Haloa ʻAina Forest Inventory

Forest Solutions Inc.

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Responsible Forester:

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1. CLIENT AND PROPERTY INFORMATION

1.1. Client

Landowner Name:	**Wade Lee** **JAWMIN LLC**
Address:	
Client:	Division of Forestry and Wildlife Department of Land and Natural Resources
Email:	
Phone | Fax:	
TMK number:	(3) 7-9-01-13, 14 AND 15
State and County Zoning:	Agriculture (20)
Total property acreage:	2,785

1.2. Consultant

Company:	Forest Solutions, Inc.
Name:	Aviva Gottesman, M.S.
Title:	Forester
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Responsible Forester establishes that the information in this report was acquired in an accurate manner to the best of Consultant's current state of knowledge about the Property.

Signature: **Date:**

2. Executive Summary

The goal of this forest inventory is to update a timber inventory conducted at Haloa ʻAina in 2014 and report on the current state of forest resources. To complete this inventory, Forest Solutions (FS) employed a hierarchical 3P (**P**rediction **P**roportional to **P**robability) method combining remote sensing, targeted field assessments, and spatial statistical analysis. The Haloa ʻAina (HA) property was stratified into 6 stratum according to vegetation cover boundaries, land classification maps, stem density, and management history.

Summed across the strata, the property supports 226 m^3 of ʻiliahi (*Santalum paniculatum*), of which 77 m^3 is whole tree heartwood. This relates to over 17,000 kg of stem heartwood and almost 112,000 kg of root heartwood. There is an average of 4 ʻiliahi per acre for a total of over 12,000 trees (> 5 cm). Widespread regeneration due to past harvesting has resulted in 47 regenerating stems per acre and 135,700 regenerating stems across the property. Regeneration includes seedlings, root sprouts, and saplings <5 cm.

Table 1. Property level results and inventory statistics for ʼiliahi.

ʻIliahi results summarized at the property level				
	Average Volume (m^3 ac^{-1})	(m^3 ha^{-1})	Total Volume (m^3)	$SE_{80\%}$ (%)
Whole tree (outer bark)	0.08	0.19	226	22%
Whole tree heartwood	0.03	0.07	77	28%
	Average Mass (kg ac^{-1})	(kg ha^{-1})	Total Mass (kg)	
Stem heartwood	6	15	17,029	31%
Root heartwood	40	99	111,916	23%
	Average Stems (ac^{-1})	(ha $^{-1}$)	Total stems	
ʻIliahi trees	4	10	12,090	20%
ʻIliahi regeneration	47	117	135,718	16%

The property contains a small component of koa (*Acacia* koa) across the forest, with one high-density koa strata. The property supports 21,000 koa with a volume of 924,500 Scribner board feet. Standard error was high (SE = 30%) at a low confidence interval (CI = 68%) due to the high variability of koa across the property.

Property Level	Koa (trees ac^{-1})	Total Koa	$SE_{68\%}$ (%)	Volume (bf ac^{-1})	Total Volume (bf)	$SE_{68\%}$ (%)
Koa	11	21,062	33%	474	924,558	30%

3. Introduction

3.1. Property location and description

The property is 2,785 acres in Kealakekua, North Kona District, Hawaii County, Hawaii. The property lays approximately 3.5 miles west of the coast along the western slopes of Mauna Loa, about 10 miles south of Kailua-Kona on the mauka boundary of the North and South Kona administrative districts. The property is located in an agricultural subdivision identified as "Hokukano Ranch" that consists of 25 lots controlled by an owners' association. The property is of level to rolling topography that gently up-slopes from the eastern boundary at 4,600 feet above sea level to the western boundary at 5,600 feet above sea level along the slopes of Mauna Loa.

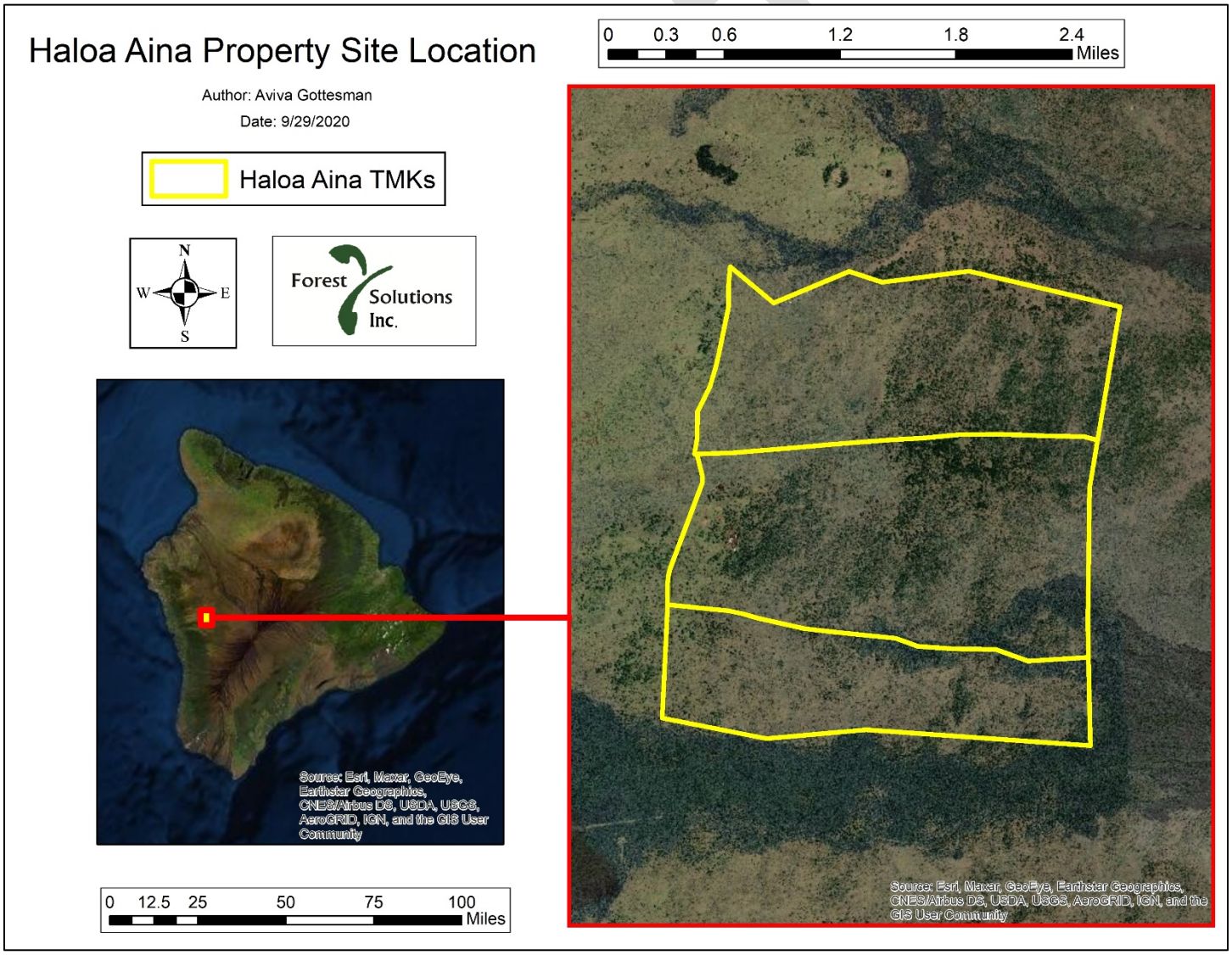

Figure 1. Property site location of Haloa 'Aina in South Kona, Hawai'i island, Hawaii.

The property is on the boundary of NRCS designated MLRA (Major Land Resource Areas) 161A and 161B[1]. 92%

[1] United States Department of Agriculture, Natural Resources Conservation Service. 2006. *Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Basin.* U.S. Department of Agriculture Handbook 296

is 161B, "*Semiarid and Subhumid Organic Soils on Lava Flows"* and 8% of the property is 161A, "*Lava Flows and Rock Outcrops*." The average annual temperature is 56.6 degrees Fahrenheit, colder months being December-April, warmer months being May-November. The average annual rainfall on the property is 25.88 inches (656.8 mm). Rainfall is sparse though occurs consistently throughout the year ranging from 1.77- 2.93 inches per month.

The majority of the property (73% cover) is characterized as open koa (*Acacia koa*)-māmane (*Sophora chrysophylla*) forest. This ecosystem is the result of a long history of grazing cattle. The overstory is very sparse, with occasional koa and ʻiliahi (*Santalum paniculatum*) reaching overstory size. The sub-canopy contains naio (*Myoporum sandwicense*), māmane, and ʻaʻaliʻi (*Dodonaea viscosa*) with a grassy groundcover over a'a. The other large ecosystem on the property is characterized as alien grassland (23% cover). The grassland is a mix of kikuyu (*Pennisetum clandestinum*), meadow rice (*Ehrharta stipoides*) and other pasture weeds, and contains native species such as: ʻaʻaliʻi, naio, māmane, ʻiliahi, ʻōhiʻa (*Metrosideros polymorpha*), pūkiawe (*Leptecophylla tameiameiae*), and koa. There are also small components of open-ʻōhiʻa forest with native shrubs over younger a'a flows on the property (4%).

Figure 2. Open koa-māmane forest structure with many standing dead snags of naio and a grassy understory of kikuyu, meadow rice, and pasture weeds.

3.2. Land use and current use:

The property is categorized as Agriculture (20a) and is currently utilized for sustainable forestry with ʻiliahi and koa trees being the primary products. The ʻiliahi and koa root sprouts and regeneration from seed regeneration are mostly due to ungulate removal and are a natural response of previous harvesting. Various native species are being out planted by landowners. Previously, the area was utilized primarily for pasture by the former owners who had removed forest.

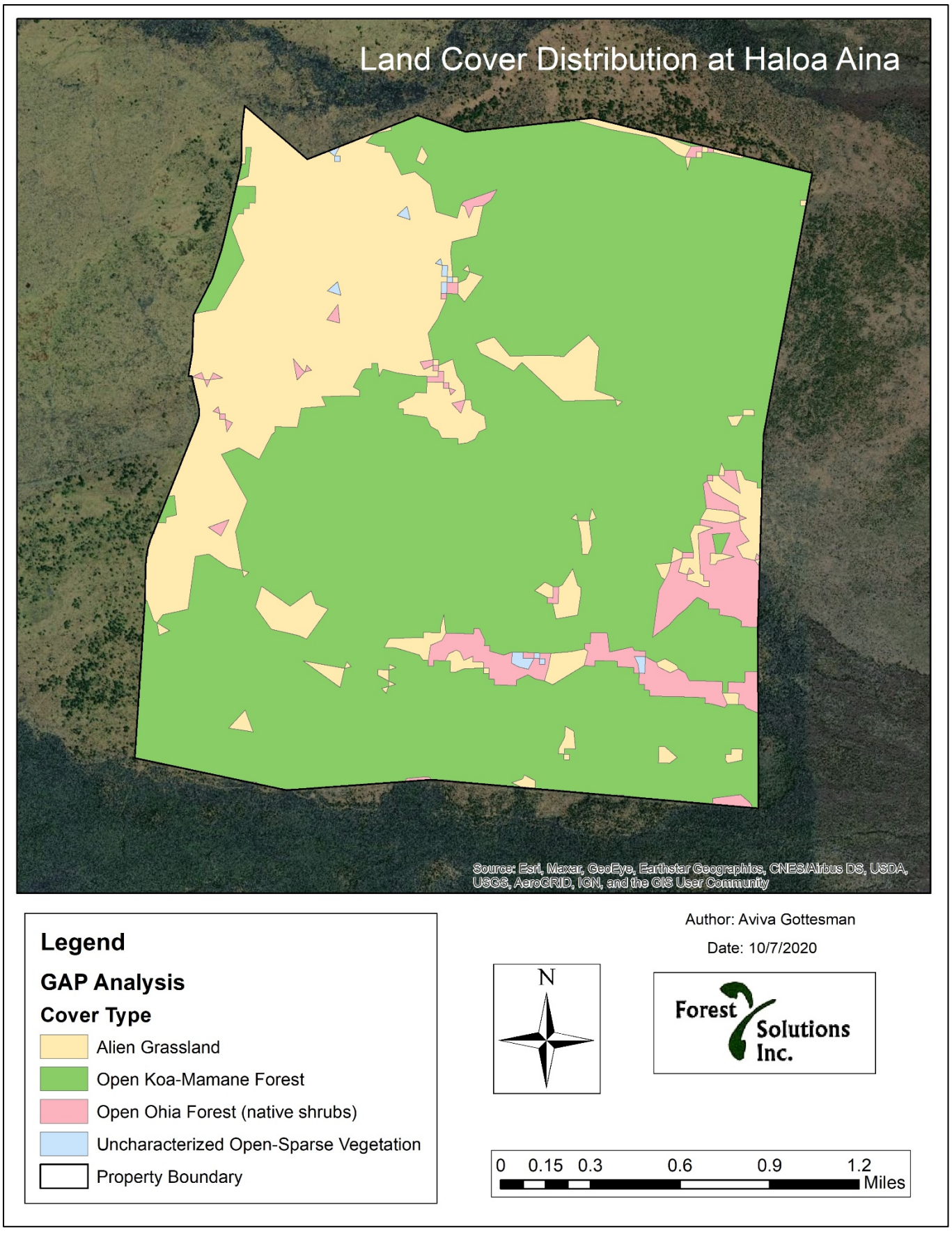

Figure 3. GAP land cover types show that the property is mostly open koa-māmane forest, with areas of alien grassland due to historic grazing. The open ʻōhiʻa forest is located on/near a young aʻa flow.

