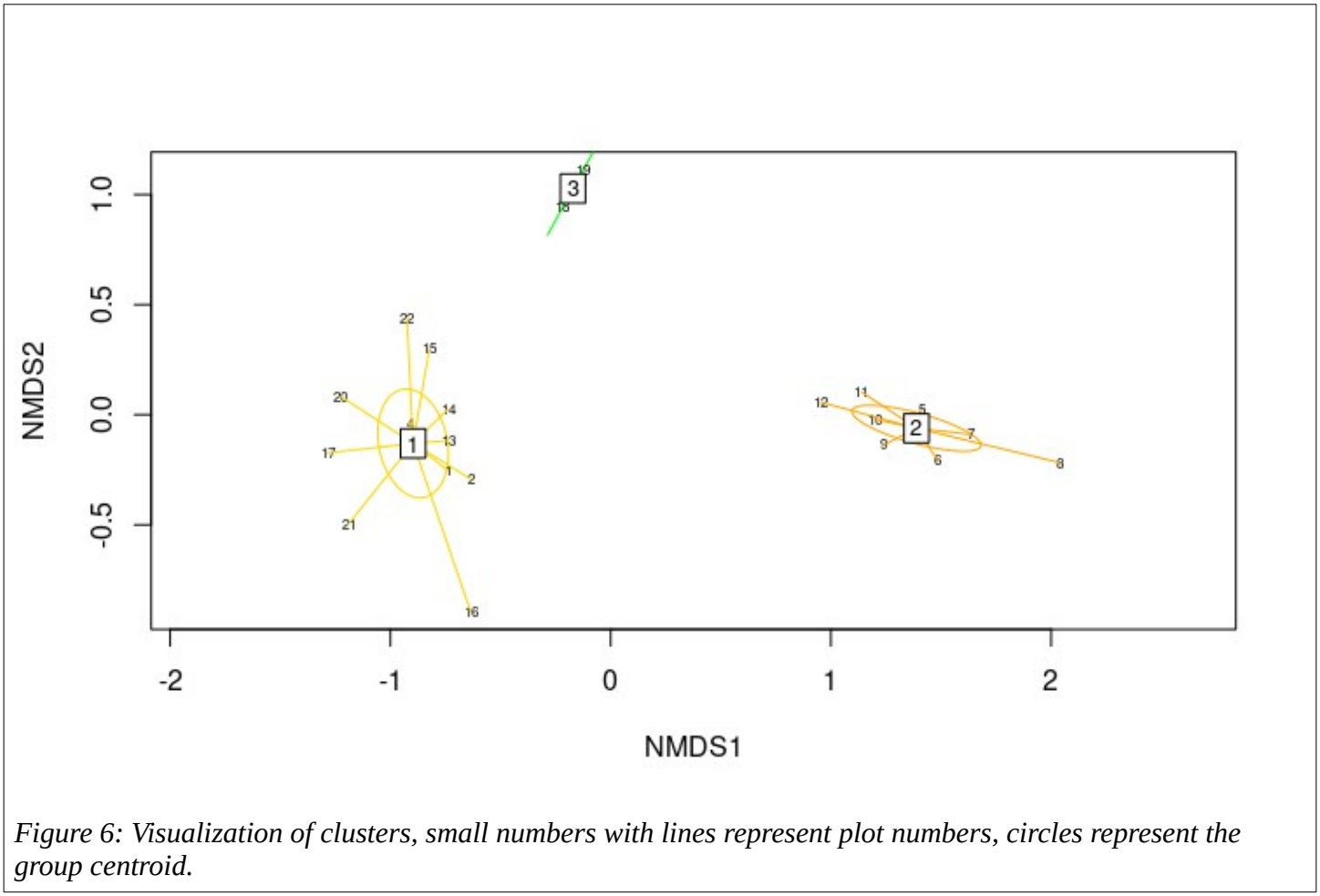


Figure 6: Visualization of clusters, small numbers with lines represent plot numbers, circles represent the group centroid.

Scaevola-Heliotropium Shrubland

This narrow shoreline community is squeezed between the ocean and the hau thicket described below. The vegetated portion occupies only about 0.6 hectares in area, or 0.8% of our study area, with about 8 hectares of rock and intertidal zone seaward. Plants growing here tolerate salt spray and strong wind. This zone is dominated by naupaka kahakai (*Scaevola taccada, ~47% cover*), which often forms large pure stands. It is typified by this shrub, and in all places is generally low-statured (5 m, 15 ft tall, often less). In places hala (~34%), coconut palm and tree heliotrope (*Heliotropium foertherianum, ~21%*) rise above the naupaka shrubs. The vine *Ipomoea violacea* grows near the southeastern end of the coastal strip. Other plants forming a more minor component of this zone include false kamani (*Terminalia catappa*), laua‘e, holly fern (*Cyrtomium falcatum*), crab grass (*Digitaria ciliaris*), the indigenous vine mohihi (*Vigna marina*), and the endangered endemic grass *Ischaemum byrone*. In the extreme southeastern corner behind the cobble beach, the naupaka is less, and the vegetation is dominated by coconut palm and false kamani.

Occasionally, barren areas are vegetated by mau‘u ‘aki‘aki (*Fimbristylis cymosa*) and little else, sometimes with a thin layer of sand. This littoral zone is often scoured by heavy surf, but is dry for periods too long to sustain marine vegetation. The upper tidal zone is dominated by the yellowish limu ‘aki‘aki (*Ahnfeltiopsis concinna*). Coralline alga (*Hydrolithon onkoides*) at times forms a thin pink crust dominating the intertidal rocks below the limu ‘aki‘aki.

Hibiscus-Paederia Shrubland

The trunks of hau trees here interlock to form a dense thicket. At 12.5 hectares, this shrubland represents approximately 18.6% of the study. It extends just behind the narrow naupaka zone along nearly the entire shoreline. This community has an even height, being nearly everywhere about 5m (15 ft) tall. Some of the taxa found within are maile pilau (*Paederia scandens*), moon flower (*Ipomoea alba*), noni (*Morinda citrifolia)* and clock vine (*Thunbergia fragrans*). Moa (*Psilotum nudum*) is fairly frequent, terrestrially, and epiphytically. Occasionally the ferns ‘ekaha (*Asplenium nidus*) and laua‘e grow among the tangled branches. Trees of kukui, and niu may be feral progeny of remnant cultivation, or themselves planted by people.

