



TECHNICAL REPORT HCSU-006

**RAPID ASSESSMENT OF VEGETATION
AT
SIX POTENTIAL 'ALALĀ
RELEASE SITES
ON
THE ISLAND OF HAWAI'I**

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ABSTRACT

The U.S Fish and Wildlife Service (FWS), as part of its participation in the effort to recover the endangered 'Alalā (*Corvus hawaiiensis*), is supporting efforts by the 'Alalā Recovery Team (ART) to rank areas for suitability as reintroduction sites for this species. A part of this ranking exercise is determination of the current state of the vegetation present at the sites. Although some of these sites have been surveyed using various methods in the recent past, specific, comparable measurements of key aspects of the plant communities are needed for ranking sites for 'Alalā recovery.

Here we summarize new and compiled data for each of the release sites that address the current status and potential recovery of the tree canopy and understory vegetation relative to potential suitability for 'Alalā release. This project focused on two objectives: 1) Assess the current status and distribution of forest canopy cover based on an analysis of recent satellite imagery and other spatial datasets, and 2) Collect new field data from the six potential release sites to provide quantitative information on the status of the vegetation, with particular focus on density and species composition of plants used by 'Alalā as food, overall density of forest understory, and degree of closure of tree canopy. The field data also served as ground-truth points for the spatial analysis.

The methods of assessing habitat potential for 'Alalā recovery presented here represent a simple measure of vegetation attributes taken from a limited number of plots within each study area. A primary problem is in attempting to summarize large study areas that incorporate considerable variation in climate, substrate, and land use history.

An examination of several versions of the preferred food species richness value ranks the two Ka'ū study sites first and second. This study does not consider the amount of fruit produced by different species, and therefore it is possible that some additional weighting of preferred food plants might better quantify food resource availability in different landscapes. We also assessed continuity of forest units with other similar habitats outside the study areas, the amount of site disturbance as indicated by percent cover by alien grass species, as well as several other combinations of variables that may help in ranking the sites.

INTRODUCTION

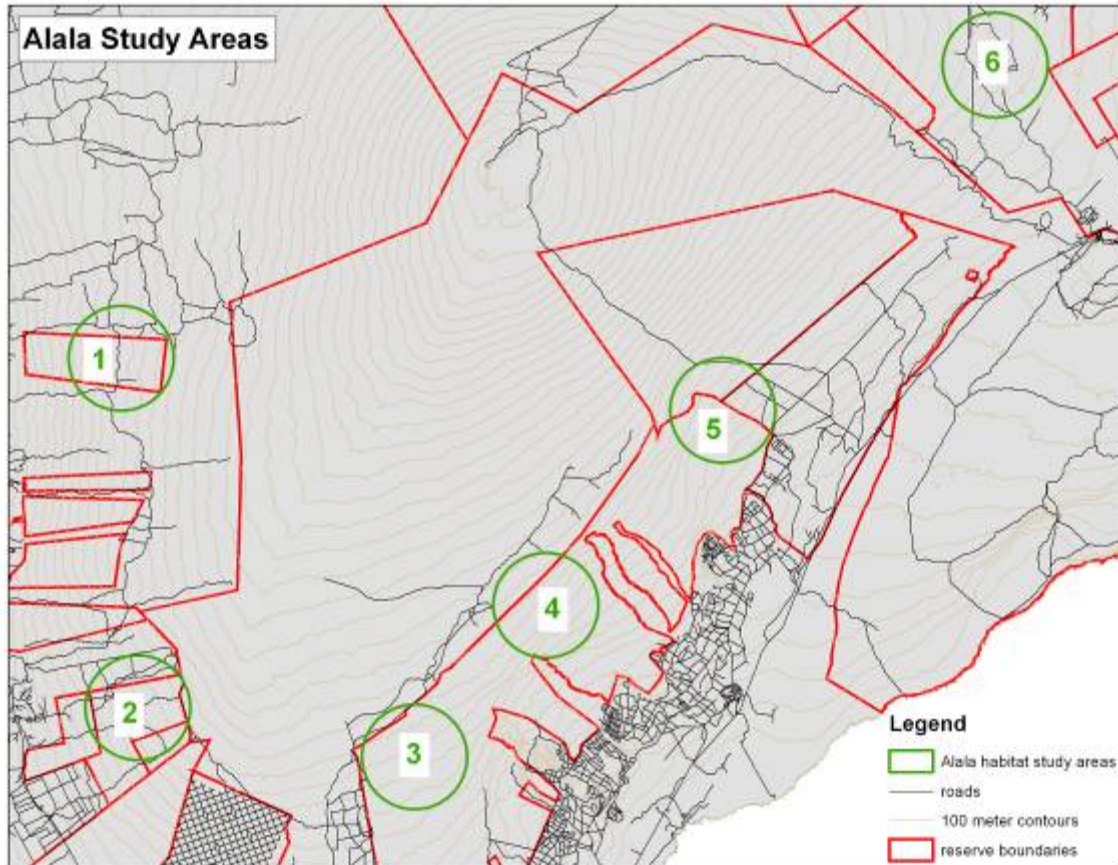
The U.S Fish and Wildlife Service (FWS), as part of its participation in the effort to recover the endangered 'Alalā (*Corvus hawaiiensis*), is supporting efforts by the 'Alalā Recovery Team (ART) to rank areas for suitability as reintroduction sites for this species. A part of this ranking exercise is determination of the current state of the vegetation present at the sites. Although some of these sites have been surveyed using various methods in the recent past, specific, comparable measurements of key aspects of the plant communities are needed for ranking sites for 'Alalā recovery. Therefore, the Service has supported this rapid assessment of the vegetation at six sites on the island of Hawai'i that have been identified by the ART as of high interest for future 'Alalā reintroductions (Figure 1).

Here we summarize new and compiled data for each of the release sites that address the current status and potential recovery of the tree canopy and understory vegetation relative to potential suitability for 'Alalā release. This project focused on two objectives: 1) Assess the current status and distribution of forest canopy cover based on an analysis of recent satellite imagery and other spatial datasets, and 2) collect new field data from the six potential release sites to provide quantitative information on the status of the vegetation, with particular focus on density and species composition of plants used by 'Alalā as food, overall density of forest understory, and degree of closure of tree canopy. The field data also served as ground-truth points for the spatial analysis.

Study Sites

Vegetation assessments were conducted in six study areas on the southern side of the island of Hawai'i (Figure 1). These sites were selected by the ART based on documented historic range of the 'Alalā, presence of appropriate habitat, and local expertise.

Figure 1. Vegetation assessment study areas.



Six potential 'Alalā release sites were identified to be surveyed:

1. Kona Forest Unit: Kona Forest Unit of Hakalau Forest National Wildlife Refuge and adjacent private lands.
2. Kona Hema: Kona Hema Preserve and the Honomāline Section of the South Kona Forest Reserve.
3. Southwest Ka`ū: Southern portion of the Ka`ū Forest Reserve and portions of the Kahuku section of Hawai'i Volcanoes National Park.
4. Central Ka`ū: Central portion of the Ka`ū Forest Reserve northeast of the 1950 lava flow.
5. Kapāpala: Northern portion of the Ka`ū Forest Reserve and portions of the Kapāpala Ranch and Kapāpala Forest Reserve
6. Keauhou-Kūlani: Portions of Keauhou Ranch, Kīlauea Forest, and Kūlani Correctional Facility

METHODS

Locating Sampling Plots

The center of interest within each study area was defined as circular area 6 km in diameter in order to quantitatively compare different sites. This area approximates the area used by previously released cohorts of `Alalā. However, the study areas delimited here do not represent the only potential habitat in the area nor do they represent the most likely distribution of birds upon release. These circular regions simply represent a standardized spatial basis for direct comparison among study areas.

In order to sample within each of the six study regions as extensively as was feasible within time constraints, numerous plots were located in different areas representing variation in forest structure and food resource availability. Four one-day scoping trips were made to Kona Hema and the three Ka`ū study areas in order to determine road access, to examine the degree of movement possible in different types of forest, and to finalize data sampling methods. Several assumptions were based on observations from these trips. First, we estimated that an individual plot data collection would take up to 30 minutes (see section on data sampling). We also were able to estimate transit time in dense forest during the scoping trips by considering the distance traveled (as measured by GPS) in a measured amount of time. Considering a desired spacing of 500 m between study plots (in order to maximize coverage within the study area), we estimated the number of plots that can be sampled in a single day by one two-person team under different conditions (Table 1).

Table 1. Estimated number of plots that could be sampled per day.

	Estimated average speed	Transit Time Between Plots	Total time per plot (transit plus 30 minutes data collection)	Minimum number of plots per 8 hr. day
Driving and walking 100 m off road, or walking along trail or fenceline	3 km/hr	15 min	45 min	11
Walking in dense vegetation with day pack	1 km/hr	30 min	1 hr	8

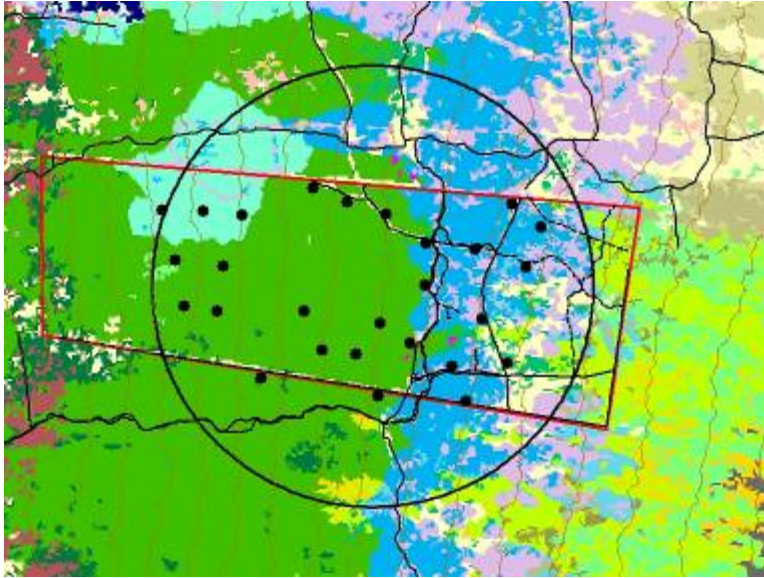
Using these assumptions and examining the availability of roads, trails and fencelines in each study area, we estimated the number of plots feasible within the time available for field work. By maximizing use of roads and trails, and by allocating more field days to those study areas requiring more time (particularly the two Kahuku-Ka'ū areas), we estimated that 30 plots could be sampled in each of the six focal areas within the allotted time. Study plots were placed according to several criteria: 1) only accessible units (not private land areas), 2) only areas broadly covered with forest vegetation (e.g. not lava flows or pasture), 3) spaced at least 500 m apart, 4) spread across different vegetation units according to the Hawaii GAP Analysis (HIGAP) landcover map (Gon 2006), Jacobi's (1989) vegetation map, and an unpublished vegetation map of the Ka'ū area by Marcos Gorresen (USGS-BRD), 5) spread across different elevations, and 6) spread across different substrate ages (where necessary) based on the geologic map by Wolfe and Morris (1996).