3.3. Project description

The purpose of this forest inventory of the Haloa ‘Aina property is to update the 2014 forest inventory report.

1. Utilize a plot-3P methodology to determine merchantable ‘iliahi (*Santalum paniculatum*) volume and koa (*Acacia koa*) volume.
2. Collect data on all forest trees (including non-commercial species) over 10 cm diameter at breast height (DBH), provide results in terms of stems per acre and basal area per acre.
3. Collect and report % cover by species of shrubs and groundcover.

Figure 4. A photo of a healthy ‘iliahi shrub at Haloa ‘Aina.

4. Inventory procedures

The inventory analysis was conducted using metric units as was done in 2014. The global sandalwood market uses metric units (cubic meters, kilograms, hectares), therefore the results provided in this report are metric. However, the Department of Forestry and Wildlife use English units in their reporting. For this reason, summary tables reported in the results section display both metric and English units.

4.1. Estimation procedures

In 2014 the P3P inventory was completed by counting the number of total trees, irrespective of species, within a total of 235 circular plots of radius either 30 m in strata with low stem densities (HA3 and HA4) or 20 m radius for all other strata. These raw tree count estimates were multiplied by a correction factor based on an expected volume value for equivalent map units from a 2010 inventory[2] . The product of raw count and expected volume yielded (a) a predicted number of *S. paniculatum* trees per plot and (b) a predicted volume of *S. paniculatum* aboveground heartwood per plot. To preserve consistency in estimated volumes and minimize the percent error associated with the estimation procedure, a single person was employed to count every plot within a given stratum. For quality control, tree counts were corroborated for a subset of 10 plots per stratum by a second worker.

Estimated values were derived for a total of 235 plots; a subset of 77 plots was selected for detailed measurement using a probability-influenced selection process. The estimated volume and tree count values were summed across blocks to provide a total expected volume aggregate. A target sample size of between 65 and 85 was selected from previous experience with this type of inventory, and this aggregate value was divided by the target sample size to yield the expected population and volume values for each plot to be sample. Subsequently, a plot-level value was calculated as the product of a random number between 0 and 1,

[2] Senock, R.S. Preliminary Check Cruise Resource Inventory Results for JAWMIN LLC Hokukano Ranch Property. 2010. On Solid Ground Consulting. CA.

exclusive, and the aggregate (KZ). Plots whose estimated *S. paniculatum* volume or tree population exceeded the KZ value for either parameter were selected for field measurements.

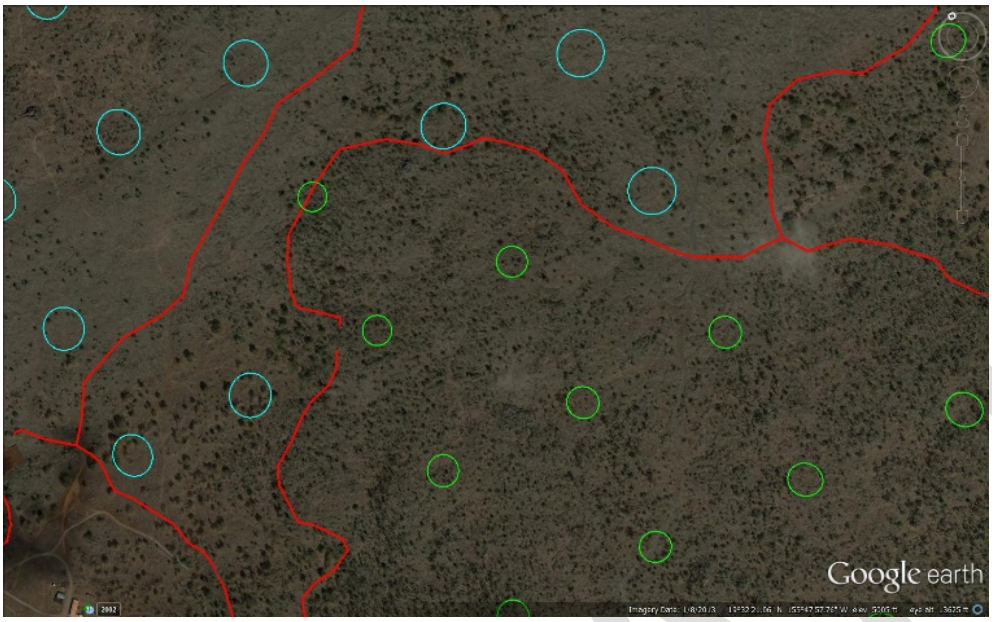

Figure 5. Individual trees were counted both in low-density areas where determining identity of individual stems was trivial (top left) and in high-density areas where the total number of stems was difficult to assess (bottom right). Plots in lower density areas were 30 m in radius (blue), whereas plots in higher density areas were 20 m in radius (green). The satellite imagery quality assisted with fast assessment, though cannot yield a species-level census. This tradeoff between speed and accuracy is expected in P3P methodology and allows resources to be efficiently allocated.

4.2. Stratified P3P stratum summary

In the 2014 inventory, 77 plots were selected for detailed measurement out of 235 plots. The plots were selected using a probability-influenced selection process based on expected ʻiliahi volumes. To update the inventory in 2020 for this project, the same 77 plots were remeasured. An additional 19 plots were selected using the same probability-influenced selection method to increase the sample size and provide additional measurements for the analysis.

In total, six strata were defined: high stem density (per hectare) with low intensity (HA1) and high intensity of logging (HA2), low stem density with low (HA3) and high logging intensity (HA4), medium stem density (HA5) with extensive past logging, and land covered by relatively recent aʻa lava flows. An estimated 60 acres (24 hectares) of land dedicated to processing infrastructure were excluded from this inventory.

At the stratum level, most measured plots were located in the HA2 (23 plots) and HA5 (35 plots) strata, with 14 plots in HA1 and 13 plots in HA3. This differential in total measured plot number arises from a combination of different stratum sizes as well as different stem densities. In this P3P sampling system, volume, mass and tree population are ultimately a function of raw, non-specific tree counts. It is important to note that the aʻa flow (88 hectares, 218 acres) did not receive any measured plots due to its near total lack of *S. paniculatum* trees derived from the 2014 inventory. However, estimated volume of ʻiliahi in the aʻa strata was determined

from the P3P method and therefore is included in the reported total volume. Finally, the infrastructure reservations may have minor amounts of ‘iliahi. These trees are located near buildings and front-end access roads and the estimated area (24 hectares, 60 acres) was completely excluded from the inventory.

Table 2. Description of the forest strata, former strata name, area, and defining characteristics.

2020 Stratum Name	2014 Stratum Name	Area (ha)	Area (ac)	Stem density	Logging history	Characteristics
A'a	A'a	88	218	Low	None	Open forest over a'a flow, contains mostly ohia and pūkiawe
HA1	HD1	92	227	High	Low intensity	Dense sub-canopy, māmane, etc.…
HA2	HD2	173	427	High	High intensity	Patchy understory with grassy regions and thicker regions
HA3	LD1	285	704	Low	Low intensity	Open grassland, occasional trees and shrubs
HA4	LD2	151	374	Low	High intensity	Open grassland, occasional trees and shrubs
HA5	MD	283	699	Medium	Extensive logging	Open forest with dense regeneration, small trees, and various shrubs

Figure 6. Pictures depicting the various stratum taken from plot center.

4.3. Field measurements

4.3.1. ‘Iliahi data collection

Figure 7. A photo of ‘iliahi saplings regenerating from a harvested stump, as well as root sprouts.

At each of the 96 locations for measured plots, inventory crews navigated to the center of the plot and established temporary monumentation, typically a spray-painted rock. Within a 30 m radius of the plot center or a 20 m radius for all other strata, every ‘iliahi tree over 5-cm diameter was counted, measured, and assigned a crown health classification. Measured parameters included diameter at 1.4 m above ground on the high-ground side of the tree (DBH), and root-collar diameter (diameter taken at the base of the tree). It is important to note that measuring the DBH of ‘iliahi is near impossible, as it branches often and low on the main trunk. Because of this, DBH was taken either above or below 1.4m at a height most representative of the volume of the actual tree. Finally, ‘Iliahi log segments were counted for each measured tree. A segment is defined as being over 0.33 m (1 foot) in length and over 5 cm (~ 2 inches) diameter.

Both alive and standing dead trees were measured, and the crown health status recorded. Very healthy trees were classified as 1 (at least 75% of the original crown density present), progressing through 25% classes, up to a value of 5 for completely dead trees. Depending on forest density, plot size used varied between 20 m and 30 m radius, allowing crews to identify a representative sample without sacrificing excessive time to unnecessary measurements. Personnel completing the tree measurements relied on the GPS units to remain within the plot. In cases where it was unclear whether the location of the tree was inside the plot, trees were marked on the GPS and checked using GIS after returning from the field. Trees more than 20 m (or 30 m) from the selected plot center were not measured. A photograph was taken from due North at the boundary of every plot.

Additionally, crews performed a detailed count of ‘iliahi regeneration. Individual saplings with a diameter less than 5-cm was counted within the entire plot. When there was a group or clump of stems (which occurred often), individual trees were identified based on their height, defined by having a leading/main stem and a unique root stump.

4.3.2. Koa and auxiliary species

All koa in the plot with a DBH (1.4m) greater than 10-cm were measured and recorded. They were categorized as "mature" or "not mature" depending on their size, coloration, and figure.

Additionally, a nested sub-plot design was implemented to collect data on non-commercial tree species and shrubs. A 10-m subplot was installed from the plot center to measure all forest trees over 10 cm DBH. However, there were little to no trees over 10 cm besides 'iliahi and koa. A species list of all species found within the 10-m plot was recorded instead. Additionally, a 2-m subplot was established to collect and report percent cover by species of shrubs and all groundcover species.