In the previous section on Vascular Plants, we commented on the contention surrounding the distributional origin of hau. The presence of limited strawberry guava (*Psidium cattleianum*) thickets within the shrubland, but without any seedlings under the hau, indicated no/limited recruitment in hau thickets. In plot no. 19, there were no strawberry guava seedlings found beneath the two mature and fruiting trees within the plot. The hau may have been planted as a windbreak along the shore in ancient times or in early post-contact times. Such a windbreak would have protected crops and villages alike. Regardless of distributional origin, the presence of strawberry guava thickets within the hau might indicate the community as it is today formed after strawberry guava’s introduction in 1825 (Herbst & Staples 2005).

Mangifera-Thelypteris-Oplismenus Forest

At around 45.4 hectares, this zone represents 67.8% of the area studied. This forest has a nearly continuous canopy mostly 15–25 m (50–75 ft) tall, and is the most diverse vegetation community. The canopy reflects this, with the most abundant large tree being mango (~50%), followed by cecropia (~22%) and kukui (~17%). In a few places *Melochia umbellata* and *Trema orientalis* join the canopy. In others, ‘ulu (*Artocarpus alitis*) and coconut palm predominate. The understory is relatively open in most places, making walking easy along the numerous pig trails. In places there is an understory of shrubs or small trees, especially Myrtaceae like guava

Illustration 1: ▲ Cecropia canopy "dieback"——the tall snag in the upper left is cecropia.

▼Healthy cecropia canopy.

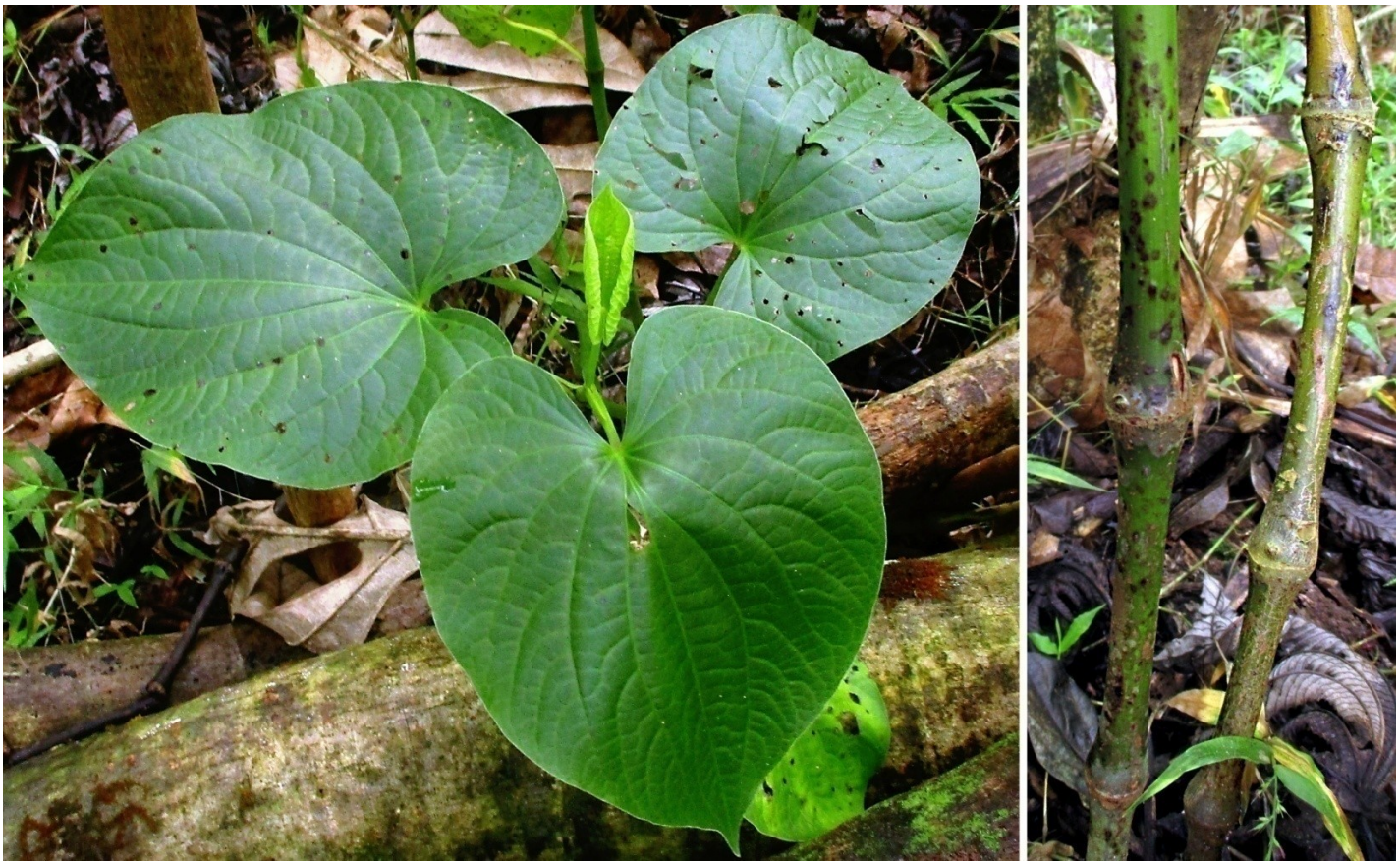


Illustration 2: ‘Awa, Piper methysticum

(*Psidium* spp.) or *Syzygium* spp. and Rubiaceae like noni (*Morinda citrifolia*) or coffee (*Coffea arabica*). Much of the ground in the forest area is covered with the grass honohono kukui (*Oplismenus hirtellus*) and naturalized ferns, especially wood fern (*Thelypteris parasitica*), these two plants are nearly ubiquitous and highly characterize this group. Herbs are remarkably sparse; in fact, the only grass seen in the forest during our survey was honohono kukui. A considerable proportion of the ground is bare due to the rooting of pigs and/or the dense shade cast by some of the trees.

Queensland Longhorn Beetle

A recent introduction to Hawai‘i County, the Queensland longhorn beetle (QLB; *Acalolepta aesthetica*), is posed to have a dramatic impact upon vegetation island-wide (BIISC 2024). Adult QLB are known to affect a wide range of hosts, like citrus, cacao, kukui, cecropia, breadfruit, and many others. A single grub, excised from a dead kukui tree, was identified as QLB by Ann Kobsa, and Jade Miyashiro of BIISC (pers.

Illustration 3: QLB (Acalolepta aesthetica) larva

comm.). We often encountered dying cecropia at Wai‘ele with a number of bore holes and stringy frass around their trunk. Although the only grub was found in a kukui tree, cecropia were dead nor dying more than any other tree species at Wai‘ele. QLB should be investigated as the cause of the cecropia dieback currently advancing at the site.