Most plots were located on the ground by field crews navigating to pre-programmed coordinates using GPS. In a few instances where a GPS signal was not available, plot locations were approximated using points generated in GIS and printed on detailed maps. For many day-long and part-day transects, a triangular configuration was used to maximize the spread of the sample plots yet minimize the number of directional changes (only two). Other transects followed fencelines, stream courses or other features in order to speed movement. Plots were generally taken as close as possible to the predetermined point, however in some cases they were moved slightly in order to avoid locally anomalous vegetation. While overnight transects were originally proposed for the Southwest Ka'ū and Central Ka'ū sites, day transects were determined to be better due to logistical restraints and easier movement with a daypack through dense vegetation. We were able to sample nearly 30 plots in each study area for a total of ~180 plots.

Figure 2. Maps of plots recorded in each study area.

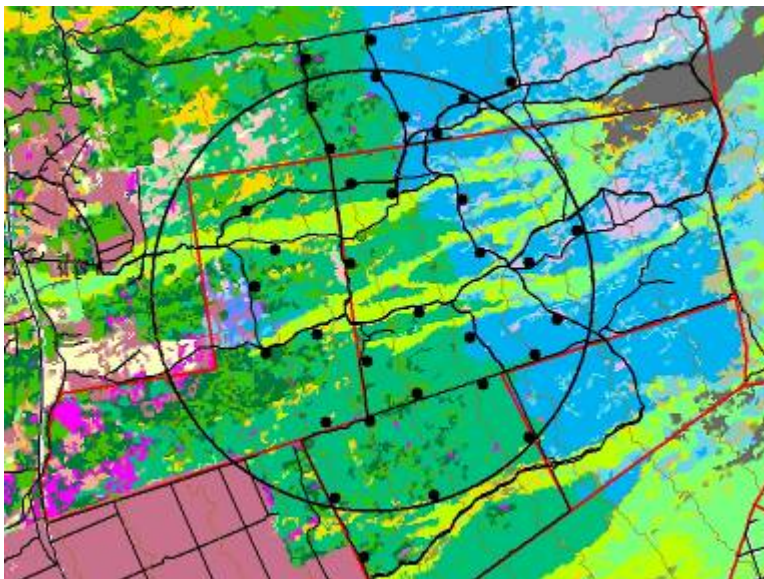
Study areas are shown as black circular boundaries (refer to Figure 1 for relative locations). Study plot locations (most taken using GPS) are shown as black dots. The HIGAP land cover map is shown as a background to demonstrate that plots are located in different forest types. 100 m contours are shown as brown lines. Roads are shown as solid black lines. Thick red lines indicate boundaries of major conservation units.

Study Area 1 – Kona Forest Unit



Study plots were distributed near roads, which are spread throughout the refuge, as well as in three part-day transects.

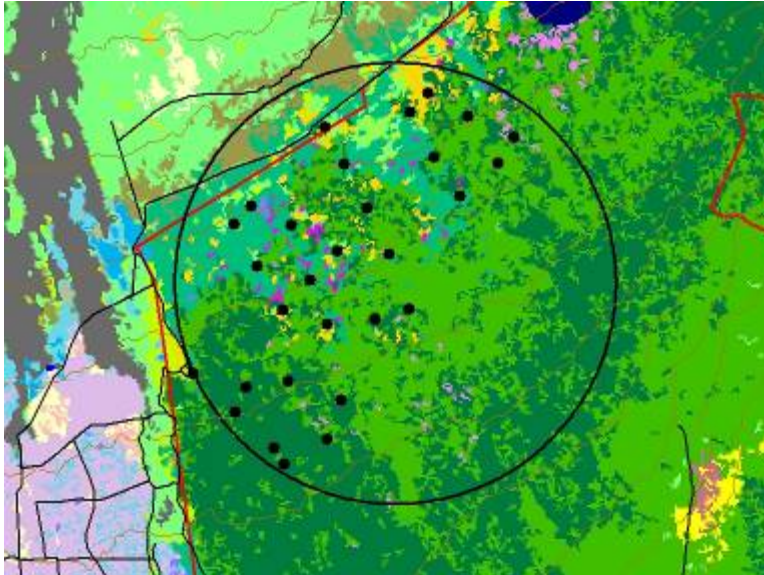
Study Area 2 – Kona Hema Preserve



Study plots were distributed near roads which are spread throughout the preserve and the neighboring Honomāline tract of State land. Three supplemental plots (outside the main study area) were taken in the northern portion of the Pāpā Unit and one taken in the southern portion of the Kapua Unit.

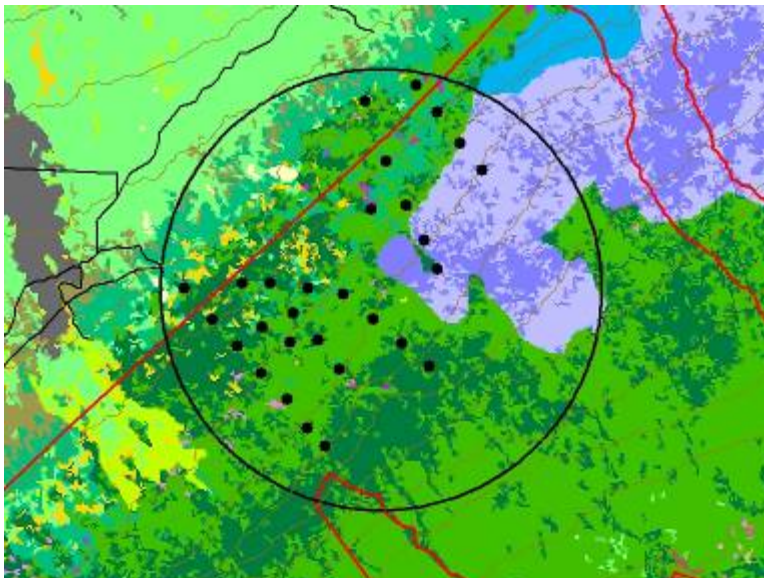
Figure 2 (Continued). Maps of plots recorded in each study area.

Study Area 3 – Southwest Ka'ū



Road access in this area is limited and so all plots were accessed by foot. This involved several day-long transects.

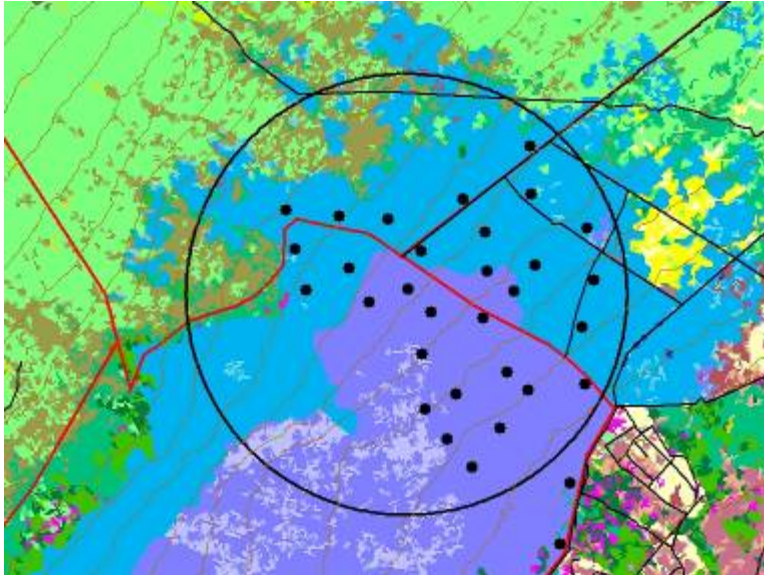
Study Area 4 – Central Ka'ū



Road access in this area is limited and so all plots were accessed by foot. This involved several day-long transects.

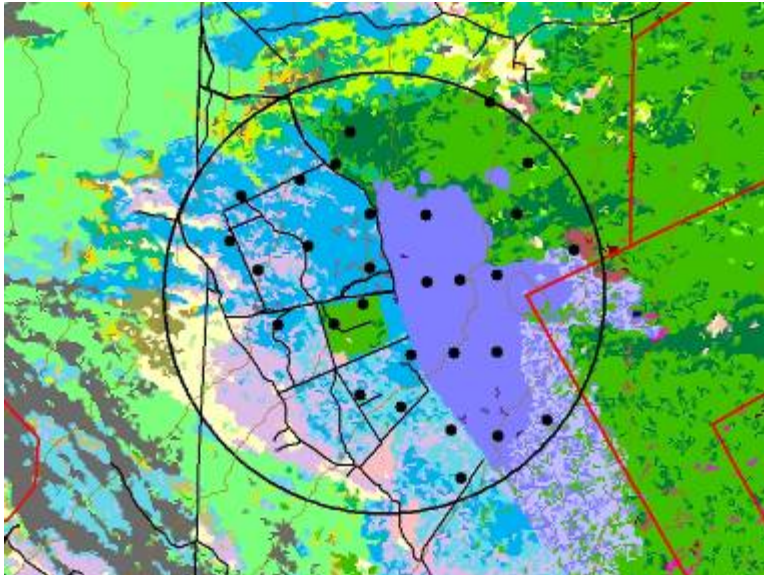
Figure 2 (Continued). Maps of plots recorded in each study area.

Study Area 5 – Kapāpala



Road access in this area is good in the eastern portion and many plots were located near roads. In the upper elevations and southern part of the study area, plots were accessed by foot via several day-long transects.

Study Area 6 – Keauhou-Kūlani



Study plots are mostly distributed near roads spread throughout the area. In the eastern portion of the study area there are easily walkable fencelines and existing marked transects along which plots were be located. In less accessible areas, plots were accessed on part-day transects.

Data Collection

Sampling was designed to quantify several characteristics of vegetation important for Alalā recovery. A team of two field workers visually assessed key aspects of vegetation within a 25 m radius of the center of a given sampling plot, representing an area of approximately 2000 m² or 0.2 hectares. After walking around the plot, team members discussed their observations and agreed on estimates of different sampling variables, then recorded the data either in a field notebook or in a pre-programmed personal digital assistant (PDA) with appropriate fields for the data and drop down menus. Prior to beginning sampling, teams gathered and standardized estimation values for three different plots to ensure that different teams generate similar estimates for each type of data. Generally, data were congruent among teams. Field workers also changed pairings throughout the study, which ensured some degree of homogenization in data perception.

Canopy Structure

Canopy structure was summarized for each of five vegetation layers: a primary tree layer, a secondary tree layer, a tree fern layer, a shrub layer, and a ground layer (Table 2). For each layer the prominent species (the one or two species making up the largest amount of cover within that layer) were noted, and the total combined cover of all species in the layer was estimated. Cover estimates were recorded in cover classes, or ranges of percentages (Table 3). Estimates were made by both team members walking the plot area, then agreeing on the appropriate cover class. A rough conversion of square meters to percent cover could be calculated from an estimate of 2,000 m² for the whole study plot (for example, 1% cover equals 20 m² [this is the area of a circle with a 5 m diameter], 10% cover equals 200 m², 50% cover equals 1,000 m², etc.) to aid in determining the appropriate cover class. Since many food species had relatively low amounts of cover, approximations were made within narrowly-defined cover classes with low amounts of cover; higher amounts of cover were estimated to ranges in 10 percent intervals.