4.4. Statistical analysis

4.4.1. Volume

Crown Health Classification	Percent Deduction
1	0%
2	6.50%
3	13%
4	19.5%
5	26%

1. Measured parameters DBHOB (original cm units) and log segments were employed as input to the 'iliahi allometric equations. Crown class served as a further multiplication factor, with healthy trees (class 1) resulting in no reduction in harvest-adjusted volume, while dead trees (class 5) were reduced by the full 26%.
2. Estimated volume for the unmeasured plots was adjusted by the ratio of measured, trial-adjusted volume (m^3) to estimated volume (m^3) derived from the subset of measured plots. Estimated tree populations were adjusted in a similar fashion by the ratio between measured and estimated total trees as well as regenerating saplings. This adjustment ratio was calculated as the quotient of the sum of measured quantity and the sum of estimated quantity—*defined for measured plots only*. The adjustment of estimated plots was the product of the estimate and the ratio of sums.
3. Quantification of measurement-related error was conducted using the difference between ***measured*** and ***adjusted*** parameters (2), which is a plot-level quantity. Parameters calculated included the average, standard deviation (sd), sample size (n), standard error of the mean (se), and percent standard error[3]. The average of the difference quantity is 0, so it cannot be used for further statistical calculations, but the distribution of error and variability in the difference reflects the error in the adjusted estimates, so the adjusted estimates average can be substituted.
4. Uncertainty measurements (coefficient of variation (CV%), percent standard error (SE%)) were calculated both for separate strata (HA1, HA2, HA3, HA4, HA5, and AA) *and* for the HA property as a whole. **The overall inventory error assessment is presented at the property level**. The average value of interest (e.g. heartwood volume, m^3 per plot) was calculated for each stratum. Stratum level averages and upper and lower confidence limits were summed to calculate the property level volume (or tree number) average and upper and lower ranges.
5. There were two sources for uncertainty: error associated with the estimation procedure (error of the estimate) and error associated with the property average (measurement error). Combined error of the

[3] Standard error of the mean (se) was calculated as sd / sqrt (n), CV% as quotient of sd and the mean, and SE% as quotient of the se and the mean.

estimation procedure (4) with the error of expanding to property level (5) was calculated as the square root of the sum of the squares of the percent standard errors (additive uncertainty propagation).

6. Net per hectare aboveground and belowground heartwood volume, and total number of trees and regeneration, were computed by multiplying property and stratum-level average estimated volume per plot corrected to estimated volume per hectare by the ratio of sums to yield net volume per hectare. Overall volume, population, and associated statistics are generalized at the property level ***only***. Total volume (or population) was therefore the product of net volume per hectare and the total area of the property.

4.4.2. Allometric equations

Koa volume (Scribner board feet) was calculated using an internal species specific allometric equation derived from koa trees on a property neighboring Haloa ʻAina.

Table 3. Volume equation for *Acacia koa* specific to montane leeward dry ecosystems in South Kona, HI. Result is in Scribner board feet. Source: Baribault, T. Proprietary equations. Forest Solutions Inc.

Koa Volume Equation	Coeff_a	Coeff_b	Source Population	Location Type
a*DBH^b	0.1022	2.4746	South Kona	Montane Leeward Dry

Volume and mass of ʻiliahi was calculated using species specific allometric equations developed by Forest Solutions[4]. Total volume of the whole ʼiliahi tree was calculated using the outside bark whole tree parameters. Heartwood volume was calculated using the whole tree heartwood volume parameters. ʻIliahi heartwood mass was calculated using tissue specific parameters for the stem and root of the tree. All variables were calculated using the same model in which the equation is a function of root collar and segment counts. However, root tissue mass uses a different model, which is the same equation except without the segment count.

Table 4. Allometric equations for ʻiliahi that were used in the inventory analysis to report on total tree volume (1), total heartwood volume (2), stem heartwood mass (3), and root heartwood mass (4). Equations developed by Forest Solutions.

		Equation	Fraction	Component	a	b
1	Volume	exp((a) - (b/(rcd_mm * seg_count)))	Outside Bark	whole tree	-0.788	2013.7
2		exp((a) - (b/(rcd_mm * seg_count)))	Heartwood	whole tree	-1.656	2262.7
3	Mass	exp((a) - (b/(rcd_mm * seg_count)))	Heartwood	stem tissue	5.23	1098.2
4		exp((a) - (b/(rcd_mm))	Heartwood	root tissue	5.634	454.3

[4] *Inventory of Santalum species on Hawai'i Island*. July 31, 2020. Rice, W & Koch, N. Forest Solutions Inc.

5. Inventory Results

The ʼiliahi allometric equations are in metric (cubic meters and kilograms) and were reported on a per hectare basis in the 2014 report. For this reason, most of the results will be presented in hectares. However, for the purposes of the Division of Forestry and Wildlife, the following property-level summary table provides results on a per acre basis. Regardless of presenting results per acre or per hectare, the final property level total results are the same. In the summary table, averages were calculated as an average across all plots, while the totals are a sum of the stratum totals.

Summed across the strata, the property supports 226 m^3 of ʻiliahi (*Santalum paniculatum*), of which 77 m^3 is whole tree heartwood. This relates to over 17,000 kg of stem heartwood and almost 112,000 kg of root heartwood. There is an average of 4 ʻiliahi per acre for a total of over 12,000 trees (> 5 cm). Widespread regeneration due to past harvesting has resulted in plentiful regeneration with 47 regenerating stems per acre and 135,700 regenerating stems across the property.

Table 5. Property level results and inventory statistics for ʼiliahi.

Iliahi results summarized at the property level				
	Average Volume (m^3 ac^{-1})	(m^3 ha^{-1})	Total Volume (m^3)	$SE_{80\%}$ (%)
Whole tree (outer bark)	0.08	0.19	226	22%
Whole tree heartwood	0.03	0.07	77	28%
	Average Mass (kg ac^{-1})	(kg ha^{-1})	Total Mass (kg)	
Stem heartwood	6	15	17,029	31%
Root heartwood	40	99	111,916	23%
	Average Stems (ac^{-1})	(ha $^{-1}$)	Total stems	
ʻIliahi trees	4	10	12,090	20%
ʻIliahi regeneration	47	117	135,718	16%

It is important to note that the property standard error (Table 3.) is calculated at an 80% confidence interval for the purposes of the scope of this inventory. For the remainder of the results, the standard error is at the raw 68% confidence interval, which is also used to calculate the upper and lower limits of each variable.

5.1. Total ‘iliahi volume: whole tree and heartwood

The property-level whole tree volume is 226 m^3 with a standard error of 22% at 80% confidence (17% @ $SE_{68\%}$). Strata HA1 has the highest average volume with 0.42 m^3 per hectare. HA2 and HA3 both have an average of 0.25 m^3 per hectare. HA4 has the smallest average (aside from the a‘a strata) with 0.13 m^3 per hectare. Strata HA5 has a low average of 0.19 m^3 per hectare. However, HA3 and HA5 have the highest total volume because they are the biggest stratum with 70 m^3 and 54 m^3 respectively.

Note that the standard error of the estimate was quite low (6% - 11%) reflecting an inability to distinguish species in the satellite imagery. In contrast, higher standard errors occur in the measurement process, due to strong spatial variability in the ‘iliahi volume.

Table 6. Plot configurations (measured, estimated), average volume (m^3 ha^{-1}), and stratum and property-level statistics for total tree volume.

Stratum	Area (ha)	Plots		Total Volume (m^3 ha^{-1})		$SE_{68\%}$ (%)	
		Measure	Estimate	Avg.	CV (%)	Estimate	Total
A'a	88	0	19	0.01	43%	10%	48%
HA1	92	14	4	0.42	44%	10%	65%
HA2	173	23	16	0.25	42%	7%	73%
HA3	285	13	47	0.25	85%	11%	31%
HA4	151	11	19	0.13	52%	9%	49%
HA5	283	35	34	0.19	64%	8%	24%
All	**1,072**	**96**	**139**	**0.20**	**89%**	**6%**	**17%**

Table 7. Per-hectare and stratum-level total volume with lower and upper limits of the 68% confidence interval for volume (m^3).

Stratum	Area (ha)	Total Volume		Volume range (m^3)	
		(m^3 ha^{-1})	(m^3)	Lower	Upper
A'a	88	0.01	1	0	2
HA1	92	0.42	39	13	64
HA2	173	0.25	43	12	74
HA3	285	0.25	70	48	91
HA4	151	0.13	20	10	29
HA5	283	0.19	54	41	67
All	**1,072**	**0.20**	**226**	**125**	**327**

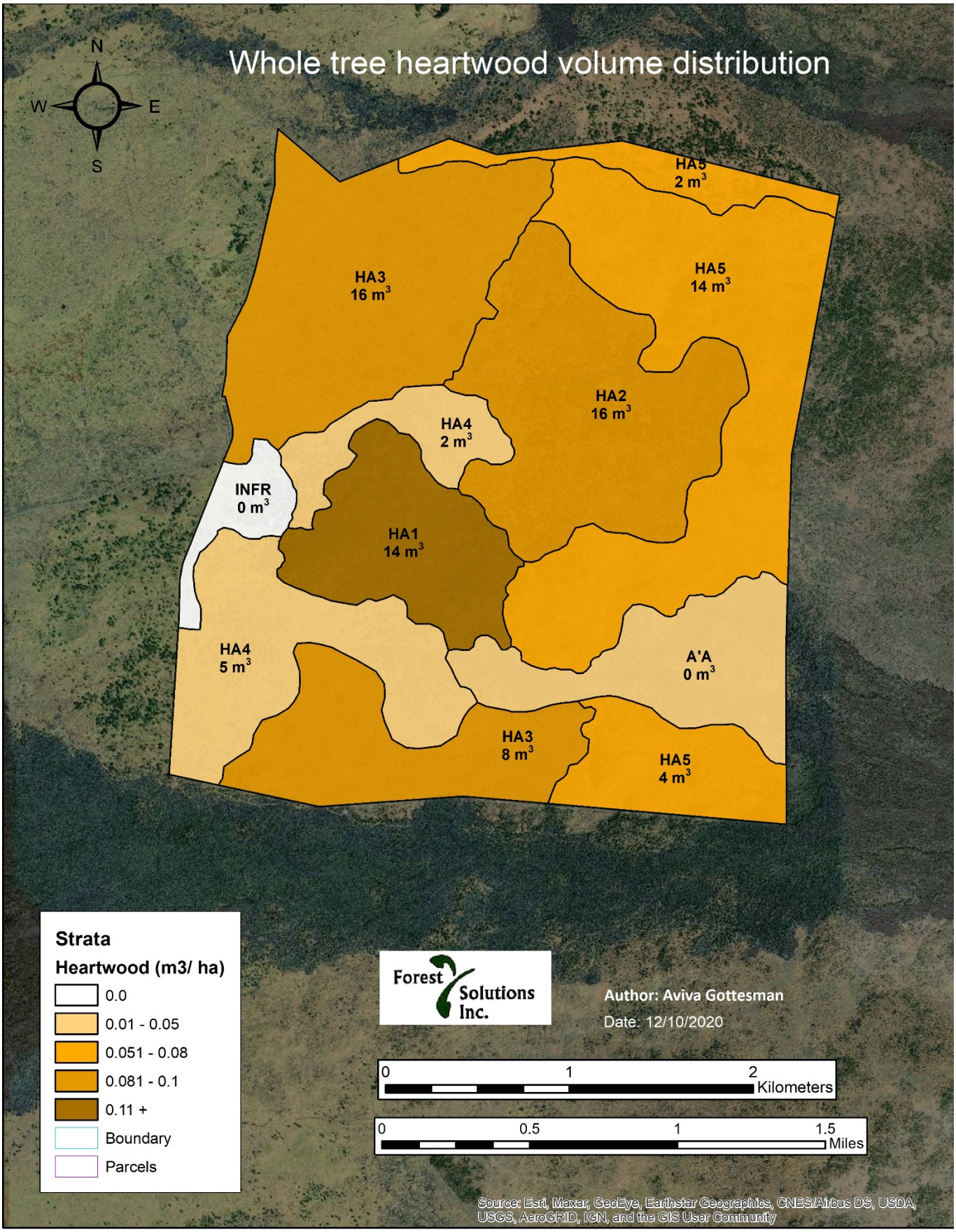

Figure 8. Total heartwood volume distribution at Haloa ʻAina, the light color stands have the lowest per-hectare densities and the dark orange stands have the highest per-hectare densities. The label is the total volume in the stand.