Limitations

The results of our botanical survey are reflective of the specific season and environmental conditions prevalent during the period of study. It is important to acknowledge that slight variations in these conditions could potentially lead to different outcomes. While we have made every effort to ensure comprehensive coverage, the dynamic nature of ecosystems means that our findings may not capture the full extent of taxa diversity present at other times of the year or under different environmental scenarios.

Recommendations

The volumes of research in Hawaiian and other ecosystems have highlighted the significant impact of feral pigs (*Sus scrofa*) on vegetation dynamics. Almost every plot in the *Mangifera-Thelypteris-Oplismenus Forest* community had some degree of pig disturbance. At times nearly 50% of the forest floor was bare, and pigs were seen often on field days. Implementing control measures typical for Hawai‘i, such as fencing, hunting, or trapping, could have profound implications for the ecosystem.

We have selected a few species as notable for removal (*Macaranga sp., Passiflora laurifolia, Ficus microcarpa, Schinus terebinthifolius,* see supplemental maps). There is a notable stratification of dispersal strategy by date of introduction. Pre-contact and early post-contact species represent more anthropochorus (human-dispersed) turned barrochorus (weight-dispersed) taxa (i.e. *Aleurites moluccana, Mangifera indica, Syzygium malaccense, Cocos nucifera,* &c). The later post-contact species within Wai‘ele’s interior more often tend to be zoochores/ornithochores (animal/bird-dispersed, i.e. *Ficus microcarpa, Miconia crenata* sp.) (Shiels

Illustration 4: Cyrtomium falcatum, among Terminalia cattapa leaves near the shore.

Illustration 5: Begonia sp.

2010). *Cardinalis cardinalis* and *Carpodacus mexicanus*, encountered in our survey, are both known seed predators, passing seeds below 2 mm (Carpenter *et al.* 2020).

As management and traffic increases in the area, there is the potential for this balance to shift in the favor of introduced exoanthropochores (on-the-outside-of-people) like *Desmodium* spp., *Bidens pilosa*, &c. that are common about the Puna district of Hawai‘i Island today. Early implementation of sanitation procedures could help control the spread of such weeds.

The wide dispersion of seedlings of certain invasive species implies constant monitoring would be required for population control. *Macaranga tanarius* & *M. mappa* both are clearly increasing in abundance within Wai‘ele, even in remote areas.

In addition to a monitoring and control program, a strategic outplanting program could be implemented to enhance native and Polynesian biodiversity as well as preserve the site’s unique genetic resources.

Illustration 6: Heliotropium foertherianum, center.

VASCULAR PLANTS OF WAIʻELE

FORMAT

This list divides the vascular plants of our survey into 3 groups, according to their distributional origin stats: Native (including indigenous and endemic taxa), Polynesian, and Naturalized, following their category in either: the *Hawaiian Native and Naturalized Vascular Plants Checklist* (Imada 2012, hereafter referred to as the *2012 Checklist*), the *Hawaiian Naturalized Vascular Plants Checklist* (Imada 2019, the *2019 Checklist*) or assigned to the Naturalized section if the taxon appears in neither.

Scientific names and their author's abbreviation follows either the *2012 Checklist,* the *2019 Checklist, A Tropical Garden Flora* (Herbst & Staples 2005), or Plants of the World (citation).

ABBREVIATIONS

We use two common abbreviations throughout the following tables:

- ssp. = subspecies
- syn. = synonym. A scientific name that has been superseded by a newer name.

Native Plants

Scientific name	Common name(s)	Notes
Ferns & Fern Allies		
Asplenium nidus L.	ʻEkaha, bird's nest fern	The largest, most common, and most conspicuous epiphyte in the forest.
Haplopteris elongata (Sw.) E.H.Crane	ʻOheʻohe	Infrequent, usually epiphytic on ʻekaha, sometimes epiphytic directly on upper tree trunks.
Lepisorus thunbergianus (Kaulf.) Ching	Pākahakaha	Occasional epiphyte.
Nephrolepis × medlerae W.H.Wagner		Frequent. *N. exaltata* seems to have disappeared from Waiʻele. This hybrid between naturalized *N. brownii* and native *N.exaltata* is sterile, though robust and can persist indefinitely and spread by plantlets that form on runners.
Ophioglossum pendulum L.	Puapuamoa, syn. *Ophioderma pendulum*	A single large specimen was seen growing epiphytically on ʻekaha.
Psilotum nudum (L.) P.Beauv.	Moa, whisk fern	Occasional. Most plants seen here grow epiphytically.

Native Plants

Scientific name	Common name(s)	Notes
Thelypteris hudsoniana (Brack.) C.F.Reed	Laukahi, syn. *Pneumatopteris hudsoniana*	Relatively common on the forest floor, dominating the understory in a few places, though much less common than its non-native relative *Thelypteris parasitica*
Trichomanes minutum (Blume) K.Iwats.	syn. *Gonocormus minutus*, *Crepidomanes minutum*	A common but tiny and inconspicuous fern growing among mosses and liverworts on tree trunks and logs.
Flowering Plants		
Cassytha filiformis L.	Kaunaʻoa pehu	These leafless orange hemiparasitic vines climb trees here and there.
Fimbristylis cymosa R.Br. ssp. *spathacea* (Roth) T.Koyama	Mauʻu ʻakiʻaki	Common along immediate shoreline. This small sedge grows closer to the ocean than any other non-marine plant, seaward of the naupaka fringe, where storm waves occasionally splash.
Guilandina bonduc L.	Kākalaioa, syn. *Caesalpinia bonduc*	High-climbing lianas. Shrubby young plants numerous on the forest floor.
Hibiscus tiliaceus L.	Hau	A broad thicket fronts nearly the entire Waiʻele coast. The hau may have been planted long ago as a wind break.
Ipomoea indica (Burm.) Merr.	Koali	Scattered thin vines; prefers a more open environment than provided at Waiʻele.
Ischaemum byrone (Trin.) Hitchc.		Less than a dozen plants scattered along the shoreline at the edge of the naupaka. See photo above.
Mucuna gigantea (Willd.) DC. ssp. *gigantea*	Kāʻeʻe	Common. Large lianas climb to tree tops.
Pandanus tectorius Parkinson ex Z	Hala	Groves scattered along shore and within the forest. Hala, the only native tree in Waiʻele, is common, dominating several areas.
Pipturus albidus (Hook. & Arn.) A.Gray	Māmaki	An area behind the hau near the boulder beach supports several scattered shrubs; scarce elsewhere.
Scaevola taccada (Gaertn.) Roxb.	Naupaka	This shrub forms a dense fringe between the hau thicket and the ocean.
Vigna marina (Burm.) Merr.	Mohihi, nanea	A dried-up vine with viable seeds seen among naupaka along the shore.