Table 2. Tree layer height classes.

Height Class	Height Range (m)
1	3-5
2	5-10
3	10-25
4	>25

Table 3. Classes used to record species cover.

Cover Class	Cover Range (%)
1	>1
2	1-5
3	5-10
4	10-20
5	20-30
6	30-40
7	40-50
8	50-60
9	60-70
10	70-80
11	80-90
12	90-100

The tree fern layer was predefined as the layer in which tree ferns (any of three *Cibotium* species and occasionally large *Sadleria* species) of a relatively consistent height range occur. This was typically height class 1 or sometimes 2, but was always considered separate from the secondary tree layer. The shrub layer was predefined as consisting of woody plants 1 to 3 m, and the ground layer was predefined as consisting of herbaceous plants and woody seedlings less than 1 m. In addition to height, the approximate range of trunk diameters and the modal trunk size were estimated for trees

in the primary tree layer (e.g. "10 – 50 – 100" indicates a median size of 50 cm with a range of 10-100 cm). Below is a table with sample structural summary data (Table 4).

Table 4. Example of species structural data for a sample plot.

	Prominent Species	Height Class	Trunk Diameter (cm)	Combined Cover %
Tree 1	MetPol/AcaKoa	3	10-50-100	90-100
Tree 2	<i>Psychotria hawaiiensis</i>	2	-	20-30
Tree Fern	<i>Cibotium</i> spp.	1	-	50-60
Shrub	<i>Rubus hawaiiensis</i>	-	-	20-30
Ground	Native Ferns	-	-	50-60

Food Resources

Separate from the general structure of the community, the abundance of important fruit-bearing food resources was recorded (Table 5). In most cases these were recorded at the species level, however in some cases species level determination was not possible (when diagnostic fruit or flowers were absent), and therefore information was taken at the level of genus. For each species either known to have been an important food resource (Sakai and Carpenter 1990; Sakai et al. 1986; Banko and Banko, in review) or known to have fleshy fruits that may be consumed by birds (Price, unpub. data), the percent cover was estimated. In addition, non-native species such as Common Guava (*Psidium guajava*) that were potential fruit resources were also considered. The primary layer in which a species occurred was noted, in addition to any other layers in which the species notably occurred. For example numerous seedlings of the tree *Psychotria hawaiiensis* were recorded as "G", although most cover was in the "2" tree height class.

Table 5. Sample data of cover estimates of food resources for a single plot.

Layer	Food Species	Cover %
2, G	<i>Psychotria hawaiiensis</i>	10-20
1, S	<i>Ilex anomala</i>	1-5
S	<i>Coprosma</i> spp.	5-10
S	<i>Rubus hawaiiensis</i>	10-20
S	<i>Clermontia clermontoides</i>	<<1
G	<i>Cyanea floribunda</i>	<<1

In addition to quantitative data taken in plots, supplementary data were taken along transects and roadsides while traveling between plots. This took the form of recording all food resource plant species encountered, notes indicating the locations of apparent changes in forest structure and composition, and incidences of notable populations of important food resource plants.

Analysis of Plot Data

Plot data were summarized in several ways to characterize vegetation units and compare study areas. Whereas many data were collected and can be analyzed in numerous ways, we selected three measures of habitat quality that capture different aspects of vegetation.

Tree Canopy Cover

To define the amount of canopy cover potentially capable of shielding 'Alalā from predation by 'Io (*Buteo solitarius*), we summarized the amount of canopy cover above 10 m. In most cases, the tallest cover class was 10-25 m, and so we simply used the cover estimate within that class. In some cases, the tallest cover class was >25 m, which sometimes had a second canopy layer that was 10-25 m. We added canopy cover values together whenever there was more than one tree layer above 10 m. This somewhat exaggerates the cover in these situations (it could add up to more than 100 %) but it placed a higher value on those plots with two tall tree layers. We then ranked all 180 plots for all study areas from lowest to highest percent canopy cover and scaled them linearly so that the plot with the least canopy cover had a score of 0 and the plot with the most canopy cover had a score of 100.

Food Species Richness

Due to the potential importance of having a variety of food species that are available at different times of year and offer a varied diet, we counted the total number of food species in each plot. This included species that were quite infrequent, and which were not considered as important food resources because they were not necessarily abundant in the landscape. This also included non-native species such as Common Guava, which also can be utilized by Alalā. We then ranked all 180 plots from all study areas from fewest to most food species and scaled them linearly so that the plot with the fewest food species had a score of 0 and the plot with the most food species had a score of 100.

Cover of Preferred Food Species

Many food species have been observed as being important components of the diet of 'Alalā (Sakai and Carpenter 1990; Sakai et al. 1986; Banko and Banko, in review). In consultation with Paul Banko (U.S. Geological Survey, PIERC), we identified among species we encountered those likely to be preferred food for 'Alalā. These are species that are considered to be favored behaviorally, nutritionally rich, or bear abundant amounts of fruit per plant. These included: *Cheirodendron trigynum*, *Clermontia* spp., *Coprosma* spp. (except for *Coprosma ernodioides*), *Freycinetia arborea*, *Ilex anomala*, *Styphelia tameiameia*, *Melicope* spp., *Myrsine* spp., *Nothoestrum longifolium*, *Pipturus albidus*, *Pittosporum* spp., *Psychotria hawaiiensis*, *Rubus hawaiiensis*, *Vaccinium* spp. The estimated cover of all preferred food species found within a plot was summed. We then ranked all 180 plots from all study areas from least to greatest percent cover of preferred food species and scaled them linearly so that the plot with the least preferred food species cover had a score of 0 and the plot with the most preferred food species cover had a score of 100.

RESULTS

Demarcation of Vegetation Units

Vegetation plots from different areas were grouped in order to summarize the characteristics of a given vegetation type. In most cases plots in a specific area had similar characteristics, however in some cases they were grouped in order to reflect

average conditions within heterogeneous vegetation. Each study area was subdivided into several vegetation units using available GIS layers. Several *a priori* rules were applied in order to more objectively subdivide each study area into vegetation units. First, areas that were clearly unsuitable habitat, particularly non-forested areas such as barren lava flows, large expanses of pasture, and developed areas, were grouped together as "non-habitat" units within each study area. This was done primarily using the HIGAP land cover map which is a 30 meter grid based on LandSat imagery, and includes about 40 land cover classes. In general non-forested areas were accurately mapped by HIGAP. Next, areas with Koa (*Acacia koa*) as a major canopy component were selected out of the HIGAP land cover. While Koa can not be explicitly mapped using LandSat, maps by Jacobi (1989) were incorporated into the HIGAP land cover and accurately depict where Koa is a canopy component, as verified by our field work for this study. Remaining cover classes, primarily 'Ōhi'a (*Metrosideros polymorpha*) forest, but also some alien-dominated forest classes and undifferentiated forest classes, were further subdivided according to some spatially definable criteria that logically grouped similar vegetation plots. Criteria for this subdivision include: 1) areas with different management histories, 2) different elevations, especially where climatic moisture varied strongly with elevation, 3) areas with distinct geologic substrates, and 4) areas where all vegetation plots consistently shared some unique characteristic. Vegetation units were selected so as to represent a somewhat large area (no less than 1 square kilometer) and to be represented by enough vegetation plots (at least 3) so that characteristics attributed to the unit are based on multiple data points. Characteristics of vegetation units are summarized in the tables and maps of Figure 3.

Figure 3. Vegetation units identified for each of the six study areas.

Circular study areas are subdivided into vegetation units (refer to Figure 1 for relative locations). Each table and accompanying map defines the vegetation units demarcated for each study area.

Kona Forest Unit

Vegetation Unit	Unit Characteristics	Color on Map	Area (km ²)	No. plots
Non-Habitat	Open pasture in upper elevations	Red	2.6	-
Upper Koa-Ōhi'a Forest	Uppermost forest in area; understory often with much alien grass	Blue	9.8	10
Ōhi'a Forest with Native Tree Understory	Ōhi'a dominated forest across the middle elevation portion of the study area above 1200 m	Light Green	9.0	9
Ōhi'a Forest with Mixed Understory	Plots below 1200 m generally contain some degree of woody invasive species	Dark Green	4.9	5
Lower Koa-Ōhi'a with Uluhe (Dicranopteris linearis))	Distinctive area with open canopy and sparsely distributed small Koa and understory with Uluhe	Brown	1.9	3

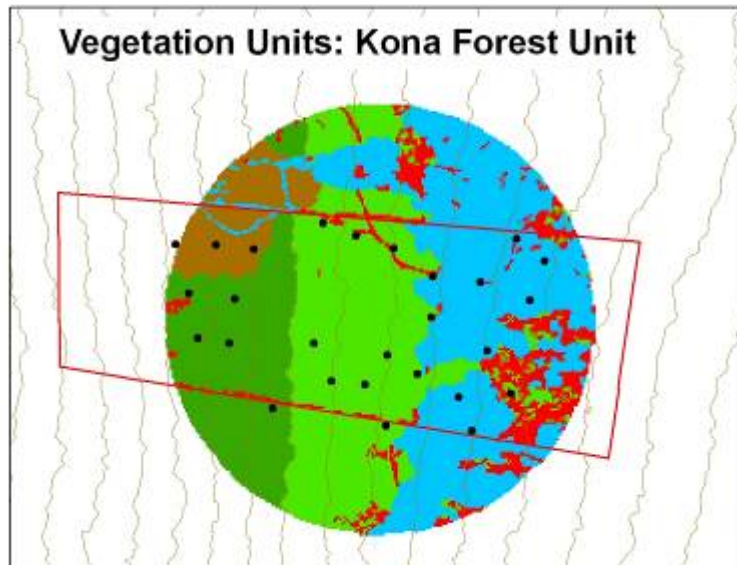


Figure 3 (Continued). Vegetation units identified for each of the six study areas.

Kona Hema Preserve

Vegetation Unit	Unit Characteristics	Color on Map	Area (km ²)	No. plots
Non-Habitat	Lava flows dissecting central area; open pasture in upper elevations and somewhat in lowest elevations within Honomāline Tract	Red	5.1	-
Upper Koa-ʻŌhiʻa Forest	Uppermost forest in area; understory often alien grass	Blue	5.9	10
ʻŌhiʻa Forest with Rich Understory	Small but well defined area in Pāpā tract with high species richness and dense cover	Dark Green	1.6	7
ʻŌhiʻa Forest with Dense Tree Fern	ʻŌhiʻa dominated forest across most of the lower portion of the study area with dense tree fern understory	Light Green	8.2	10
Mixed Lower Forest	Area is highly heterogeneous, but forest generally with considerable non-native composition	Brown	7.4	5

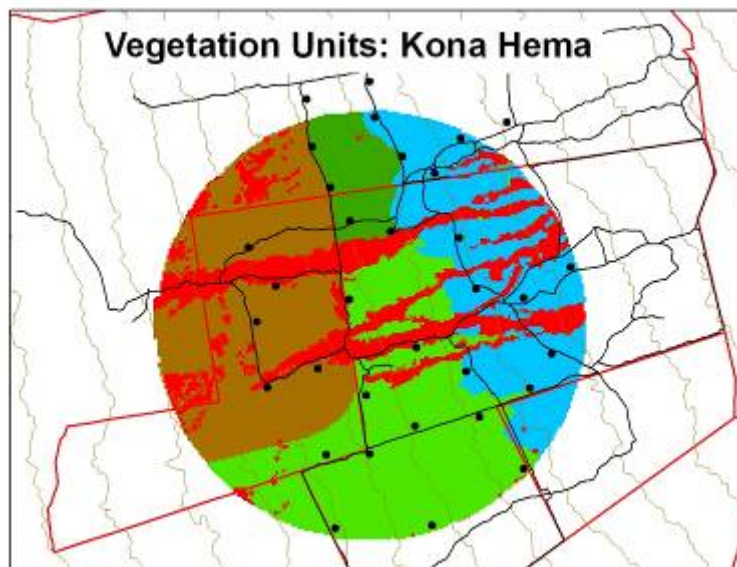


Figure 3 (Continued). Vegetation units identified for each of the six study areas.