Results of the whole tree heartwood volume equation represent the total ‘iliahi heartwood volume. The property total is 77 m^3 with a standard error ($SE_{68\%}$) of 24%, ranging from 44 m^3 to 111 m^3. HA3 contains the highest heartwood volume with 24 m^3 total, although HA1 has the highest average with 0.15 m^3 per hectare, while HA4 has the lowest average volume with 0.04 m^3 per hectare resulting in 6 m^3 total. The heartwood distribution follows the total volume distribution as the two quantities use the same volume equation with the same measured inputs (root collar, segment count), though the equation parameters are different. The distribution is HA3 with the most volume, followed by HA5 and HA2 with similar volumes, then HA1, and finally HA4 containing the least volume.

Table 8. Plot configurations, average volume per-hectare and total strata-level volume, with stratum and property-level statistics for heartwood volume (m^3).

Stratum	Area (ha)	Plots		Heartwood		SE (%)		Volume range (m^3)	
		Measure	Estimate	(m^3 ha^{-1})	(m^3)	Estimate	Total	Lower	Upper
A’a	88	0	19	0.004	0.4	10%	46%	0.2	0.5
HA1	92	14	4	0.15	14	10%	50%	7	21
HA2	173	23	16	0.09	16	7%	73%	4	27
HA3	285	13	47	0.08	24	11%	31%	16	31
HA4	151	11	19	0.04	6	9%	50%	3	10
HA5	283	35	34	0.06	17	8%	25%	13	22
All	**1,072**	**96**	**139**	**0.07**	**77**	**6%**	**24%**	**44**	**111**

Table 9. Plot configurations, average mass per-hectare and total strata-level mass, with stratum and property-level statistics for stem heartwood mass (kg).

Stratum	Area (ha)	Plots		Stem Mass		$SE_{68\%}$ (%)		Mass range (kg)	
		Measure	Estimate	kg ha^{-1}	kg	Estimate	Total	Lower	Upper
A'a	88	0	19	1	67	10%	45%	37	97
HA1	92	14	4	31	2,883	10%	58%	1,209	4,557
HA2	173	23	16	8	1,308	7%	59%	531	2,086
HA3	285	13	47	18	5,188	11%	43%	2,977	7,399
HA4	151	11	19	10	1,543	9%	37%	979	2,108
HA5	283	35	34	21	6,041	8%	26%	4,475	7,607
All	**1,072**	**96**	**139**	**15**	**17,029**	**6%**	**22%**	**10,206**	**23,853**

Table 10. Plot configurations, average mass per-hectare and total strata-level mass, with stratum and property-level statistics for root tissue heartwood mass (kg).

Stratum	Area (ha)	Plots		Root Heartwood		$SE_{68\%}$ (%)		Root Volume Range	
		Measure	Estimate	kg ha^{-1}	kg	Estimate	Total	Lower	Upper
A'a	88	0	19	6	556	10%	38%	343	770
HA1	92	14	4	204	18,748	10%	44%	10,489	27,008
HA2	173	23	16	63	10,893	7%	57%	4,648	17,138
HA3	285	13	47	117	33,402	11%	31%	23,116	43,687
HA4	151	11	19	102	15,395	9%	39%	9,366	21,425
HA5	283	35	34	116	32,922	8%	21%	26,115	39,729
All	**1,072**	**96**	**139**	**99**	111,916	**6%**	**18%**	74,076	149,757

Mass results (kg) are based on a newly developed allometric equation and are not merely a factor of cubic meters divided by the standard 880 kg, which was previously the methodology to convert volume to mass. The equation is specifically for root mass tissue (kg) and is a function of root collar diameter, without the log segment input.

The inventory resulted in a property level of over 17,000 kg of stem heartwood, with a standard error of 22% ($SE_{68\%}$). Root heartwood tissue, which makes up a large part of the total ʻiliahi mass, is almost 112,000 kg for the entire property, with a standard error of 18%. HA3 and HA5 have the most stem and root heartwood mass total in the property. HA1 has the highest concentration, with 204 kg of root mass per hectare and 31 kg of

stem mass per hectare. HA2 has the lowest density (besides the a'a strata) with 63 kg of root mass per hectare and only 8 kg of stem heartwood per hectare.

Based on these results, and the following results on tree count totals, these results indicate an average root ball mass of 9kg. This is consistent with previous research studies that physically measured the roots of 'iliahi trees at Haloa 'Aina.

5.2. Merchantable 'iliahi oil mass

Table 11. Conversion of heartwood to oil based on landowners' average rates of conversion during the process.

Tree Segment Type	Oil Percent (%)	(kg ha^{-1})	Total Mass (kg)	Total oil (kg)
Stem heartwood	**3%**	**15**	**17,029**	**511**
Root heartwood	**5.50%**	**99**	**111,916**	**6,155**
			Total:	**6,666**

Based on conversations with the property owner, there is a 3% conversion rate of stem heartwood to 'iliahi oil. This is backed up by research from Curtin University that found a mean oil concentration of 2.3-3.1% in mature natural stands[5]. For the roots, which are more potent, this rate is between 5% and 6%. Based on global sandalwood research, Sri Lanka researchers found trees with up to 6.36% oil contents[6]. A study in India reported an average of 3-8% oil content in the heartwood they tested[7]. For the purposes of this report, root heartwood oil percent is 5.5% and stem heartwood conversion rate is 3%. These percentages are consistent with the oil yield percentages found in Sri Lanka[8], displayed in Figure 9. According to the reported average rate of conversion from heartwood to oil, the property currently supports 511 kg of oil from stem heartwood and 6,155 kg of oil from the roots. This results in a total of 6,666 kg of oil across the property.

Height from ground (mm)	Heartwood (% Area)	Oil yield (%w/w)
-150	71	6.36
0	86.5	4.81
500	64.2	4.35
1000	58.6	4.59
1500	43.7	3.92

Figure 9. Example of heartwood and oil content found in a tree in Santalum album in Sri Lanka.

[5] Brand, J. E., et al. "Comparison of oil concentration and oil quality from Santalum spicatum and S. album plantations, 8–25 years old, with those from mature S. spicatum natural stands." *Australian Forestry* 70.4 (2007): 235-241.
[6] Subasinghe, S. M. C. U. P. "Sandalwood research: a global perspective." *Journal of Tropical Forestry and Environment* 3.1 (2013): 1-8.
[7] Jones, Christopher G., Julie A. Plummer, and Elizabeth L. Barbour. "Non-destructive sampling of Indian sandalwood (Santalum album L.) for oil content and composition." *Journal of Essential Oil Research* 19.2 (2007): 157-164.
[8] Subasinghe, Upul, Manuri Gamage, and D. S. Hettiarachchi. "Essential oil content and composition of Indian sandalwood (Santalum album) in Sri Lanka." *Journal of Forestry Research* 24.1 (2013): 127-130.

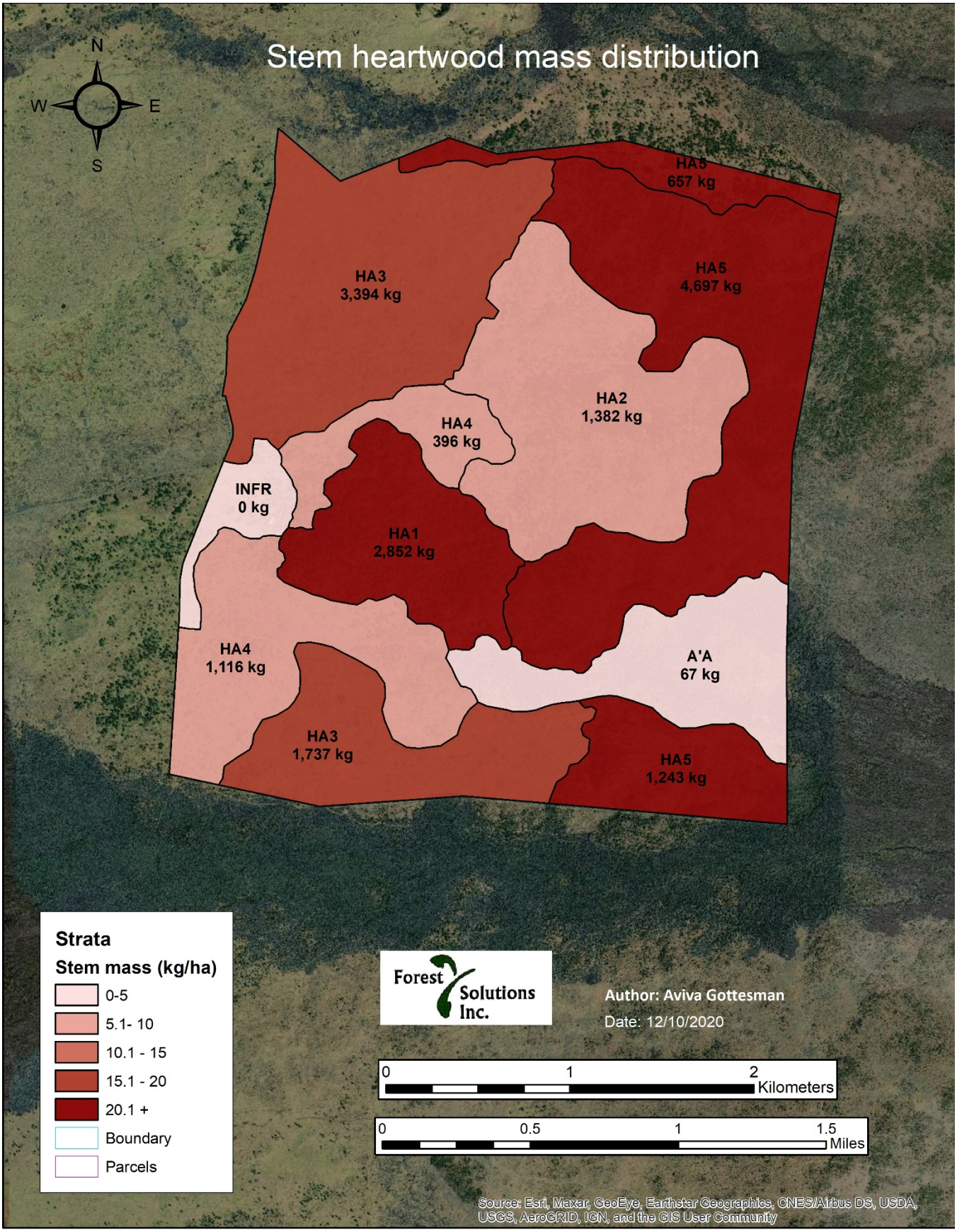

Figure 10. Total stem heartwood mass distribution at Haloa 'Aina, where the light red stands have the lowest per-hectare densities and the dark red stands have the highest per-hectare densities. The label is the total mass in the stand.