Polynesian Introductions

Scientific name	Common name(s)	Notes
Aleurites moluccana (L.) Willd.	Kukui	Abundant, forms dominant cover in many areas.
Alocasia macrorrhizos (L.) G.Don	‘Ape	A few plants seen.
Artocarpus altilis (Parkinson ex Z) Fosberg	‘Ulu, breadfruit	Common, old and younger trees scattered throughout the forest zone.
Cocos nucifera L.	Niu, coconut palm	Several groves scattered along the shore and in the forest zone. A circle of very old, very tall trees grows within the hau thicket.
Cordyline fruticosa (L.) A.Chev.	Kī, ti plant	Numerous, thinly scattered. Green-leaf form presumably of old to ancient origin, red-leaf cultivars recently planted.
Dioscorea bulbifera L.	Hoi, bitter yam	Three large patches, vines densely cover ground and climb trees.
Dioscorea pentaphylla L.	Pi‘a	Seen but not conspicuous during survey in the winter season.
Morinda citrifolia L.	Noni	Occasional, scattered.
Piper methysticum G.Forst.	‘Awa	Scarce. A patch of three small plants, a variety with black lenticels.
Syzygium malaccense (L.) Merr. & L.M.Perry	‘Ōhi‘a ‘ai, mountain apple.	Dense groves form an understory in several places.
Zingiber zerumbet (L.) Sm.	‘Awapuhi	Scattered rhizomes visible above ground. Dormant in winter season, but becomes conspicuous and common as spring progresses.

Naturalized Plants

Scientific name	Common name(s)	Notes
Ferns & Fern Allies		
Adiantum hispidulum Sw.	Rough maidenhair fern	Infrequent on the ground.
Blechnum appendiculatum Willd.		Forms a dense ground cover in patches.
Cyrtomium falcatum (L.f.) C.Presl	Holly fern	Several plants grow in a cluster on rocks near the shore.
Diplazium esculentum (Retz.) Sw.	"Hō‘i‘o", paca	Along the road only, but will probably spread into the forest..
Nephrolepis brownii (Desv.) Hovenkamp & Miyam.	Asian sword fern	Common in the forest but not pervasive as it can be in environments with more light.

Naturalized Plants

Scientific name	Common name(s)	Notes
Phymatosorus grossus (Langsd. & Fisch.) Brownlie	Laua‘e, syn. *Microsorum grossum*	Common, usually terrestrial near the shore and epiphytic in the forest.
Phlebodium aureum (L.) J.Sm.	Laua‘e haole	Occasional to fairly common epiphyte.
Tectaria incisa Cav.		Fairly common on the forest floor.
Thelypteris dentata (Forssk.) Brownsey & Jermy	Pa‘i‘ihā, syn. *Christella dentata*	Fairly common but not as abundant as T. *parasitica*, with which it may hybridize..
Thelypteris parasitica (L.) H.Lév.	Downy wood fern, syn. *Christella parasitica*	The most abundant ground cover species, common throughout the forest area.
Monocots		
Alpinia pupurata (Vieill.) K.Schum.	Red ginger	A patch along road.
Ananas comosus (L.) Merr.	Pineapple	A few plants along southern border.
Areca cf. *catechu* L.	betel	A single plant without flowers along the southeast border.
Chyrsalidocarpus lutescens H.Wendl.	Syn. *Dypsis lutescens*	A single patch along the southeast boundary.
Commelina diffusa Burm.f.	Honohono	Relatively infrequently appearing in less shady spots.
Costus guanaiensis Rusby		A patch along the road seems to be spreading by rhizomes into the forest.
Digitaria ciliaris (Retz.) Koeler	Crab grass	A few small patches along shoreline.
Epipremnum pinnatum (L.) Engl.	Taro vine	Along road and southeast boundary.
Oplismenus hirtellus (L.) P.Beauv.	Honohono kukui, basket grass	Abundant, along with *Thelypteris* spp. (syn. *Christella*) ferns forms the dominant ground cover throughout the forest.
Phaius tankarvilleae (Banks ex L'Hér.) Blume	Nun's orchid, Chinese ground orchid	One plant seen near road.
Philodendron pinnatifidum (Jacq.) Schott		This and the other three hemiepiphytic aroids were introduced along the road and now tend to spread vegetatively into the adjacent forest.
Philodendron scandens K.Koch & Sello		Spreading into the forest from roadside.

Naturalized Plants

Scientific name	Common name(s)	Notes
Rhynchospora radicans (Schltdl. & Sham.) H.Pfeiff. subsp. *microcephala* (Bertero ex Spreng.) W.W.Thomas		A single small, dense patch was spreading by plantlets that form in the inflorescence.
Syngonium auritum (L.) Schott		Spreading into the forest from roadside.
Dicots		
Herbs		
Arthrostemma ciliatum Pav. ex D.Don		A rapidly spreading weed that forms dense patches, encroaching in south area of forest.
Begonia hirtella Link.		Common shade lover.
Begonia sp.		A plant seen growing on a rock wall near southeastern boundary. Stems about 120cm tall. (see photo)
Chloranthus spicatus (Thunb.) Makino		A small patch about 30 m in from the road. Apparently does not set seed in Hawai‘i.
Crassocephalum crepidioides (Benth.) S.Moore		Infrequent.
Kalanchoe pinnata (Lam.) Pers.		A few plants along alanui kahakai trail.
Nicoteba betonica (L.) Lindau	syn. *Justicia betonica*	Large patch directly at the southern border.
Oxalis debilis Kunth var. *corymbosa* (DC.) Lourteig		Infrequent.
Pseudelephantopus spicatus (B.Juss. ex Aubl.) C.F.Baker		A single patch and a few isolated plants noticed.
Ruellia blechum L.		Single small patch seen in forest.
Synedrella nodiflora (L.) Gaertn.		Infrequently scattered in forest.
Vines & Lianas		
Ipomoea alba L.	Moon flower	Scattered in forest and in hau thicket.
Ipomoea violacea L.		Patches occurring along southeast end of the shoreline zone.
Momordica charantia L.		Scattered, common.
Paederia foetida L.	Maile kukae	Scattered.
Passiflora edulis Sims	Lilikoi	A few vines seen in forest.