Southwest Ka`ū

Vegetation Unit	Unit Characteristics	Color on Map	Area (km ²)	No. plots
Non-habitat	Shrublands and lava flows in upper elevations; some open pasture near upper road	Red	1.3	-
`Ōhi`a Forest with Dense Understory	Uppermost forest in area; understory trees and shrubs dense	Dark Green	6.2	10
`Ōhi`a Forest with Intermediate Understory	Middle forest zone with intermediate density understory; between 1440 m and 1550 m	Light Green	8.0	10
`Ōhi`a Forest with Dense Tree Fern Layer	`Ōhi`a dominated forest in lower portion of study area below 1440 m; forest type appears to continue east of area of field work	Brown	12.7	9

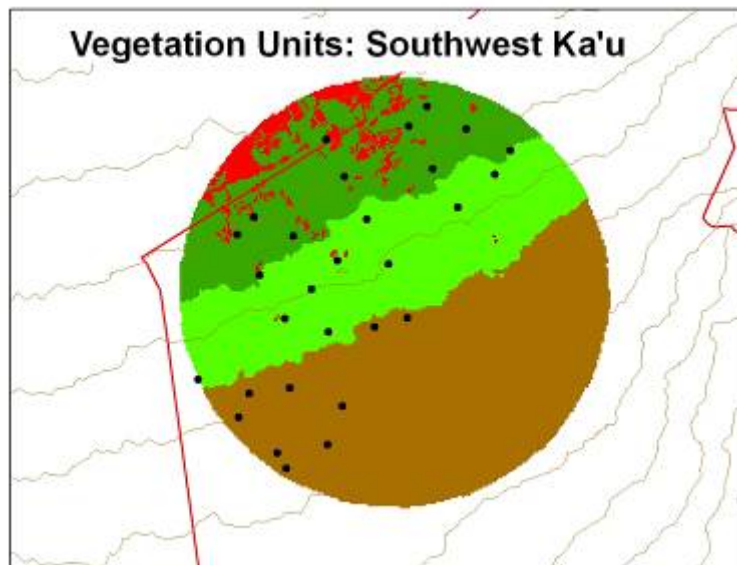


Figure 3 (Continued). Vegetation units identified for each of the six study areas.

Central Ka`ū

Vegetation Unit	Unit Characteristics	Color on Map	Area (km ²)	No. plots
Non-Habitat	Shrublands and lava flows in upper elevations; some open pasture near upper road	Red	1.6	-
Koa-`Ōhi`a Forest	Koa forest in lower eastern side of study area; area is wet with an older substrate than elsewhere	Blue	5.6	4
Upper (Mesic) `Ōhi`a Forest	`Ōhi`a dominated forest above 1740 m elevation across whole study area	Dark Green	7.9	12
`Ōhi`a Forest with Dense Broussaisia	Forest belt with more open canopy and shrub layer of Broussaisia; between 1620 m and 1740 m	Light Green	3.8	7
Open/Stunted `Ōhi`a Forest with Uluhe	Open/stunted `Ōhi`a forest below 1620 m with uluhe understory; forest type appears to continue beyond area of field work	Brown	9.3	7

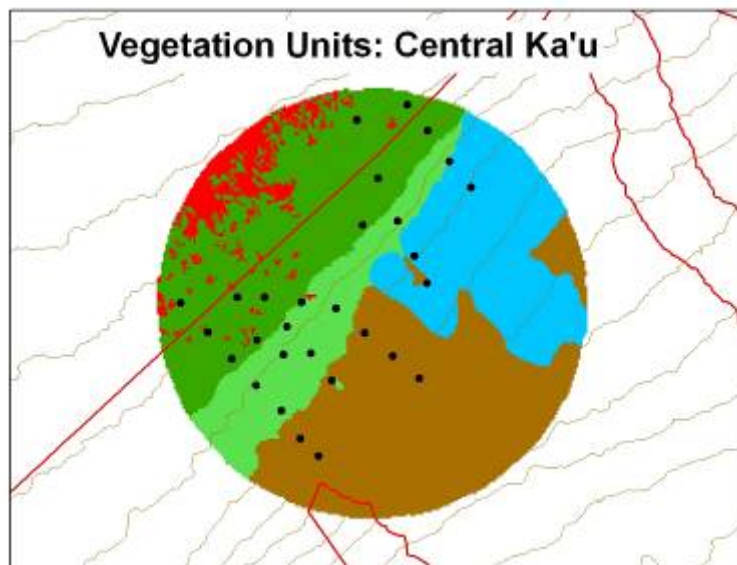


Figure 3 (Continued). Vegetation units identified for each of the six study areas.

Kapāpala

Vegetation Unit	Unit Characteristics	Color on Map	Area (km ²)	No. plots
Non-Habitat	Shrublands in upper elevations; some open pasture at eastern end of Koa Management Unit	Red	2.9	-
Kapāpala Upper (Mesic) Forest	Koa-ʻŌhiʻa dominated forest above the Koa Management Unit and above the wetter forests of Ka`ū Forest Reserve	Light Green	10.0	8
Ka`ū (Wet) Forest	Koa-ʻŌhiʻa dominated forest West of the Koa Management Unit	Dark Green	9.8	13
Koa Management Unit	Koa-ʻŌhiʻa forests within the Koa Management Unit	Blue	5.5	9

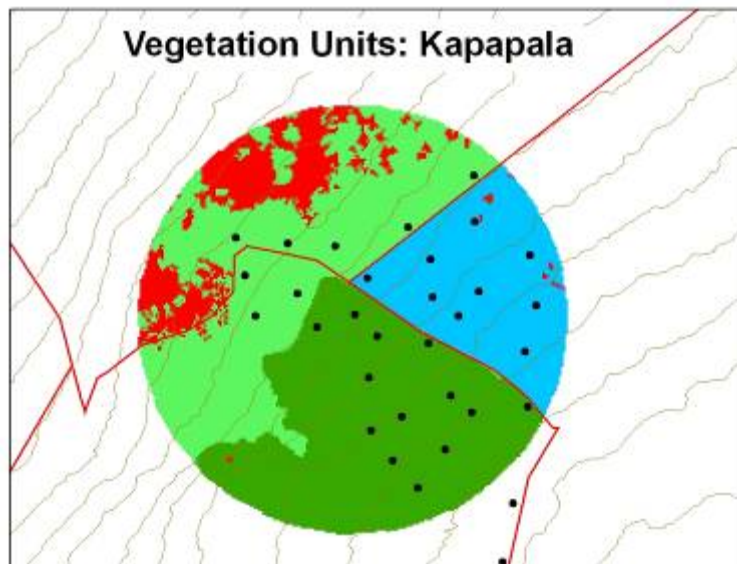
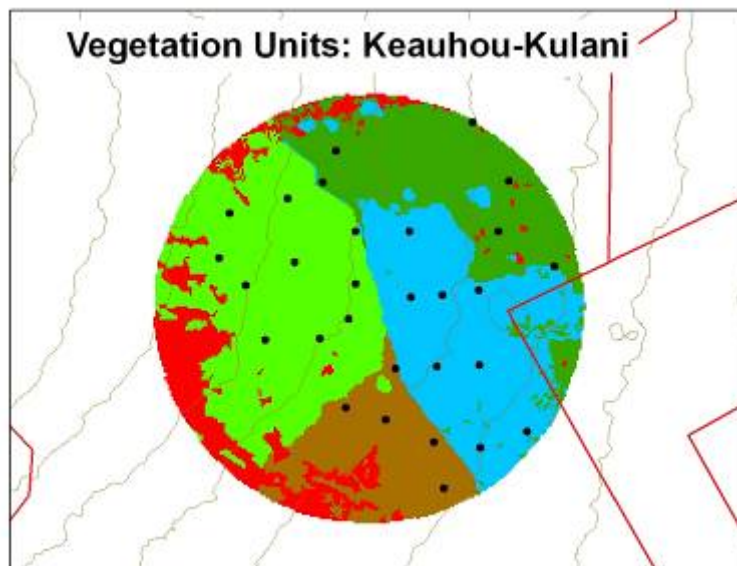


Figure 3 (Continued). Vegetation units identified for each of the six study areas.

Keauhou-Kūlani

Vegetation Unit	Unit Characteristics	Color on Map	Area (km ²)	No. plots
Non-Habitat	Young Lava Flows in north of study area; pasture areas in Western part of Keauhou Ranch	Red	3.1	-
Koa-‘Ōhi‘a Forest	Koa-‘Ōhi‘a dominated forest mostly within the Kīlauea Forest Unit	Blue	5.7	9
Kūlani ‘Ōhi‘a Forest	‘Ōhi‘a dominated forest in the Kūlani Area	Dark Green	7.1	5
Upper Keauhou Ranch	‘Ōhi‘a and Koa-‘Ōhi‘a forests within Keauhou Ranch above 1650 m elevation	Light Green	8.9	10
Lower Keauhou Ranch	‘Ōhi‘a and Koa-‘Ōhi‘a forests within Keauhou Ranch below 1650 m elevation	Brown	3.4	5



Summarizing Vegetation Units from Plot Data

The varying area of different vegetation units was used to weight how extensive a given set of vegetation characteristics was found to be. In addition to the three calculated value scores for major vegetation characteristics (canopy cover, food species richness, preferred food cover), a composite score was calculated by adding the three different scores together. This composite score equally weighs each of the three vegetation characteristics, such that a high composite score indicates a plot with favorable attributes for all three vegetation characteristics. Within each study area, scores from all plots were averaged separately within each given vegetation unit. Scores for each vegetation unit are given in Table 6.

Table 6. Summary of vegetation characteristic scores for each study area.