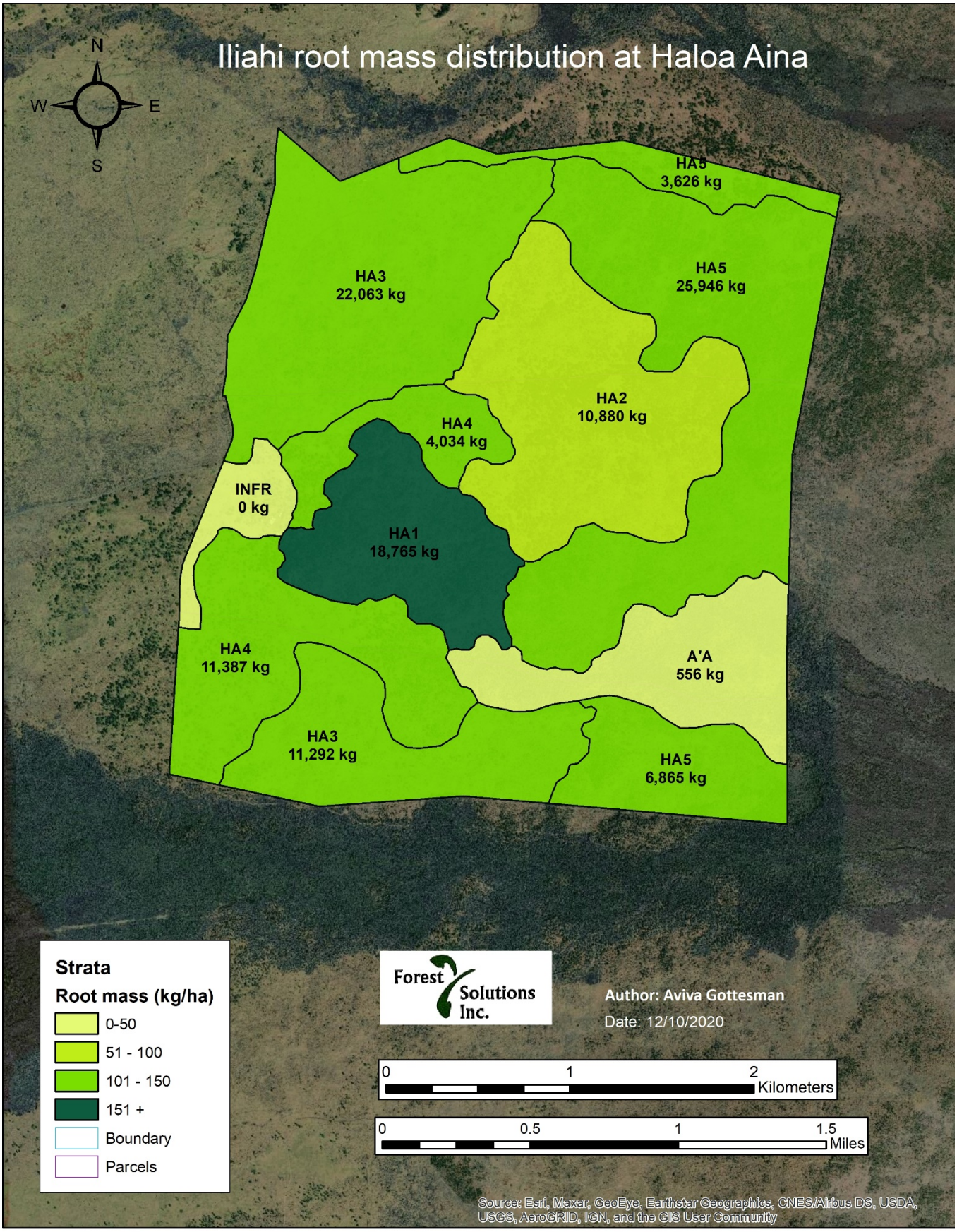

Figure 11. Total root heartwood mass distribution at Haloa ‘Aina, where the light green stands have the lowest per-hectare densities and the dark green stands have the highest per-hectare densities. The label is the total mass in the stand.

5.2.1. ‘iliahi populations

5.2.1.1. Existing cohort

This Point-3P inventory yielded an estimated 12,090 ‘iliahi trees (>5 cm) in the existing population on the property. The standard error for tree count was 16% at 68% confidence, which was used to calculate the property level tree range. The result indicates that we are 68% confident that the number of ‘iliahi trees on the property is between 8,414 and 15,766. At 80% confidence, the standard error is 20% which was the requirement for this inventory.

HA1 has the highest density of ‘iliahi with 27 per hectare. HA1 was categorized as high density stems and low intensity logging, therefore it makes sense that it remains the strata with the most trees per hectare. HA2 and HA5 are the next highest with 16 and 13 trees per hectare, respectively. However, HA5 has almost 1,000 more total trees than HA2 due to the large size of the HA5 strata. Both HA2 and HA5 were heavily logged.

HA3 and HA4 have the lowest density of ‘iliahi with 6 and 7 trees per hectare, therefore the level of logging on HA3 and HA4 did not greatly impact the current ‘iliahi population.

Table 12. Mature ‘iliahi cohort for property- and stratum-level populations and inventory statistics.

Stratum	Area (ha)	Plots		Trees		$SE_{68\%}$ (%)		Tree count range	
		Measure	Estimate	ha^{-1}	Total	Estimate	Total	Lower	Upper
A'a	88	0	19	1	55	10%	31%	38	73
HA1	92	14	4	27	2,472	10%	30%	1,721	3,223
HA2	173	23	16	16	2,807	7%	44%	1,572	4,043
HA3	285	13	47	7	2,063	11%	38%	1,285	2,840
HA4	151	11	19	6	949	9%	29%	679	1,220
HA5	283	35	34	13	3,743	8%	17%	3,119	4,367
All	**1,072**	**96**	**139**	**10**	**12,090**	**4%**	**16%**	**8,414**	**15,766**

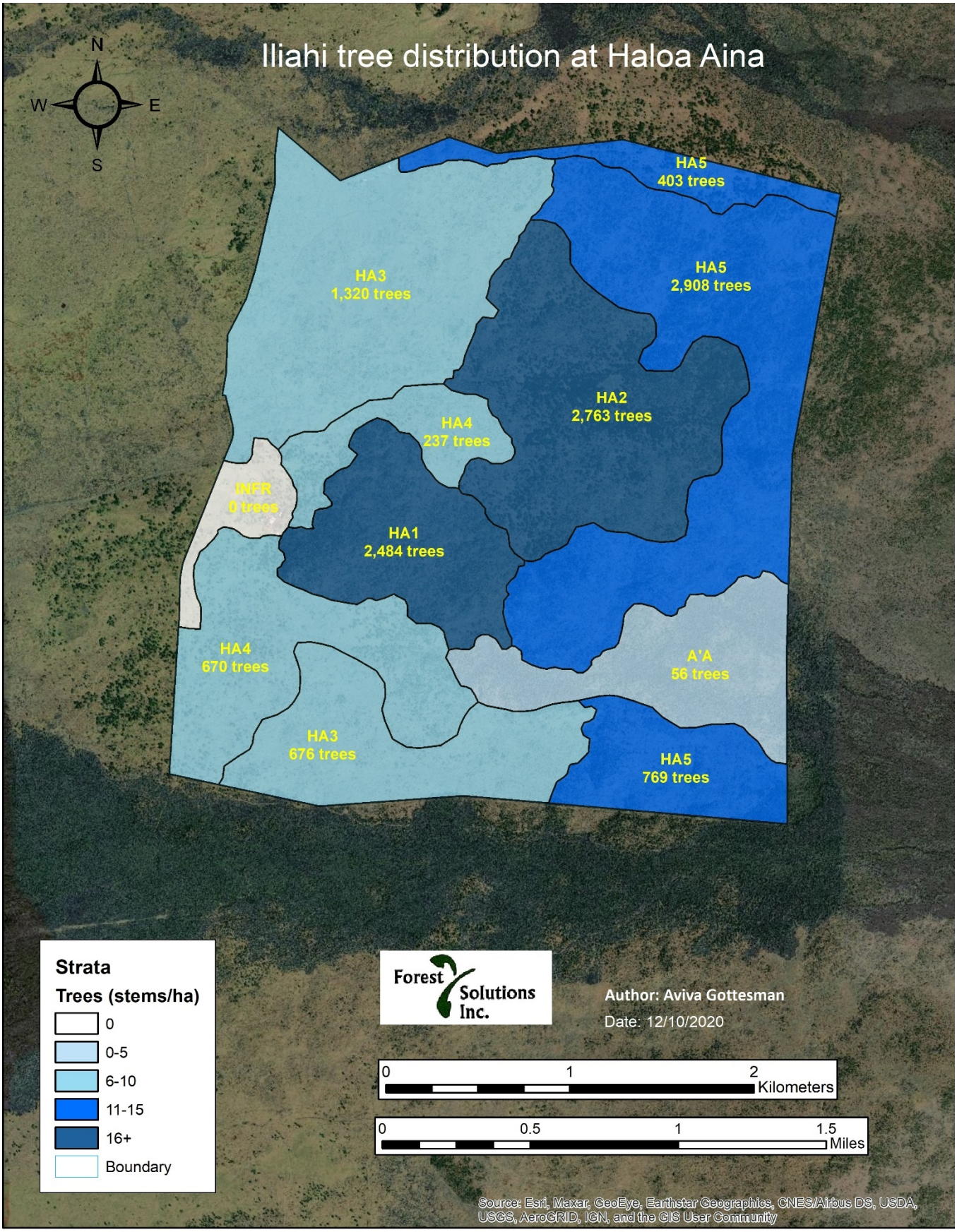

Figure 12. ʻIliahi tree distribution at Haloa ʻAina, where the light blue stands have the lowest per-hectare densities and the dark blue stands have the highest per-hectare densities. The label is the total trees in the stand.

5.2.1.2. Regenerating cohort

Table 13. ‘Iliahi regeneration census and inventory statistics for Haloa ‘Aina strata and complete property.

Stratum	Area (ha)	Plots		Regeneration (ha^{-1})		SE (%)		Range	
		Measure	Estimate	(ha^{-1})	Sum	Stratum	Total	Lower	Upper
A'a	88	0	19	5	437	10%	31%	301	573
HA1	92	14	4	403	37,080	10%	19%	30,023	44,136
HA2	173	23	16	131	22,667	7%	34%	14,854	30,479
HA3	285	13	47	91	26,058	11%	31%	17,871	34,246
HA4	151	11	19	50	7,485	9%	49%	3,815	11,156
HA5	283	35	34	148	41,991	8%	22%	32,765	51,217
All	**1,072**	**96**	**139**	**117**	**135,718**	**4%**	**12.8%**	**99,629**	**171,808**

The most significant ‘iliahi resource at the property is the abundance of root sprouts and saplings. Occasional seedlings, frequent root sprouts, and saplings <5 cm were all aggregated into the “regeneration” class and counted at each plot. Shrubs that contained many stems were counted as one individual when it came from the same stump. HA1 has the densest regeneration with over 400 stems per hectare, which is 3-4 times greater than the other stratum. Across the property, the regeneration average was over 100 stems per hectare. In total, we calculated over 135,000 seedlings and saplings at a standard error of 12.8%. The error was the lowest out of all the variables, as the spatial variability of regeneration was less extreme.

Overall, the level of regeneration is more than sufficient for replacement of the currently existing mature tree cohort. The property contains over 10 times the amount of regeneration as mature ‘iliahi trees.

Figure 13. Photo taken at Haloa ‘Aina of ‘iliahi saplings growing from a harvested stump.