Naturalized Plants

Scientific name	Common name(s)	Notes
Passiflora laurifolia L.	Jamaican lilikoi	A largish patch of vines high-climbing and on ground seen near center of forest.
Passiflora quadrangularis L.	Giant granadilla, giant lilikoi	A single vine along the southeast border.
Stictocardia tiliifolia (Desr.) Hallier f.	Pilikai	Scattered, occasional.
Thunbergia fragrans Roxb.	Clock vine	Common, scattered.
Vigna hosei (Craib) Backer		Plants seen covering a small area near northwest border.
Shrubs		
Cestrum nocturnum L.	Night-blooming jasmine	Fairly common understory shrub in the forest.
Lantana camara L.		Relatively infrequent, not thriving in the shady forest.
Miconia crenata (Vahl) Michelang.	Clidemia, syn. *Clidemia hirta*	Occasional mostly in northeast
Trees		
Annona mucosa Jacq.	Rollinia, syn. *Rollinia mucosa*	Small trees directly along Govn't Beach Rd
Annona muricata L.	Soursop	Seedlings along southeast border.
Artocarpus heterophyllus Lam.	Jak tree	Occasional, scattered, mature trees and seedlings seen
Calliandra houstoniana (Mill.) Standl. var. *calothyrsa* (Meisn.) Barneby		Several plants seen in east area of forest, with spreading seedlings. This plant, a recent invader of Puna forests, is capable of forming koa haole-like thickets and has the potential to become a serious pest.
Cecropia obtusifolia Bertol.		Abundant, filling much of the space between the larger mango and monkeypod trees. The trees appeared unhealthy with sparse foliage and dead trees common. They may be being attacked by the Queensland long-horned beetle (*Acalolepta aesthetica*).
Citrus sp.		2 saplings seen in separate parts of south area, one with the leaf-pattern of *C. maxima*.
Coffea arabica L.	Coffee tree	2 dense patches seen in the forest understory.
Falcataria moluccana (Miq.) Barneby & J.W.Grimes	Albizia	A tree with 20cm trunk diameter reported in west corner. Will be eradicated.

Naturalized Plants

Scientific name	Common name(s)	Notes
Ficus microcarpa L.f.	Chinese banyan	Occasional young trees scattered in forest. This species, with its gigantic mature size and aggressively invasive nature, is likely to dominate the forest in the future if left unchecked.
Heliotropium foertherianum Diane & Hilger	Tree heliotrope	Common along the shore.
Macaranga mappa (L.) Müll.Arg.		Some young plants seen in east area of forest.
Macaranga tanarius (L.) Müll.Arg.		This tree has recently appeared in the area and is rapidly spreading. It has gained a foothold in the forest among the cecropia and melochia.
Mangifera indica L.	Mango	Numerous large, old mango trees grow throughout the forest, forming a major component of the canopy. The larger individuals commonly exceed 100cm diameter at breast height, dbh
Melochia umbellata (Houtt.) Stapf		Common but not dominating.
Persea americana Mill.	Avocado	Clusters of old and young trees in several places.
Pouteria caimito (Ruiz & Pavón) Radlkofer	Abiu	A young tree seen along the road where it presumably has been planted.
Psidium cattleianum Sabine	Waiawī, strawberry guava	In dense stands of large, old trees that often seemed to be enclosed within rock walls that may have been used as cattle paddocks in early post-contact times. A few of the plants seen may represent the common round red-fruited type, but no fruit was seen to confirm this.
Psidium guajava L.	Guava	Occasional.
Samanea saman (Jacq.) Merr.	Monkeypod	Several large trees scattered around the forest.
Schinus terebinthifolius Raddi	Christmas berry	Some shrubby plants seen near northwestern corner of forest.
Schefflera actinophylla (Endl.) Harms	Octopus tree	Not yet common.
Spathodea campanulata P.Beav.	African tulip tree	Not yet common.
Syzygium cumini (L.) Skeels	Java plum	A few trees along southwestern boundary.

Naturalized Plants

Scientific name	Common name(s)	Notes
Syzygium jambos (L.) Alston	Rose apple	Seedlings and young trees scattered, fairly common; mature trees seem to be absent.
Terminalia catappa L.	False kamani, Indian almond	Grove behind boulder beach at southeast corner and scattered somewhat inland from there.
Trema orientalis (L.) Blume	Gunpowder tree	Fairly common. Some large, old trees.

ANIMALS

Animals were not a focus of this study, but we did incidentally notice a few species. Undoubtedly more species occur. The Polynesian rat (*Rattus exulans*), the black rat (*Rattus rattus* L.) and the mouse (*Mus musculus* L.) are presumably present, but not encountered in our survey.

Scientific name	Common name(s)	Notes
Heteroscelus incanus	ʻŪlili	Few seen on shoreline rocks.
Cardinalis cardinalis	Cardinal	Seen along edge of hau thicket.
Carpodacus mexicanus	House finch	Flocks heard singing in treetops.
Streptopelia chinensis	Spotted dove	Heard in trees, small flock seen descending to ground in forest.
Eleutherodactylus coqui	Coqui frog	Heard during rain.
Sus scrofa	Pig	Common in the forest, seen on most Waiʻele expeditions. Trails, rooted-up ground, and wallows abundant.
Herpestes javanicus	Mongoose	Occasional.
Acalolepta aesthetica	Queensland longhorn beetle	Adults not seen but a large grub that we believe to be of this species was heard clicking and was dug out of a kukui tree. Exit holes and large frass were observed on trunks of several tree species.
Aedes albopictus	Forest day mosquito	Present but not overwhelming.
Wasmannia auropunctata	Little fire ant	These ants were noticed in a small area along the northwest boundary. Efforts are underway to eradicate them from this area. Unidentified black ants were widespread in the forest.

MOSSES

Wai‘ele provides a variety of micro-habitats ideal for mosses to thrive. A few are shown here. Moist plants are pictured. Most look quite different when dry.