Kona Forest Unit

Vegetation Unit	Average Canopy Score	Average Richness Score	Average Preferred Food Score	Average Composite Score
Upper Koa-'Ōhi'a Forest	40.4	29.3	19.3	87.9
'Ōhi'a Forest with Native Tree Understory	32.5	38.5	25.7	98.6
'Ōhi'a Forest with Mixed Understory	25.4	33.3	18.1	82.1
Lower Koa-'Ōhi'a with Uluhe	34.6	44.4	22.0	102.9

Kona Hema Preserve

Vegetation Unit	Average Canopy Score	Average Richness Score	Average Preferred Food Score	Average Composite Score
Upper Koa-'Ōhi'a Forest	12.1	41.2	24.6	80.4
'Ōhi'a Forest with Rich Understory	33.4	80.0	64.2	176.8
'Ōhi'a Forest with Dense Tree Fern	33.5	48.0	18.5	102.1
Mixed Lower Forest	23.9	32.0	12.2	69.1

Table 7 (Continued). Summary of vegetation characteristic scores for each study area

Southwest Ka`ū Forest

Vegetation Unit	Average Canopy Score	Average Richness Score	Average Preferred Food Score	Average Composite Score
`Ōhi`a Forest with Dense Understory	45.4	50.7	42.2	147.7
`Ōhi`a Forest with Intermediate Understory	41.9	44.0	54.8	145.8
`Ōhi`a forest with Dense Tree Fern Layer	35.7	35.6	57.3	136.0

Kahuku/Central Ka`ū Forest Reserve

Vegetation Unit	Average Canopy Score	Average Richness Score	Average Preferred Food Score	Average Composite Score
Koa-`Ōhi`a Forest	48.1	40.0	40.4	133.9
Upper (mesic) `Ōhi`a forest	67.3	32.8	31.3	145.5
`Ōhi`a Forest with Dense Broussaisia	50.3	46.7	26.6	132.6
Open/stunted `Ōhi`a Forest with Uluhe	19.9	43.3	24.6	91.9

Kapāpala

Vegetation Unit	Average Canopy Score	Average Richness Score	Average Preferred Food Score	Average Composite Score
Kapāpala Upper (Mesic) Forest	41.4	35.8	37.3	123.1
Ka`ū (Wet) Forest	44.4	41.0	33.6	126.0
Koa Management Unit	26.2	34.1	29.4	95.2

Keauhou-Kūlani

Vegetation Unit	Average Canopy Score	Average Richness Score	Average Preferred Food Score	Average Composite Score
Koa-`Ōhi`a Forest	56.4	54.8	59.9	167.2
Kūlani `Ōhi`a Forest	38.5	60.0	52.3	157.5
Upper Keauhou Ranch	33.7	40.0	34.6	115.3
Lower Keauhou Ranch	27.2	41.3	18.3	92.6

Weighting Scores for Study Areas by Area of Vegetation Units

By multiplying the average score for each vegetation unit by the area of that unit, an area-weighted score was obtained. Non-habitat areas were given scores of zero for each score type. By adding each of these area weighted scores, a single score was obtained for each study area that weighted the relative cover of vegetation units with different attributes. Scores for each study area are given in Table 7.

Table 8. Weighted vegetation scores for each study area.

Study Area	Weighted Canopy Score	Weighted Richness Score	Weighted Preferred Food Score	Weighted Composite Score
Kona Forest Unit	31.1	31.2	19.5	83.1
Kona Hema	20.4	35.5	17.4	74.7
Southwest Ka`ū	37.9	39.6	50.6	134.9
Central Ka`ū	41.8	37.8	28.5	115.7
Kapāpala	35.2	33.6	30.7	106.1
Keauhou-Kūlani	35.0	43.8	38.4	121.1

Ranking Study Areas According to Scores

Using the weighted scores, each of the study areas was ranked according to each type of score. It should be emphasized that the composite score was calculated for each individual plot, and thus indicates high scores co-occurring within a plot. It should also be noted that the scores were all weighted equally in calculating the composite score. Therefore, each vegetation attribute can also be considered on its own, according the importance attributed to it. Ranks based on scores are given in Table 8.

Table 9. Study area ranking based on assessment scores.

Study Area	Ranked Canopy Score	Ranked Richness Score	Ranked Preferred Food Score	Ranked Composite Score
Kona Forest Unit	5	6	5	5
Kona Hema	6	4	6	6
Southwest Ka`ū	2	2	1	1
Central Ka`ū	1	3	4	3
Kapāpala	3	5	3	4
Keauhou-Kūlani	4	1	2	2

DISCUSSION

The methods of assessing habitat potential for 'Alalā recovery presented here represent a simple measure of vegetation attributes taken from a limited number of plots within each study area. A primary problem is in attempting to summarize large study areas that incorporate considerable variation in climate, substrate, and land use history. Even by collecting data at plot locations representative of this variability, a meaningful number of plots are needed to properly reflect community-scale variation. In this case, vegetation units are represented by three to thirteen plots for areas ranging from somewhat over one km² to nearly thirteen km². The richness score in particular was highly variable within vegetation units, and therefore average values may be based more on the chance placement of a small number of plots than on any consistent differences in local species richness.

Besides the scores calculated (representing canopy cover above 10 m, total food species richness, and total cover of preferred food species), there are several other scores that could be calculated. For example, by adding the estimated cover values for all potential food species (rather than only preferred species), a total food score is generated. An examination of this value (complete with scaling plots and weighting by area) ranks the two Ka'ū study sites first and second. For another example, one might want to calculate the richness of preferred food species (rather than all potential species), assuming the presence of multiple preferred species may be an important value. An examination of this calculation (complete with scaling plots and weighting by area) indicates a similar result, with the two Ka'ū study sites ranking first and second. Another way to view canopy cover would be to add all of the cover below 10 m (as opposed to the primary tree canopy index which summarizes cover above 10 m). An examination of this calculation (complete with scaling plots and weighting by area) indicates a similar result yet again, with the two Ka'ū study sites ranking first and second. For summaries of these three additional indices, see Appendix 1 and 2.

Other habitat considerations beyond those possible from the data collected for this study might also merit consideration. For example, since 'Alalā also feed on young nestlings of forest birds and arthropods, an assessment of these resources may help define areas of high habitat quality. Another consideration might be the actual timing and volume of fruit produced by different species. This study did not consider the

amount of fruit produced by different species, and therefore it is possible that some additional weighting of preferred food plants might better quantify food resource availability in different landscapes.

The quality of habitat beyond the confines of study areas is another important consideration. The ability of 'Alalā to move considerable distances suggests that habitat availability in the larger landscape may ultimately be a better indicator of the potential of a given study area to sustain reintroduced birds. We used the HIGAP landcover map to assess the general extent of potential habitat outside the study areas. The two South Kona sites (Kona Hema and the Kona Forest Unit) are both located between non-forested upper elevations and heavily disturbed lower elevations. Moreover, the lateral expanse of native forest is fragmented such that there is little continuity between these two sites. Between Kona Hema and the Southwest Ka'ū study area, forest cover is interrupted by young lava flows, an extensive development (Hawaiian Ocean View Estates), and a heavily disturbed pasture area in the Kahuku section of Hawai'i Volcanoes National Park. Between the Southwest Ka'ū site and the Central Ka'ū study area there appears to be a relatively contiguous native forest cover. Similarly between the Central Ka'ū and Kapāpala study areas there appears to be contiguous native forest cover. While the areas above these three study areas are relatively non-forested, native forest extends to elevations below them, although the quality is uncertain since the lowest elevation vegetation units in each of these were generally of intermediate quality. Finally the Keauhou-Kūlani study area has non-forested areas above, below, and to the West, but has extensive forested areas to the East. However, these Eastern windward areas have a considerably wetter climate than any of the study areas, and lie outside the historically known range of 'Alalā.

Finally, each of the study sites has been subjected to human impact to some degree and vary with respect to the intensity of on-the-ground management they receive. It is worth considering the potential for improving habitat quality at each site in the near future. First, significant habitat improvement can be expected from two of the study areas (Kona Hema and Keauhou-Kūlani) where ungulates have been removed from large areas. Additional fences and animal control measures have the capacity to improve additional areas. However the capacity for regeneration of important woody understory species likely varies among study areas. One type of data collected in this

study that may help measure regenerative potential is the amount of alien grass present in the understory. All study areas have been subjected to grazing activity although the intensity has varied considerably. Ostensibly the more grazing activity an area has received, the more the understory has been converted to grass cover. Additionally, ongoing studies demonstrate that dense cover of grass inhibits seedling growth of native Hawaiian woody species (Scowcroft 1982; Scowcroft and Conrad 1992; Sierra McDaniel, pers. comm.). By considering the occurrence of plots where grass was the primary component of the ground layer and where total ground cover was above 75 % (i.e. where there was little bare ground or litter), it is feasible to estimate where regeneration might be inhibited. We therefore assessed the locations of plots with these characteristics and found several study areas where grass was prevalent. For a summary of grass cover, see Appendix 1. The Kona Forest Unit had the highest prevalence of grass cover with a majority of plots being dominated by grass with over 75 % cover, followed by the upper elevations of Kona Hema preserve, and the Western portion of Keauhou-Kūlani area. The Kapāpala study area had only three such plots, and in the two Ka'ū study areas, not a single plot had a ground layer dominated by grass with over 75 % cover. Therefore, while both of these sites rate highly, this consideration adds to their potential value.

ACKNOWLEDGEMENTS

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APPENDIX 1

Supplemental analyses

Several supplemental scores, which may represent important habitat qualities, were calculated from plot data. These include:

- Total potential food species cover (rather than cover of preferred food species only). This considers all food species and may be a better measure of total resource abundance.
- Preferred food species richness (rather than richness of all potential food species). This considers richness only for species so far observed to be important.
- Aggregate percent cover of all woody layers below 10 m. This measures how much cover is in the understory beneath the 10 m and above considered in the canopy estimates. A greater amount of cover indicates potential lower visibility and maneuverability for predators (particularly if birds actively hide in the understory).
- Percent cover in ground layer when dominated by alien grass. This is a measure of the potential for regeneration of understory food species. Higher grass cover likely inhibits regeneration of seedlings of woody species that may be important food resources.

These additional measures were calculated for each plot. Plot values were scaled from 0 to 100 across all study areas. Percent grass dominant cover was scaled in reverse so that 0% cover received a 100 score and 100% cover received a zero score (so that low grass value is a high habitat quality value). As with other scores, non-habitat areas received a zero score. Average values for each Vegetation Unit were weighted by area, producing a weighted average value for each study area. Ranks from weighted scores resulting from these alternative measures are presented in the following table.