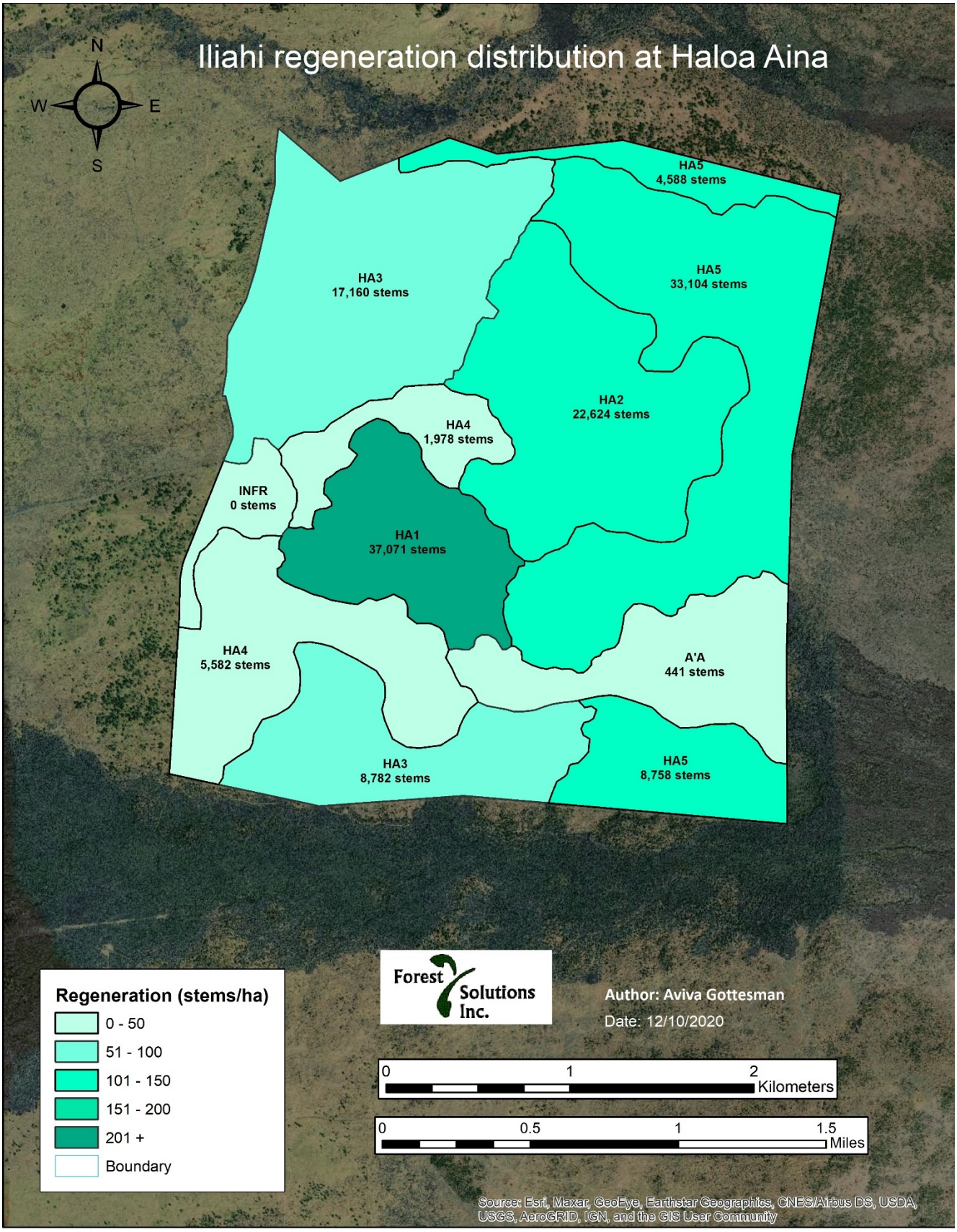

Figure 14. ʻIliahi root sprout and sapling (regeneration) distribution at Haloa ʻAina, where the light teal stands have the lowest per-hectare densities and the dark teal stands have the highest per-hectare densities. The label is the total regeneration in the stand.

5.2.2. ‘Iliahi diameter distribution

Of the total trees on the property, 62% have a root collar less than 4 inches, though these trees only represent 2% of the total volume. Most of the volume is in trees that are over 8 inches (58% of the volume). The 5-7 inch size class contains 28% of the trees and 40% of the volume. However, for trees over 4 inches the heartwood root mass is about the same for the 5-7 inch size class and the 8 + inch size class. This is because the roots spread out quickly when the tree is young, growing large even before the tree itself has grown.

Table 14. Distribution of ‘iliahi trees, total volume, and heartwood root mass by diameter class (in).

Root Collar Diameter Class		Tree		Volume (m^3)		Roots (kg)	
cm	inches	(ha^{-1})	Total	(ha^{-1})	Total	(ha^{-1})	Total
5	2	3.4	3,981	0.00	0	1	1,037
8	3	1.8	2,039	0.00	0	3	3,109
10	4	1.3	1,457	0.00	5	6	7,049
13	5	1.2	1,360	0.02	18	12	13,625
15	6	1.0	1,214	0.03	35	18	20,262
18	7	0.7	777	0.03	37	16	18,361
20	8	0.6	728	0.06	64	20	22,276
23	9	0.1	97	0.01	7	3	3,954
25	10	0.3	291	0.03	37	12	13,601
28	11	0.1	97	0.02	19	5	5,377
36	14	0.0	49	0.00	5	3	3,265
	Total:	**10**	**12,090**	**0.19**	**226**	**99**	**111,916**

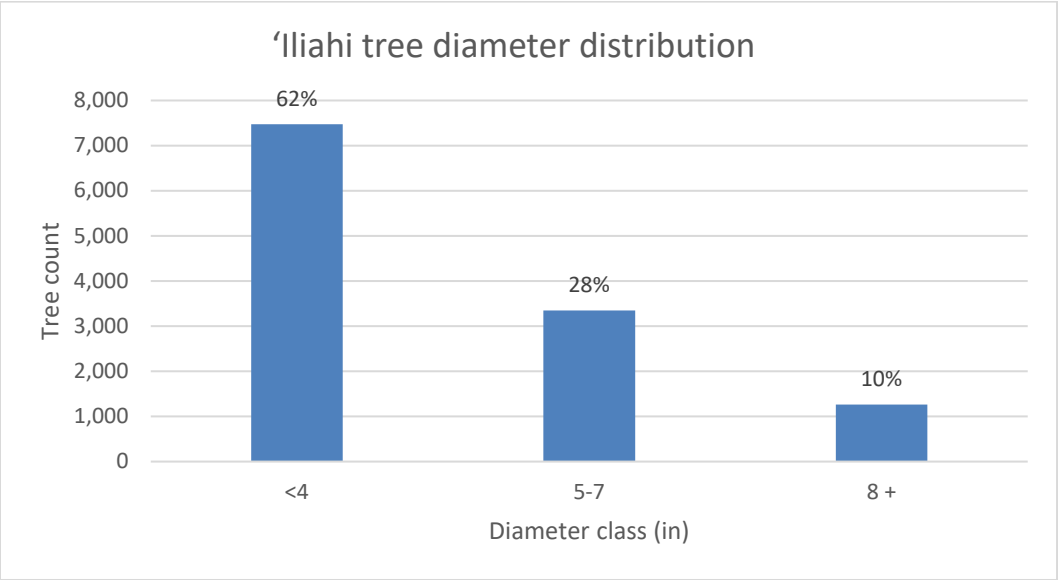

Figure 15. Distribution of total trees by diameter class (in) with percent of total trees labeled above each bar.

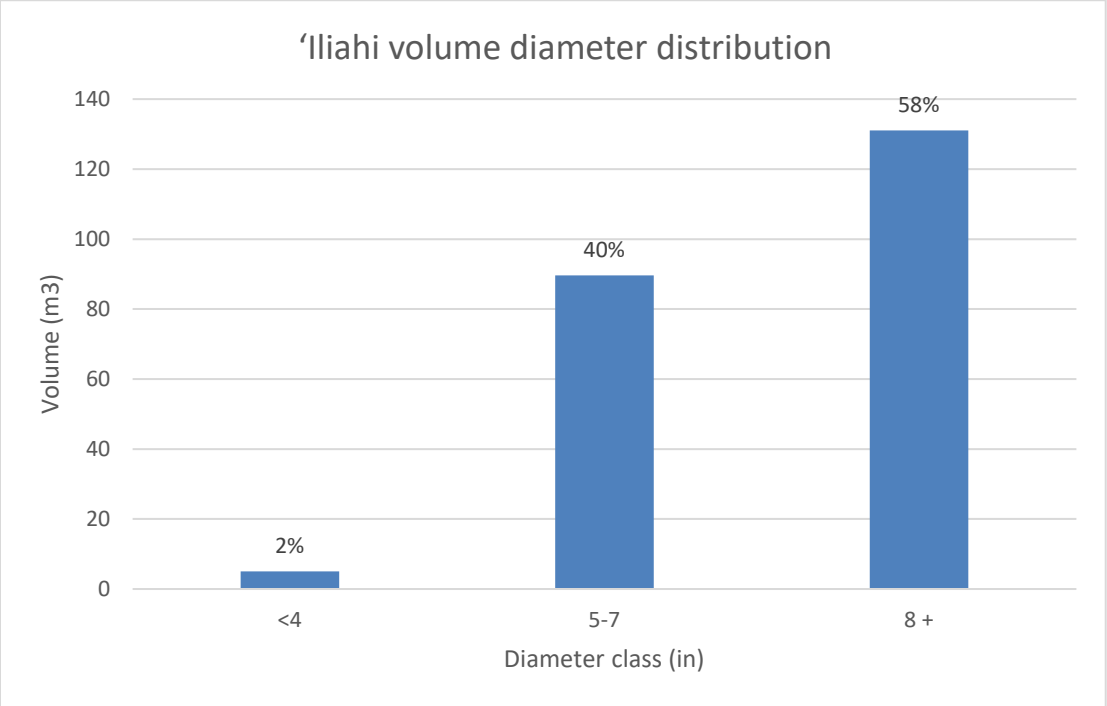

Figure 16. Distribution of total volume (m^3) by diameter class (in).

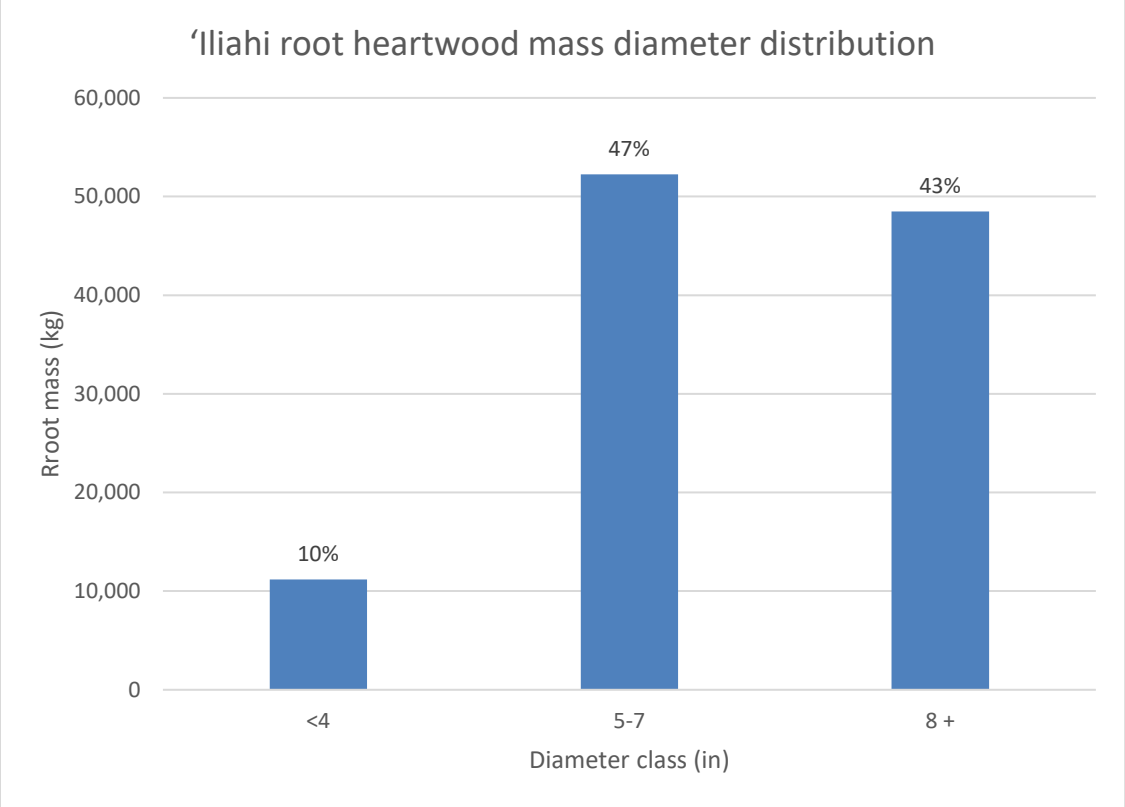

Figure 17. Distribution of root heartwood mass by diameter class (in).