A. Octoblepharum albidum Forms cushions on tree trunks.

B. Racopilum cuspidigerum Abundant on tree trunks, rocks, and debris on the ground. The most common moss in the forest.

C. Pyrrhobryam spiniforme Common on fallen debris on the ground or on lower tree trunks.

D. Calymperes tenerum On rocks and trees near the shore.

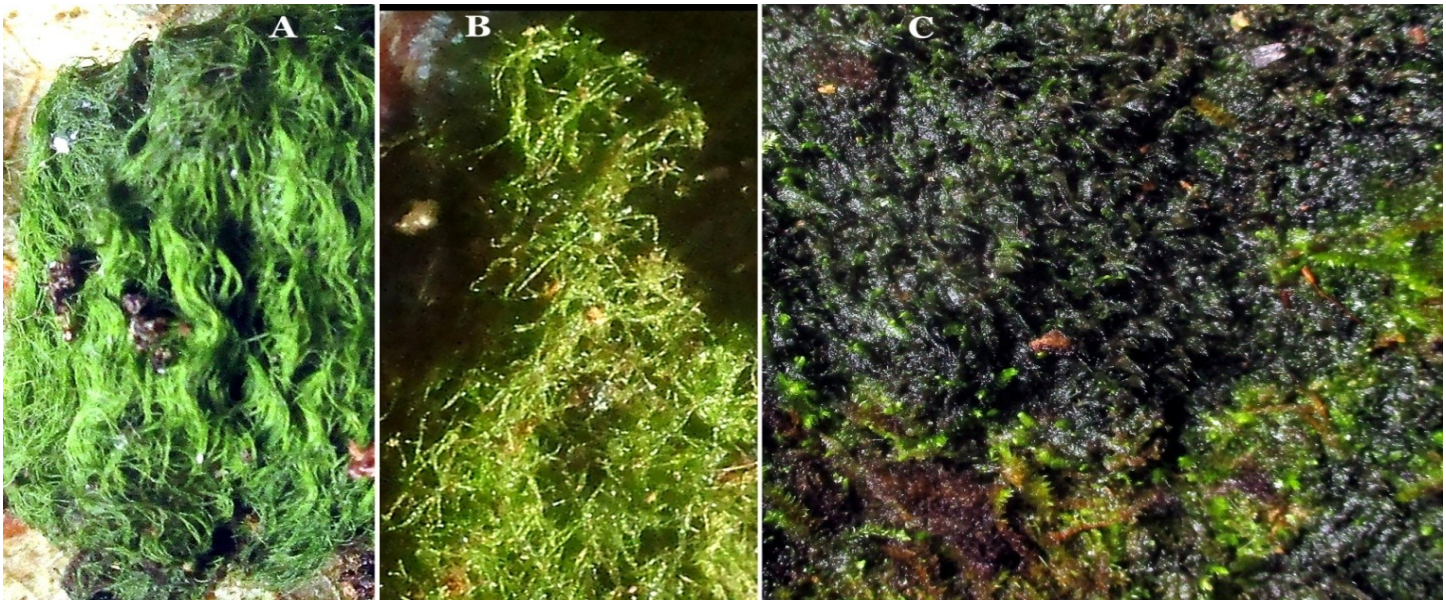
Unidentified mosses Additional moss species found on tree trunks and logs in the Wai‘ele forest. Scale in millimeters.

LIVERWORTS

Liverworts are abundant in the shady, moist forest zone. They grow among mosses and lichens on tree trunks, branches, rotting logs, and rocks. A few of the common species growing on tree trunks and logs are shown here.

A. Riccardia sp. Scale in millimeters.
B. Frullania sp.
C. Liverwort sp. a
D. Liverwort sp. b

A, B. Liverwort sp. c Differs from sp. a in having sprigs assurgent in tiers rather than appressed to substrate.
C. Liverwort sp. d Scale in millimeters.
D. Liverwort sp. e Scale in millimeters.

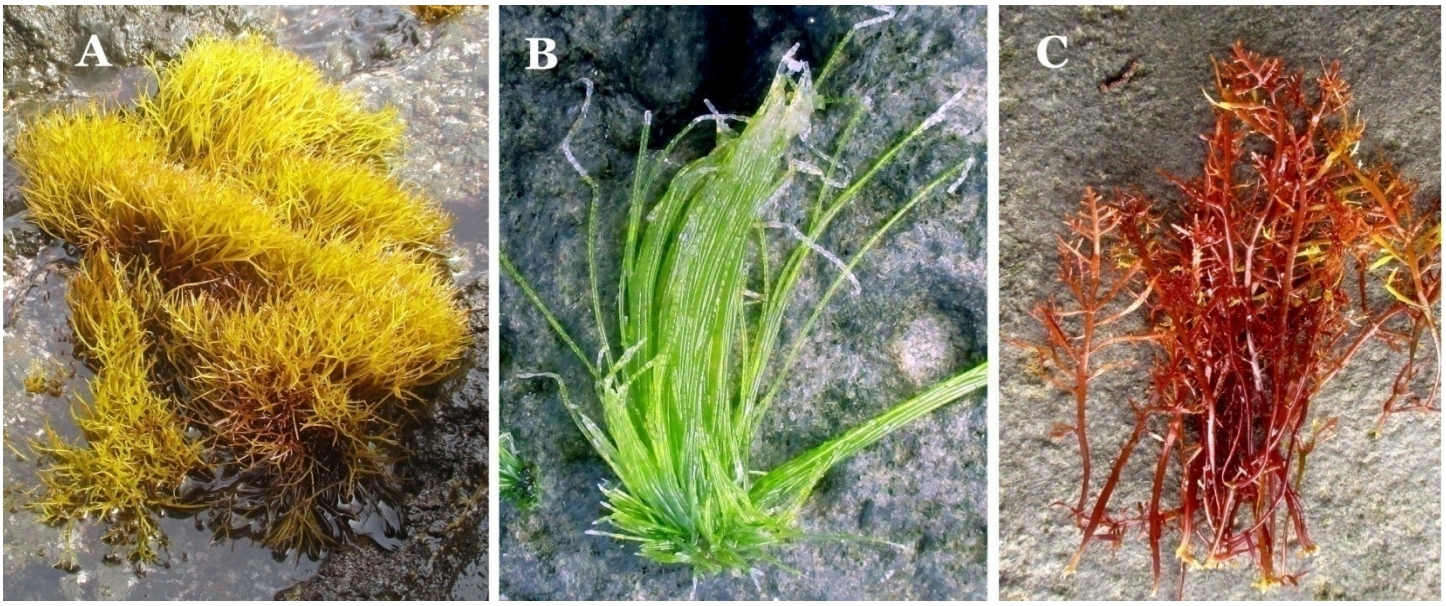


A, B. Chlorophyta sp. This terrestrial green alga grows on shaded shoreline rocks and wood in reach of salt spray. Magnified view shows strands consisting of single ± round cells joined end to end in chainlike filaments.

C. Nostoc sp. This cyanobacterium is overgrowing a mat of mosses and liverworts on a kukui trunk. Almost black wet, it acquires a dark blue-greenish color when dry.