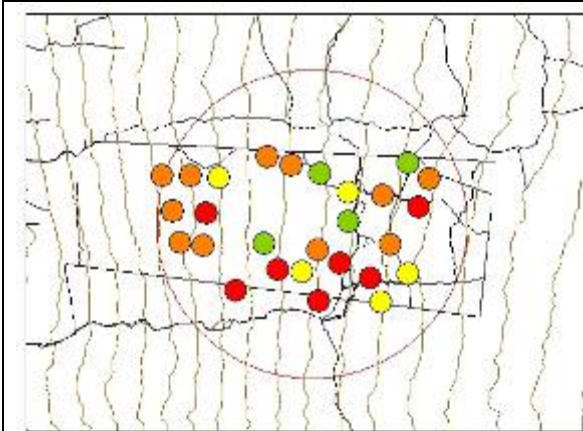
Study Area	Ranked Total Food Cover	Ranked Preferred Richness	Ranked Understory Cover	Ranked Grass Dominance
Kona Forest Unit	6	4	6	6
Kona Hema	5	6	5	5
Southwest Ka'ū	1	2	1	1
Central Ka'ū	2	1	2	2
Kapāpala	4	5	4	3
Keauhou-Kūlani	3	3	3	4

APPENDIX 2

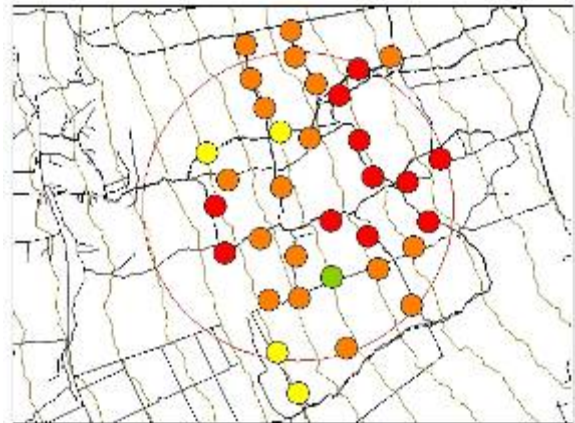
Maps of 7 types of scaled scores for individual plots

Study areas are shown as red circular boundaries (refer to Figure 1 for relative locations). 100 m contours are shown in brown and roads are shown in black for reference. For each type of score, colored circles represent plot locations. Each color in Figs. A-H indicates a range of scores scaled from 0 to 100: Red = 0 - 20; Orange = 20 - 40; Yellow = 40 - 60; Light Green = 60 - 80; Dark Green = 80 - 100.

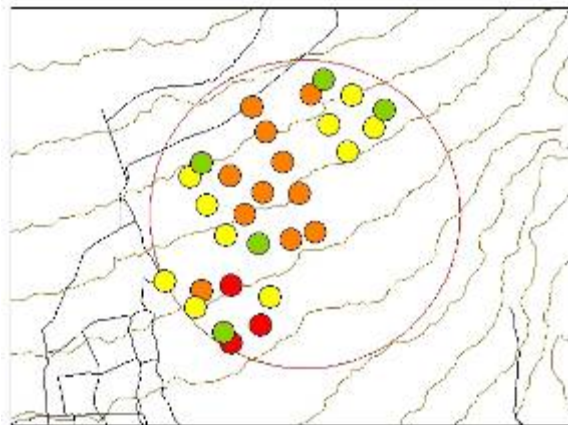
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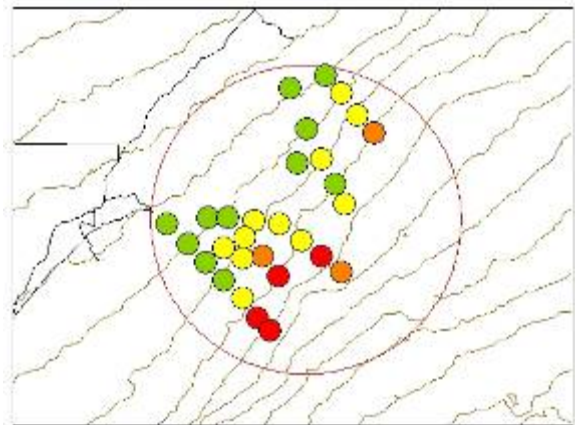
Kona Forest Unit



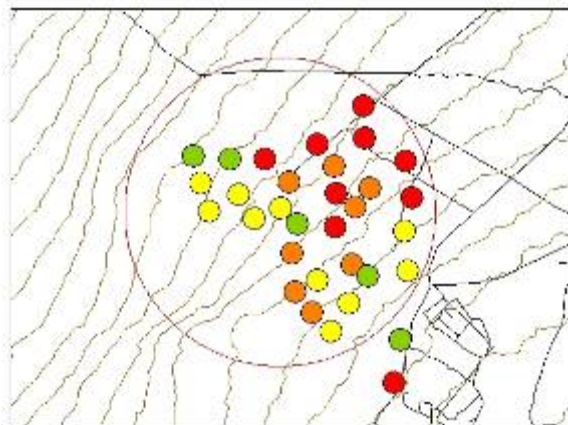
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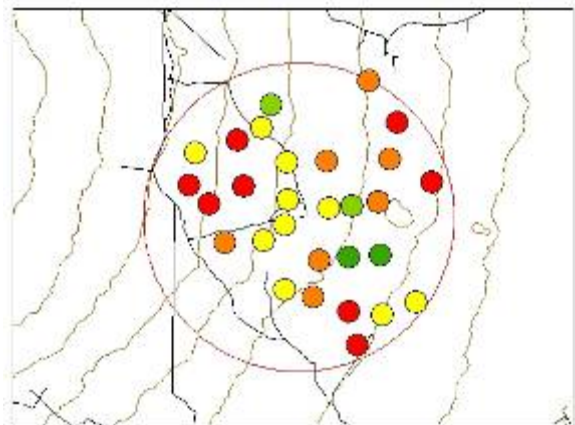
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Central Ka'ū

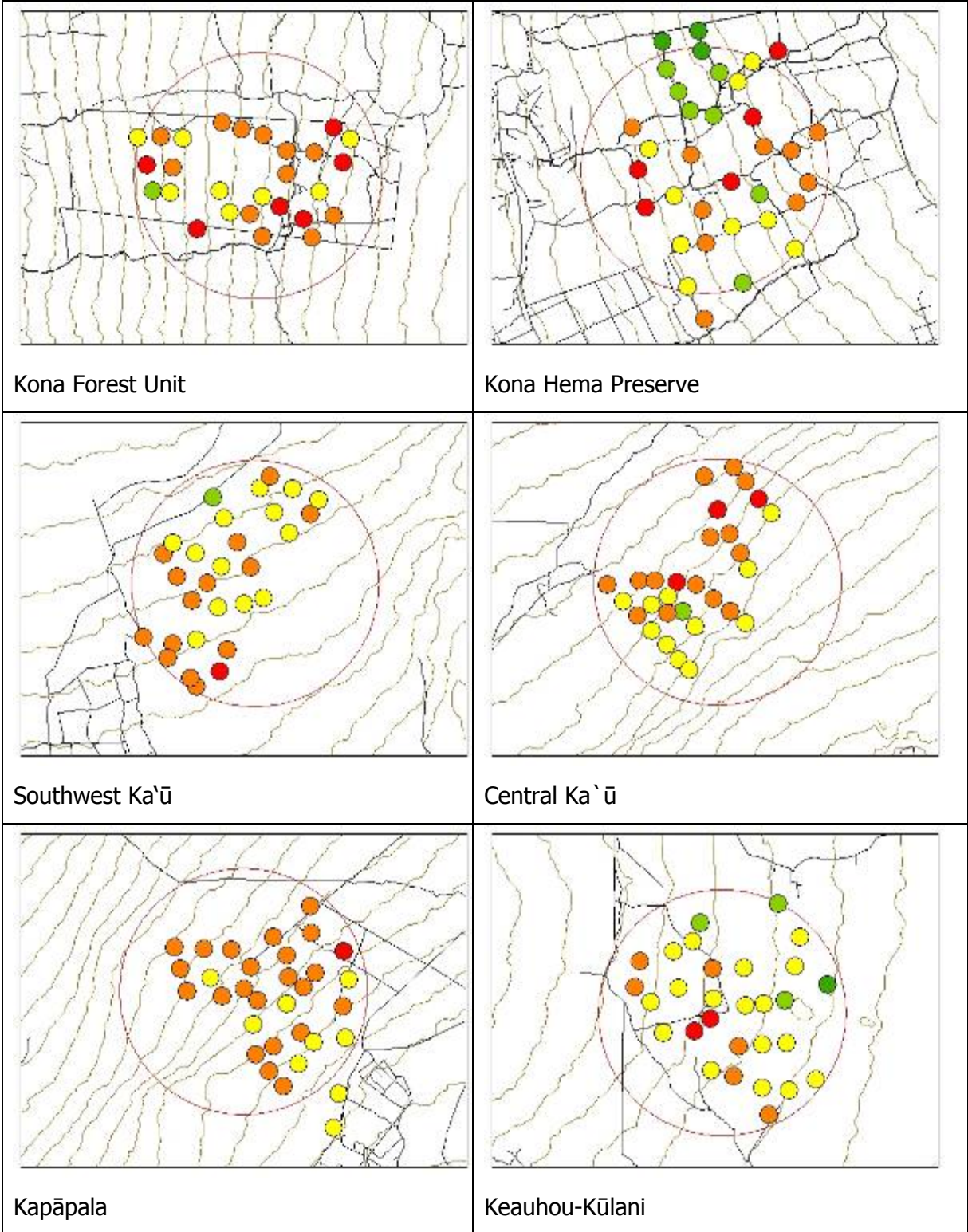


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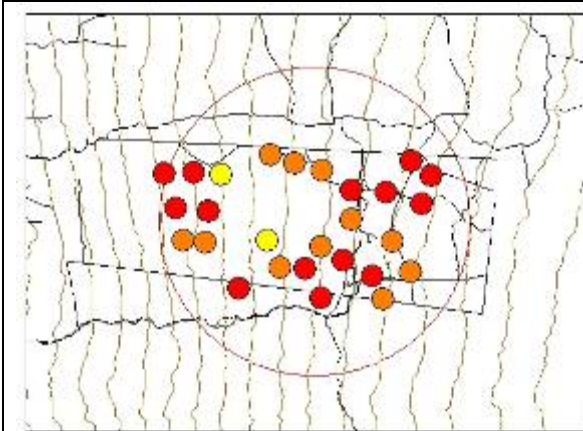


Keauhou-Kūlani

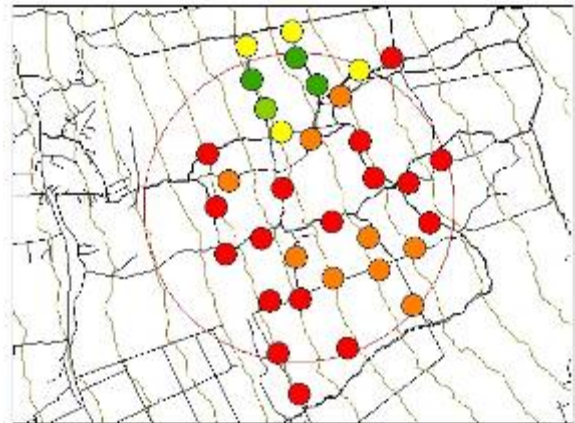
B. Scaled Food Species Richness.



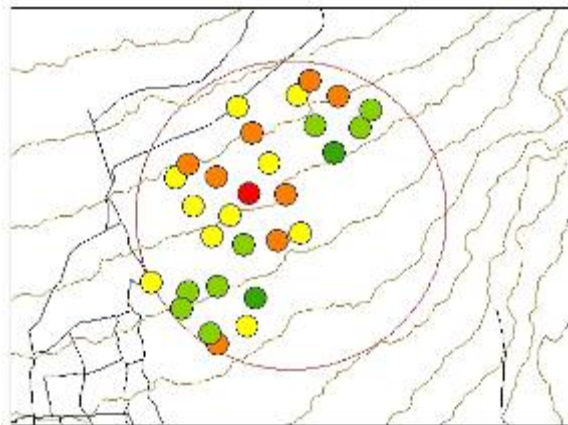
C. Scaled Preferred Food Species Cover.