6. Additional results

6.1. Koa Results

On average, there are very few koa scattered throughout most of the property resulting in 11 koa per acre and 474 board feet per acre. However, the results are heavily influenced by strata HA2 which was harvested heavily in the 1980's and now contains a dense, even-aged stand of ~ 40-year old koa. The koa stand is not consistent throughout the entire strata and instead is characterized as patchy with varying densities. HA2 contains 77% of the total koa volume with 711,292 board feet out of the total 924,558 board feet on the property. HA4 is the next largest strata containing 15% of the total volume with 139,276 board feet. HA3, HA5, and HA1 contain significantly less koa volume, especially HA2 which has almost no koa.

Due to the extreme variability and general lack of koa, the variability is remarkably high for all the stratum. The total standard error is 30% with a confidence of 68%, mostly because only one third of the plots contain koa, the remaining two thirds of measured plots were zero-koa plots.

According to the analysis, there are more koa than 'iliahi, with over 21,000 koa trees on the property ($SE_{68\%}$ = 33%). This is solely due to the concentration of 79% of the koa trees in HA2, with the remaining four stratum only containing 4,332 trees. At 32% standard error, we are 68% confident that the actual number of koa in HA2 is between 11,314 and 22,147 trees.

Table 15. Koa per-acre and totals for tree population and volume (board feet), reported at the stratum-level and property-level, as well as inventory statistics. The SE is high due to a highly variable distribution across the landscape.

Stratum	Basal area (ft^2)	
	(ft^2 ac^{-1})	SE_{68} (%)
HA1	0.1	27%
HA2	20.8	15%
HA3	0.3	26%
HA4	4.7	14%
HA5	1.0	40%
Total	**5.9**	**29%**

Table 16. Basal area (ft2 ac-1) of koa at the stratum-level and property-level with accompanying statistics.

Strata	Koa (trees ac^{-1})	Total Koa	$SE_{68\%}$ (%)	Volume (bf ac^{-1})	Total Volume (bf)	$SE_{68\%}$ (%)
HA1	0.5	105	68%	5	1,163	71%
HA2	39.2	16,731	32%	1,667	711,292	30%
HA3	0.3	233	72%	26	18,054	70%
HA4	7.9	2,965	56%	373	139,276	41%
HA5	1.5	1,029	53%	78	54,772	66%
Total	**11**	**21,062**	**33%**	**474**	**924,558**	**30%**

Koa basal area distribution is a similar distribution as koa volume, with an average of 20.8 ft^2 per acre in HA2 ($SE_{68\%}$ = 15%) and 4.7 ft^2 per acre in HA4. HA5, HA3, and HA1 only support 1 ft^2 per ac or less. This results in an average of 5.9 ft^2 per acre across the property at a standard error of 29%.

Figure 18. Examples of mature koa tree (right) and immature koa trees (left) which are characterized by stem color and diameter size.

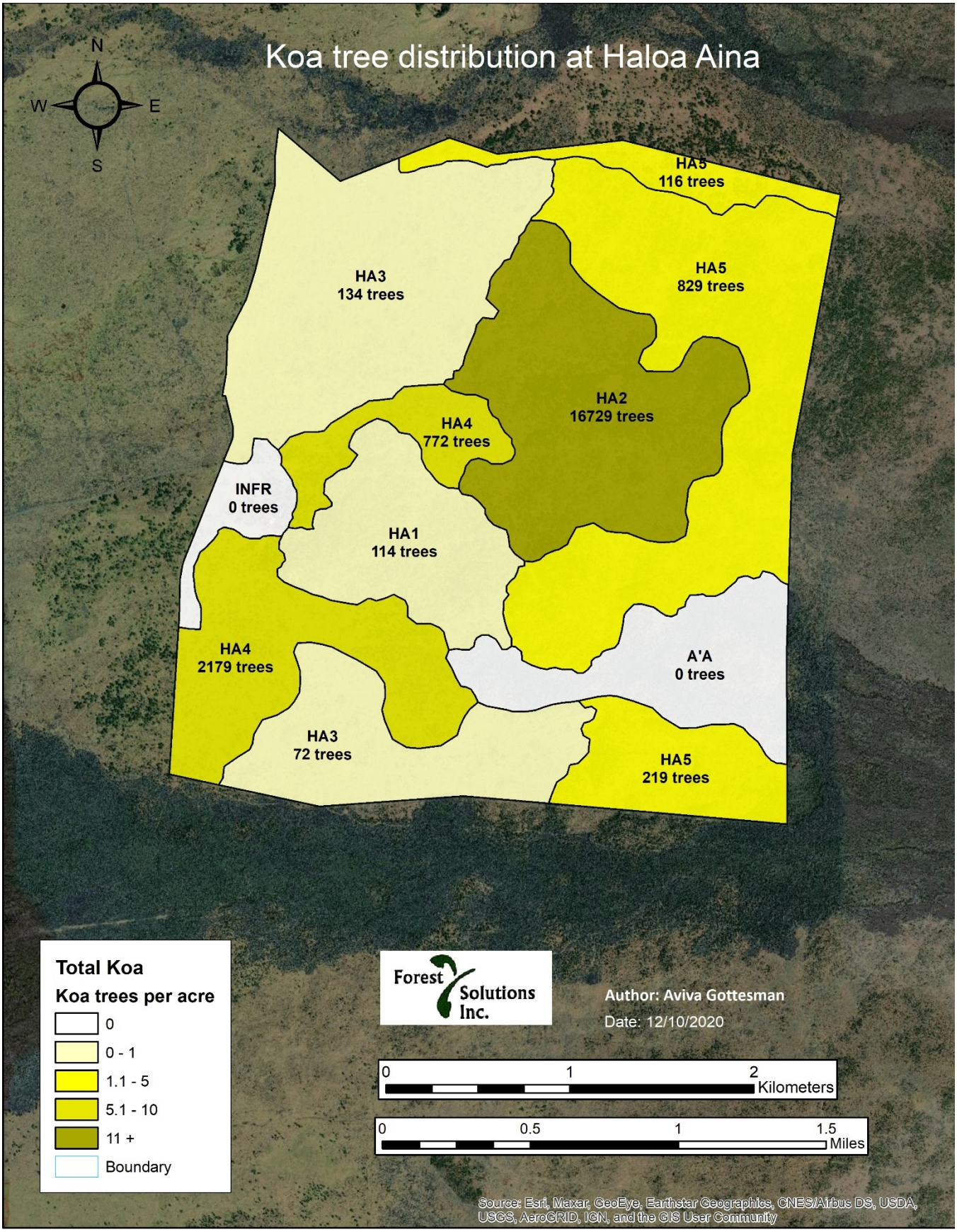

Figure 19. Koa tree distribution at Haloa ʻAina, where the lighter color stands have the lowest per-acre densities and the dark yellow stands have the highest per-acre densities. The label is the total koa trees in the stand.

Diameter Class (in)	Tree distribution	Volume (BF)	
0	58	2	**<8 inches**
2	465	1,606	
4	3,956	28,155	**Not Merchantable**
6	5,644	89,769	
8	4,480	126,750	**8- 20 inches**
10	2,967	141,696	
12	1,222	84,761	
14	989	97,787	**Merchantable**
16	640	86,178	
18	175	31,107	
20	116	27,600	**20 + inches**
22	116	33,457	
24-28	0	0	
30	58	33,804	**Highly Merchantable**
32	58	44,380	
34	116	97,504	
Total	21,062	924,558	

Table 17. Koa diameter distribution.

Figure 20. Two plot center photos picturing stands of dense even-aged koa in strata HA2.

All koa under 8 inches are considered “not merchantable” because they have not reached maturity or a big enough size to be worth harvesting. Based on the diameter distribution in 2-inch intervals, 48% of the koa trees are not merchantable, 50% are in the merchantable category, and 2% are highly merchantable. That 2% of highly merchantable trees contain 26% of the total volume of all the koa, 61% of the volume is in the merchantable category, and 13% of the total volume is not yet merchantable. A small number of large trees are responsible for most of the volume, which follows a typical forest structure. Based on the distribution of volume, 119,500 board feet are not merchantable, over 568,000 are in the merchantable category and only 236,746 board feet are highly merchantable.

6.2. Forest Health

6.2.1. Additional species

We measured 21 subplots and only one of them contained a tree other than koa and ʻiliahi that was over 10-cm, which was an ʻōhiʻa tree. Because the methodology was to record trees over 10 cm, the species of shrubs and saplings under 10 cm were recorded as an observation. Māmane was the most frequently found species, present in 90% of the subplots. Almost all the various forest types contained a māmane component, whether it was a few scattered around the plot on the southern side of the property or a dense covering of pure māmane like in the center part of the property.

ʻAʻaliʻi shrubs, naio saplings, and ʻiliahi saplings were present in ~ 50% of the subplots. ʻōhiʻa and koa regeneration was low at 10% and 14% frequency. Pūkiawe shrubs were also found in 14% of the subplots, mostly in the southern boundary near the aʻa flow strata.

Most of the older naio has died due to the thrip; however, a younger population of naio continues to thrive.

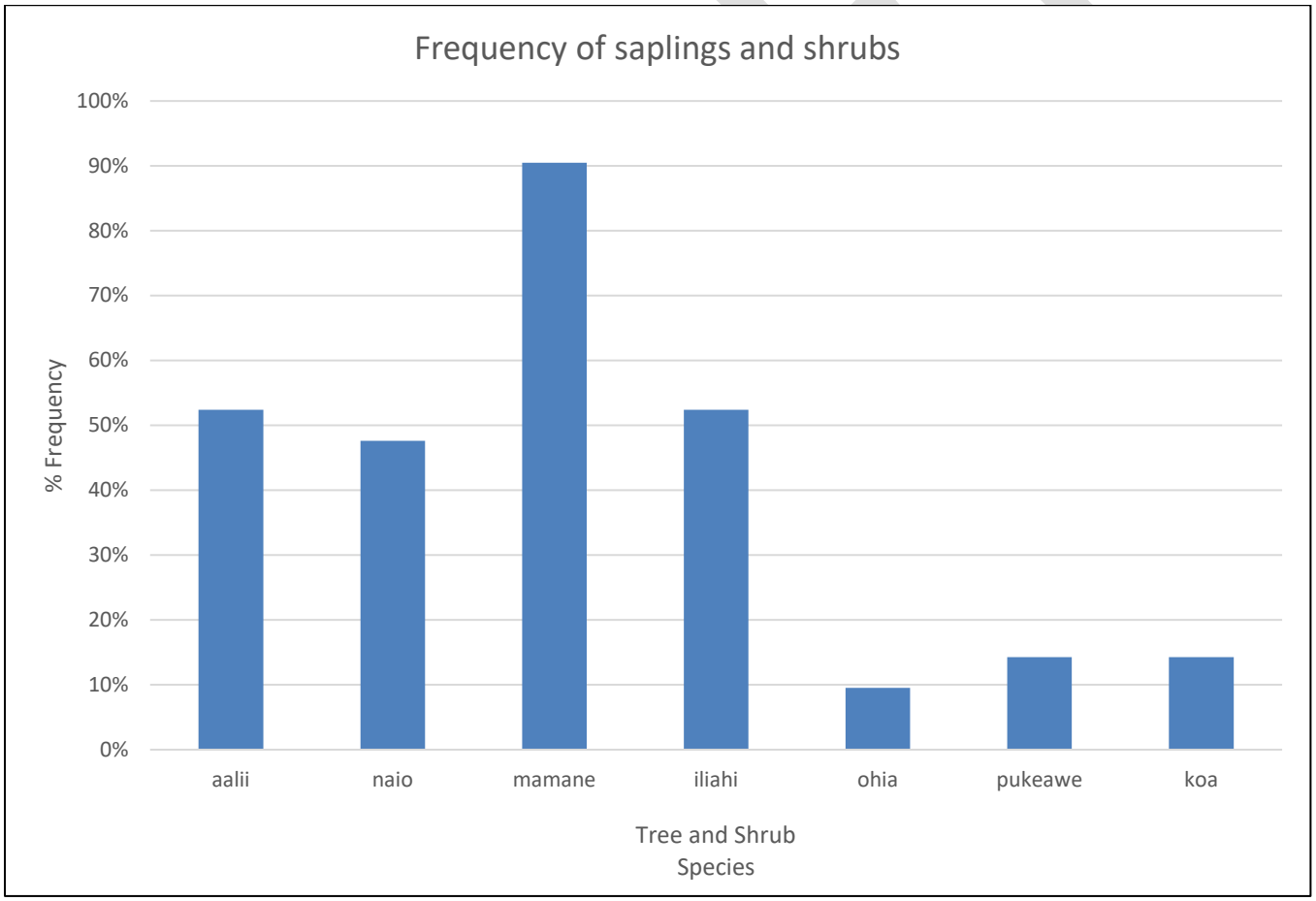

Figure 21. Frequency of native saplings and shrubs found in 10-m subplots.