MARINE ALGAE

Numerous species of algae grow in the intertidal zone along Wai‘ele's shoreline, despite being frequently scoured by high surf. These are a few of the more conspicuous species.



A. Ahnfeltiopsis concinna Limu ‘aki‘aki This yellowish limu dominates the upper intertidal zone and is abundant all along the coast.

B. Chaetomorpha antennina A limu of intertidal rocks exposed to strong surf.

C. Pterocladiella capillacea A common limu of the lower intertidal zone along exposed rocky shorelines.

LICHENS

Many kinds of lichens grow on trunks, branches, and rocks in the forest and along the shore. See supplement for more lichens.

A. Chrysothrix candelaris Occasional on bark or wood.

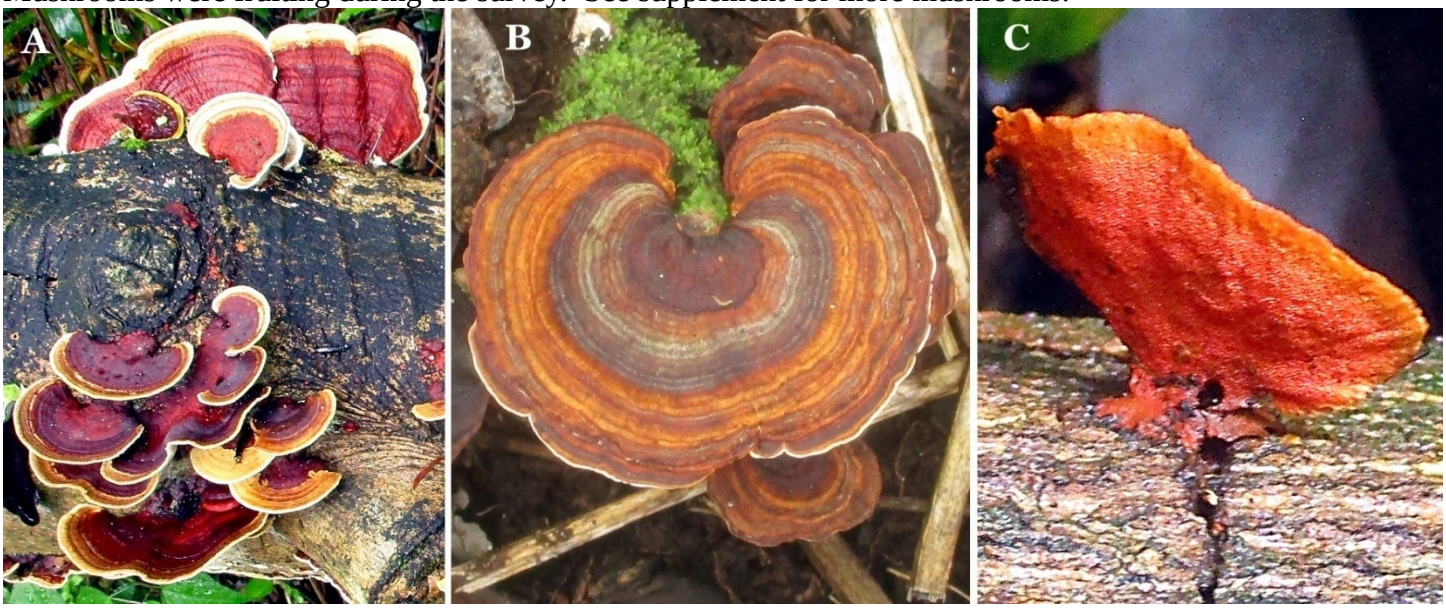
B. Coenogonium sp. a On tree trunks along the shore.

C. Coenogonium sp. b On tree trunks along the shore and within the forest. This cottony lichen can occur as isolated minute tufts or even single filaments, or may cover nearly the entire trunk of a tree.

D. Thelotrema lepadinum Recognized by the double-lipped, volcano-like perithecia. On trees, especially hala.

MUSHROOMS

Mushrooms were fruiting during the survey. See supplement for more mushrooms.



A. Earliella scabrosa Very common on kukui and mango logs, here seen on a cecropia log. (Wai‘ele 12-23).

B. Microporus flabelliformis Another common polypore on logs in the forest. (Wai‘ele 12-23).

C. Pycnoporus cinnabarinus This species can be abundant, but this small specimen was the only individual seen during the survey, (Wai‘ele 12-23).