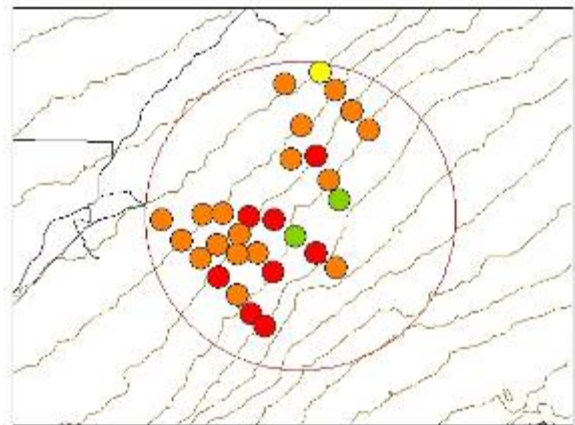
Kona Forest Unit



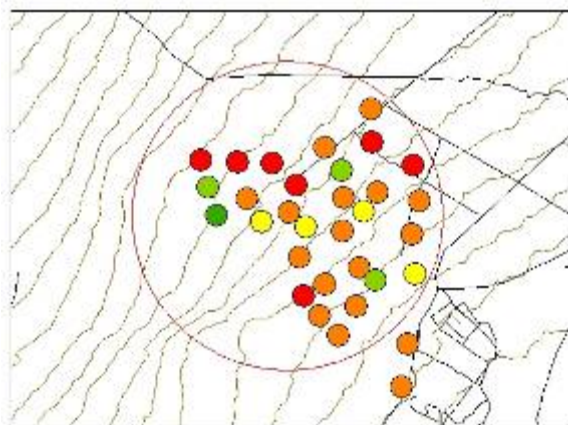
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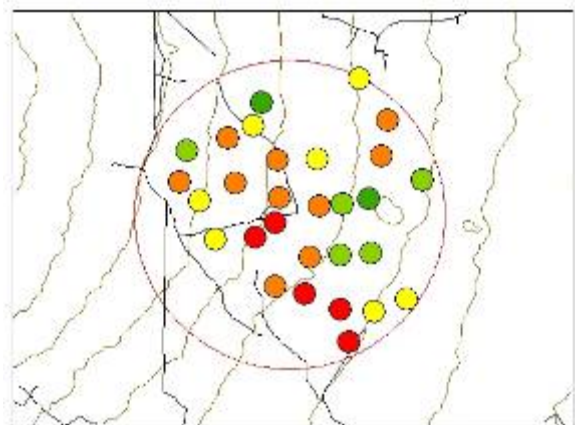
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Central Ka`ū

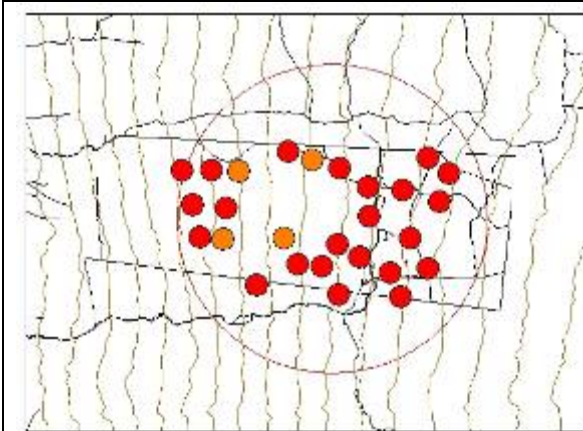


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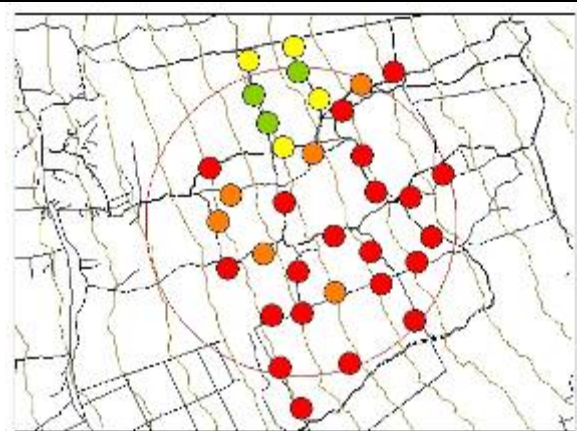


Keauhou-Kūlani

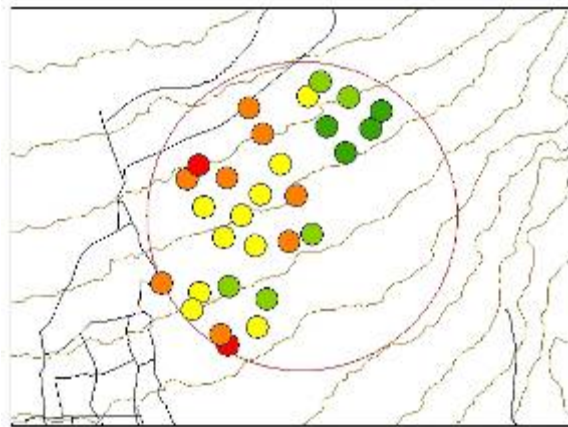
D. Scaled Total Food Species Cover.



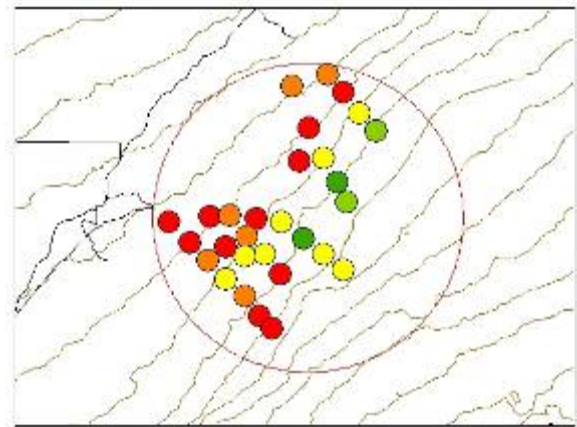
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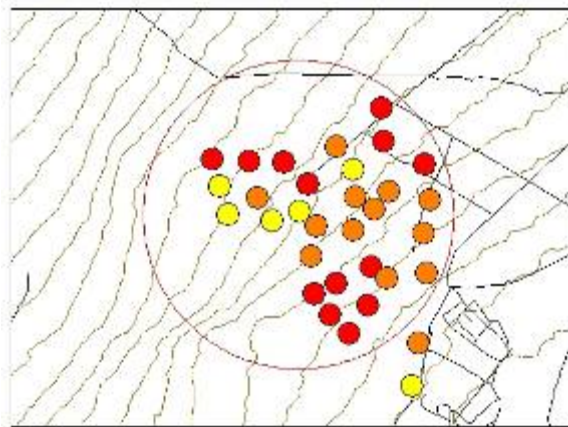
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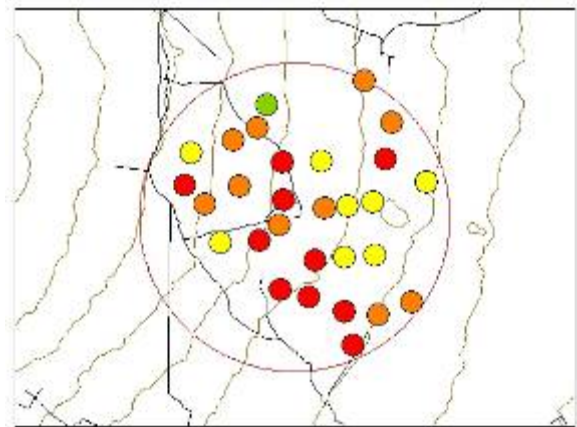
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Central Ka`ū

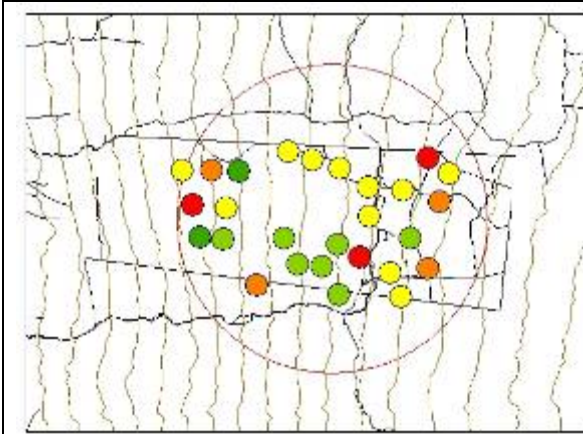


Kapāpala

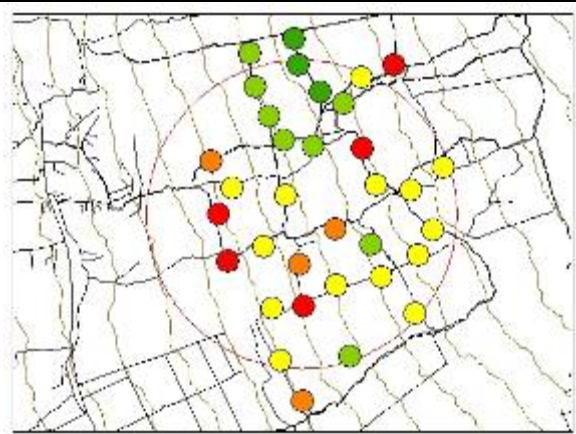


Keauhou-Kūlani

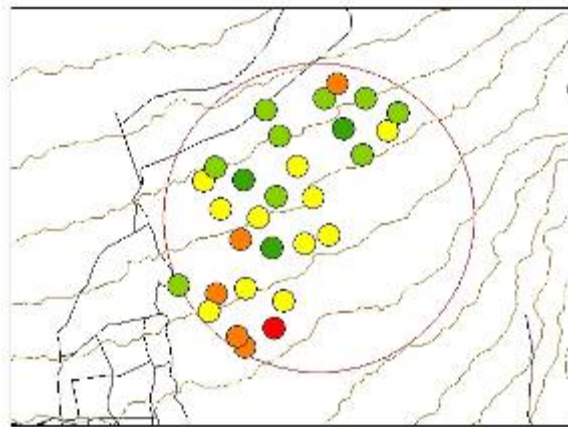
E. Scaled Preferred Food Species Richness.