6.2.2. Groundcover

Table 18. Frequency and average percent cover of native and non-native groundcover at Haloa ʻAina.

Species	Scientific Name	Native/ Non-native	Frequency (%)	Average Percent Cover (%)
Hair grass	*Deschampsia nubigena*	Native	14%	2%
ʻiliahi	*Santalum paniculatum*	Native	10%	< 2%
koa	*Acacia koa*	Native	10%	< 2%
māmane	*Sophora chrysophylla*	Native	10%	4%
iwa iwa	*Dryopteris decipiens*	Native	5%	< 2%
ʻaʻaliʻi	*Dodonaea viscosa*	Native	5%	< 2%
pūkiawe	*Leptecophylla tameiameiae*	Native	5%	6%
Pacific lovegrass	*Eragrostis atropioides*	Native	5%	5%
naio	*Myoporum sandwicense*	Native	5%	2%
kikuyu	*Pennisetum clandestinum*	Non-native	100%	53%
meadow rice	*Ehrharta stipoides*	Non-native	100%	19%
fireweed	*Senecio madagascariensis*	Non-native	62%	4%
mullein	*Verbascum thapsus*	Non-native	43%	3%
foxtail	*Alopecurus L.*	Non-native	33%	10%
African dropseed	*Sporobulus africanus*	Non-native	29%	3%
Sprawling bluebell	*Wahlenbergia gracilis*	Non-native	29%	2%
common clover	*Trifolium Spp.*	Non-native	29%	2%
cape ivy	*Delairea odorata*	Non-native	24%	2%
violet night		Non-native	19%	< 2%
Spanish needle	*Bidens pilosa*	Non-native	14%	< 2%
sweet vernal	*Anthoxanthum odoratum*	Non-native	14%	10%
Yorkshire fog	*Holcus lanatus*	Non-native	14%	3%
wireweed	*Sida acuta*	Non-native	10%	< 2%
horseweed	*Conyza bonariensis*	Non-native	10%	2%
Molasses grass	*Melinis minutiflora*	Non-native	5%	< 2%
cranesbill geranium	*Geranium homeanum*	Non-native	5%	< 2%
Hart's-tongue fern	*Asplenium scolopendrium*	Non-native	5%	< 2%
fountain grass	*Pennisetum setaceum*	Non-native	5%	< 2%
Hairy cat's ear	*Hypochaeris radicata*	Non-native	5%	< 2%
bur clover	*Medicago polymorpha*	Non-native	5%	3%
fern		Unknown	5%	5%
bare ground			33%	37%

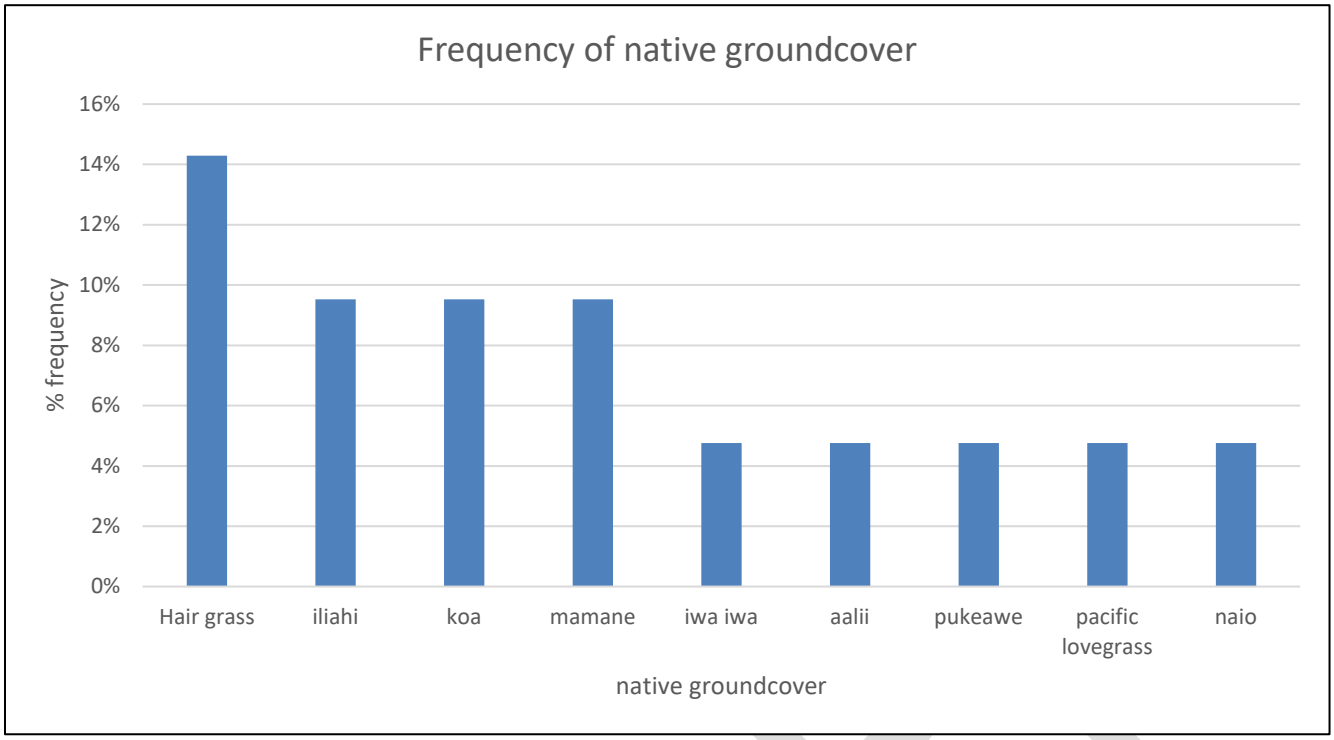

Figure 23. Percent frequency of native groundcover presence in subplots.

Figure 22. Cape ivy and banana polka photographed at Haloa ʻAina, these invasives could be problematic if left unmanaged.

7. Conclusion

The 2020 inventory had a 15% increase in total heartwood and a 33% increase in ʻiliahi trees and regeneration. This could be due to the forest growing over the past 6 years or could be a result of the standard error which is between 16-30% depending on the variable and was similarly high in 2014. This is due to the highly variable nature of the open koa-māmane forest. The main differences can be found in the mass variables. In 2014, mass was calculated by taking the volume and dividing it by 880 to convert to m^3 to kg. In this report, tissue-level mass equations were implemented to specifically determine stem heartwood and root heartwood according to newly developed models. The new allometric equations and methodology are based on additional research over the past 6 years and therefore are more accurate. The stem heartwood in 2020 does not include branches, while the 2014 "stem heartwood" referred to all the aboveground heartwood. The 2020 inventory resulted in 7 times the amount of root heartwood, which can be attributed to the newly improved equation. Overall, these results indicate that the forest is growing and that the volume of ʻiliahi is increasing.

Table 19. Comparison of the 2014 and 2020 inventory results.

ʻIliahi results summarized at the property level		
	2020 Results	**2014 Results**
	Total Volume (m^3)	
Whole tree (outer bark)	**226**	**N/A**
Whole tree heartwood	**77**	**65.8**
	Total Mass (kg)	
Stem heartwood	**17,029**	**Total aboveground heartwood: 41,785**
Root heartwood	**111,916**	**16,086**
	Total stems	
ʻIliahi trees	**12,090**	**8,143**
ʻIliahi regeneration	**135,718**	**90,317**

8. References

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9. Appendix

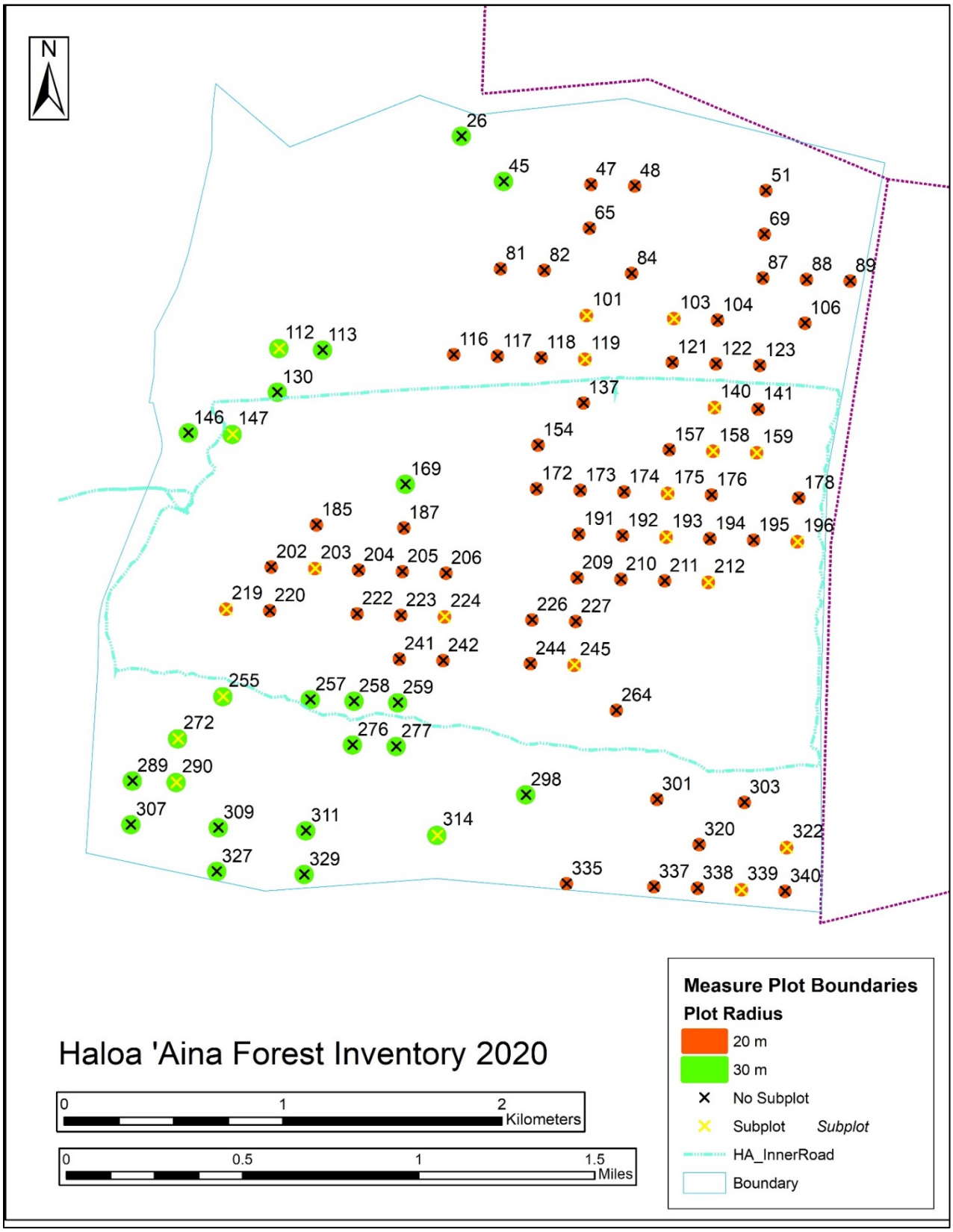

Figure 24. The measured plots of 2020, red plots are 20 m radius and green plots are 30 m radius plots.