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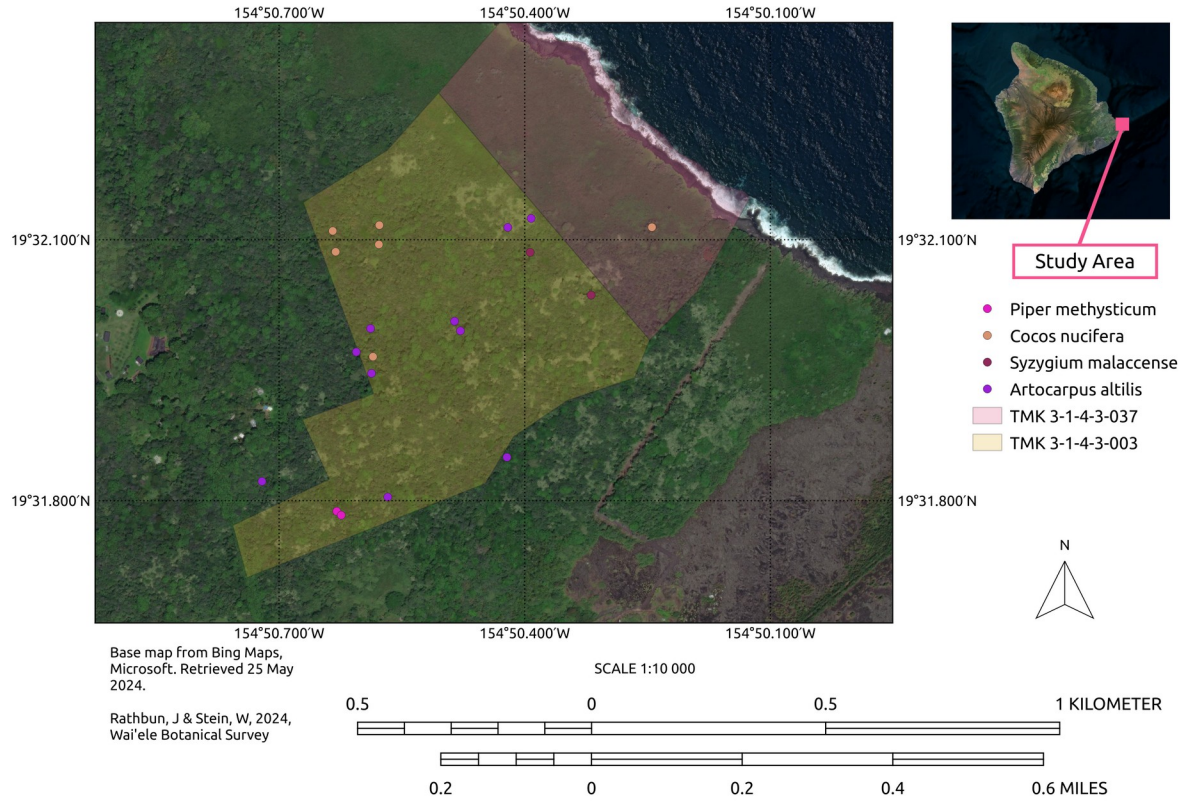
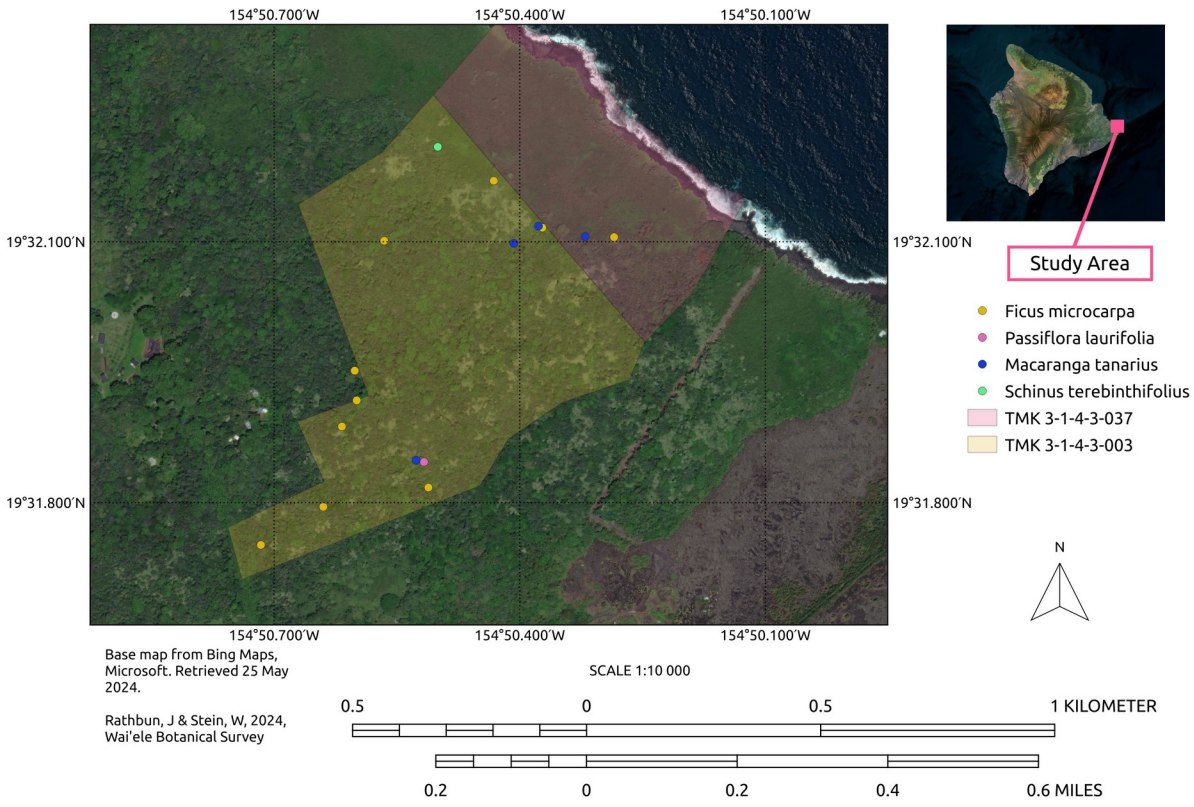


Figure 7: Top, Selected patches of notable size of Hawaiian crops. Bottom, target species for removal.



Species	Year of Introduction	Credited to	Citation
Psidium guavaja	1795	Don Franscisco de Paula Marin	Herbst & Staples 2005
Coffea arabica	1815[1] & 1825	Don Franscisco de Paula Marin & *HMS Blonde*	Herbst & Staples 2005
Syzygium jambos	1825	*HMS Blonde*	Herbst & Staples 2005
Psidium cattleianum	1825	*HMS Blonde*	Herbst & Staples 2005
Persea americana	1825	*HMS Blonde*	Herbst & Staples 2005
Mangifera indica	1825	*HMS Blonde*	Herbst & Staples 2005
Samanea saman	1847	Peter A. Brinsmade	Herbst & Staples 2005
Heliotropium foerthianum	1851		Herbst & Staples 2005
Terminalia catappa	1861[1]	Hillebrand	Herbst & Staples 2005
Trema orientalis	1870		Wagner *et al.* 1999
Syzygium cumini	1870		Herbst & Staples 2005
Melochia umbellata	1871	Hillebrand	Wagner *et al.* 1999
Schefflera actinophylla	1900		Wagner *et al.* 1999
Schinus terebinthifolius	1911		Wagner *et al.* 1999
Falcataria moluccana	1917	J. F. Rock	Herbst & Staples 2005
Cecropia obtusifolia	1926		Wagner *et al.* 1999
Macaranga mappa	1927		Wagner *et al.* 1999
Macaranga tanarius	1930		Wagner *et al.* 1999
Ficus microcarpa	1935[1]	Sugar Planters Association	Herbst & Staples 2005
Calliandra houstoniana[2]	2008		Imada 2019
Artocarpus heterophyllus[2]	2012		Imada 2019
Mean Year of Intro.	1883		

Table 2: Selected naturalized tree taxa and their dates of import/naturalization to the Hawaiian Islands. The HMS Blonde was sent as a diplomatic mission sent from Britain to return Kamehameha II's body to the Hawaiian Islands. Aboard, James Macrae, ship botanist, imported a variety of plants on behalf of the Horticultural Society of London. The mean year of introduction shows the relative antiquity of Wai'ele's naturalized species.

[1]*These entries represent the mean of the conjectured dates.*

[2]*These dates reflect only the publishing of confirmation of naturalization status. These taxa may have been reproducing on their own in the wild for some years prior.*