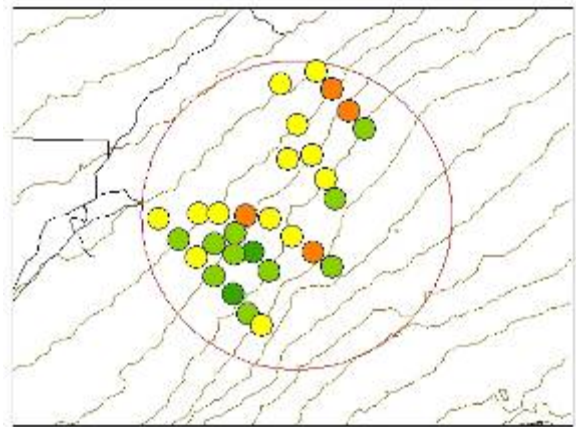
Kona Forest Unit



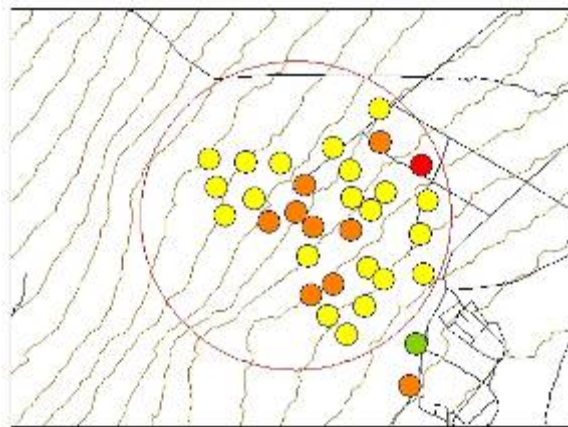
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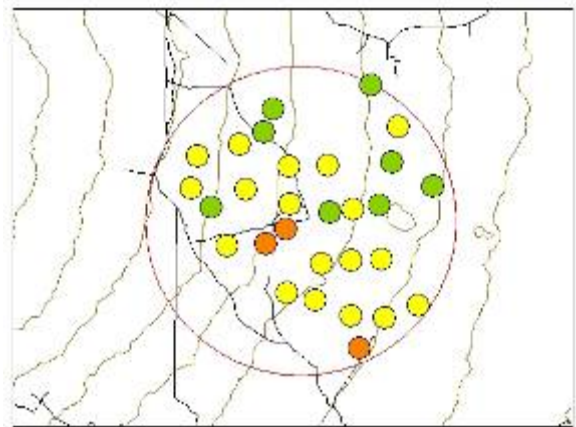
Southwest Ka`ū



Central Ka`ū

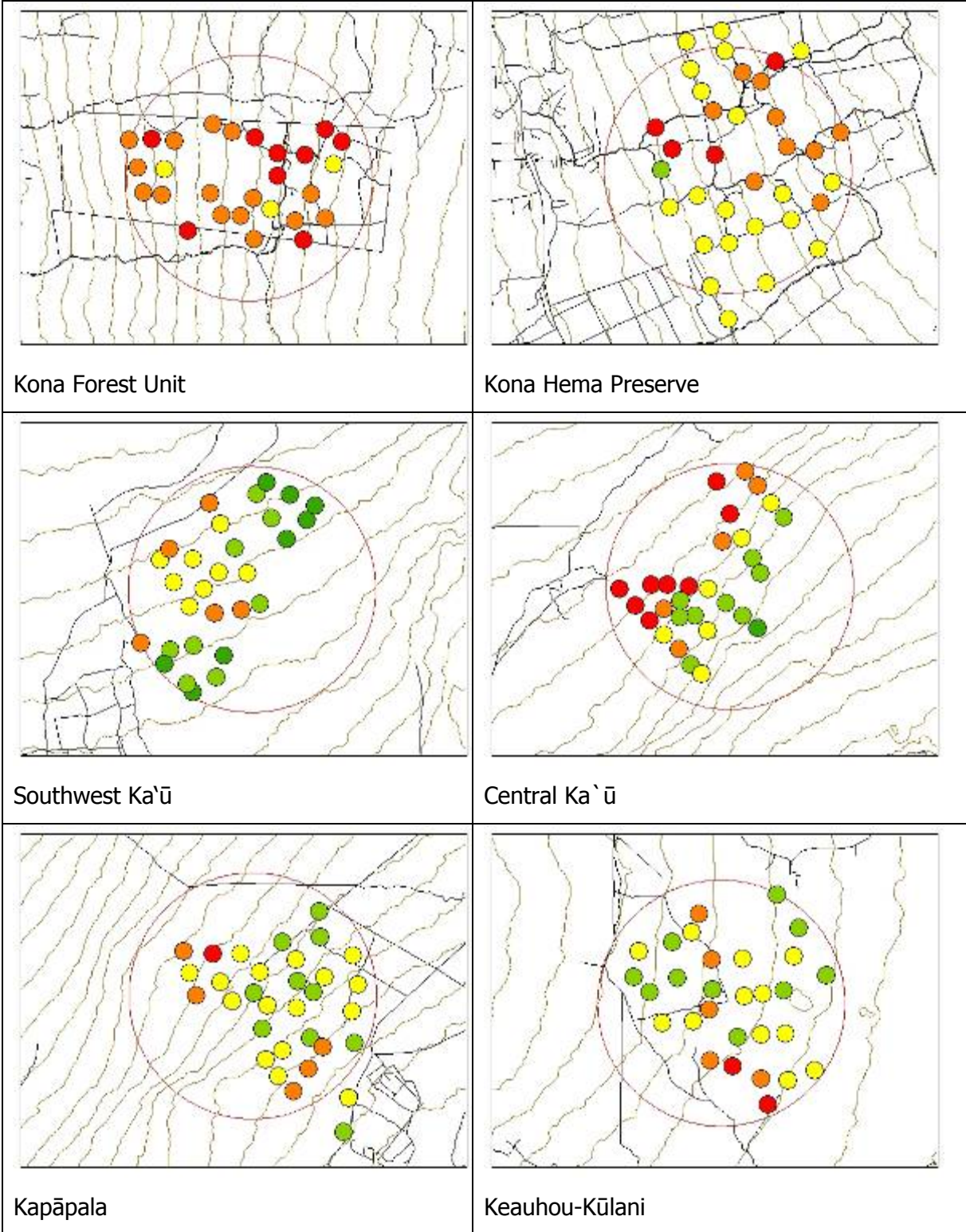


Kapāpala

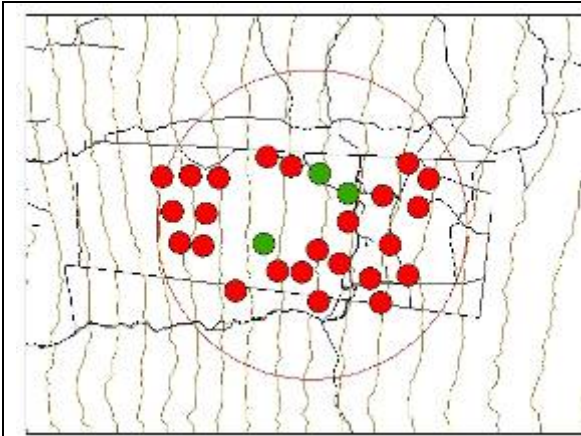


Keauhou-Kūlani

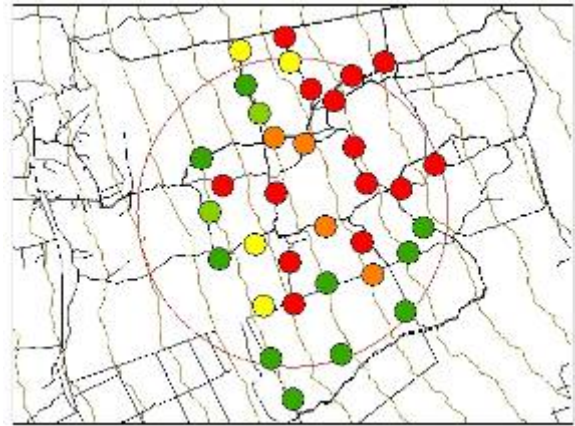
F. Scaled Understory Cover.



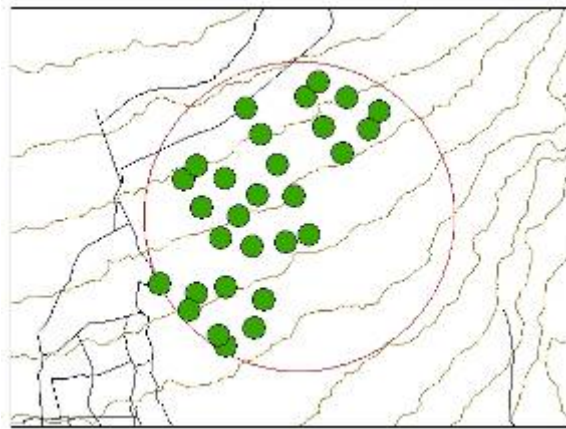
G. Scaled Exotic Grass Cover (scale reversed so that low score represents high amount of grass cover and vice versa).



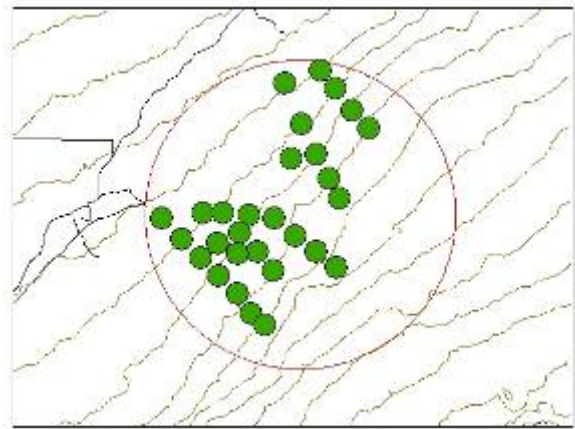
Kona Forest Unit



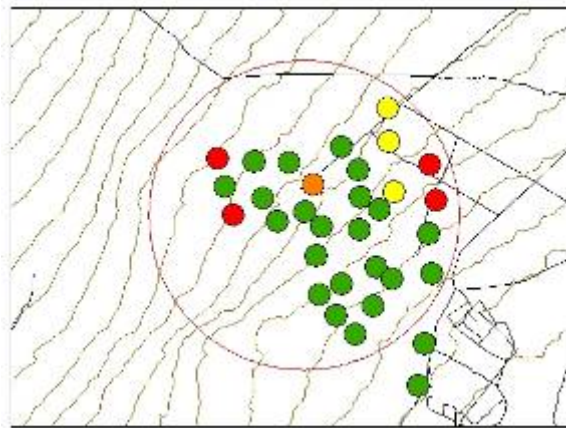
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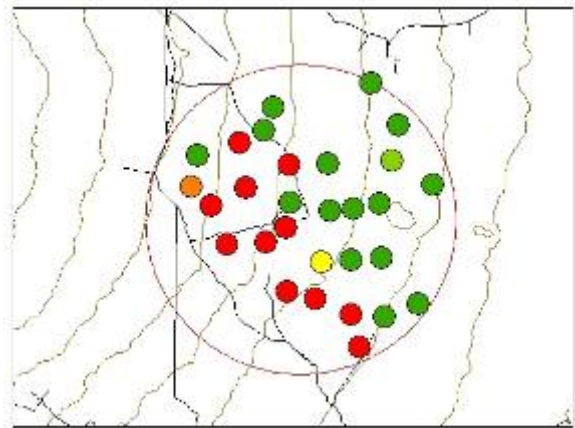
Southwest Ka'ū



Central Ka'ū



Kapāpala



Keauhou-Kūlani

APPENDIX 3.

Composite of scaled scores for canopy cover, food species richness, and preferred food species cover.

This composite score represents the summed values for three scores; it therefore does not scale from 0 to 100 but from 0 to 243. Each color indicates a range of composite scores: Red = 0 - 50; Orange = 50 - 100; Yellow = 100 - 150; Light Green = 150 - 200; Dark Green = 200 - 243.

