Kapāpala Koa Canoe Forest Inventory

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1. Executive Summary

This document presents forest inventory data comprising basal area, volume, and diameter class distribution, for *Acacia koa* (koa) at DOFAW Kapāpala Koa Canoe Management Area (KKCMA), in Kaʻū, Hawaiʻi Island. The inventory occurred between December 2019- March 2020. The property is designated as Tax Map Keys (TMK) (3) 9-8-001:014, which ranges from 3,640 to 5,100 feet above sea level across 1,240.5 acres. The primary objective of this inventory was to estimate property wide koa log volume, with a focus on categorizing logs based on the requirements of utilization for traditional canoe carving. The two secondary objectives included refining stratification of the area based on koa size and forest type, as well as providing opportunities for community members and relevant stakeholders to participate in the forest inventory. The inventory was conducted across four strata using a variable area plot sampling method. Volume data and associated statistics are calculated at the forest level for each stratum, as well as diameter distributions and canoe log distributions.

- **Total koa volume for the entire property reached over 5.5 million Scribner board feet of koa (5.38 million International ¼ in bf), approximately equivalent to 878,000 cubic feet with an error of 19.1%.**
    - **Out of that 5.5 million board feet, 1 million bf are estimated to be canoe logs and 1.46 million bf of young canoe logs. Canoe logs are rare, but they are voluminous.**
- **Results of the 100% tally along the roadsides at KKCMA identified 20 canoe trees totaling 35,000 board feet and 192 young canoe trees totaling 105,600 board feet.**

Table 1: Overall inventory results by strata for *Acacia koa* in KKCMA.

Strata	Basal Area		VBAR		Volume/ac		Acres	Total Scribner bf	Total Cubic ft
	Koa (ft^2/ac)	Other (ft^2/ac)	Scribner bf	cu. Ft	Scribner bf	cu. Ft			
K01	22.9	139	95	19	2,168	435	324	702,489	140,858
K02	20.8	135	187	31	3,878	650	386	1,496,898	250,716
K03	46.8	85	185	27	8,659	1,271	323	2,796,937	410,636
K04	25.4	127	96	14	2,450	366	207	507,064	75,801
Forest Level	**29.6**	**121**	**158**	**25**	**4,660**	**737**	**1,240**	**5,503,388**	**878,012**

Relatively few koa canoe trees and young koa canoe trees are present in K01 and K04 (the lowest and the highest strata). The middle two strata contain the most koa volume, across all categories of koa types and sizes. These middle strata also appear to be the most pristine, healthy native forest of the whole property according to the understory assessment and koa volume analysis.

The presence of ungulates and the lack of light availability in the forest has a negative impact on koa regeneration. This inventory indicates that the forest could benefit from silvicultural interventions to improve conditions for the regeneration and growth of a future population of koa canoe trees.

2. Introduction

2.1. Site Description

The Kapāpala Koa Canoe Management Area (KKCMA) is a parcel of 1,240 acres designated in 1991 for the sustainable cultivation and harvest of koa trees for traditional canoe logs. The objective of the KKCMA is to be managed for koa logs (*Acacia koa*) for the purpose of constructing traditional voyaging canoes, fishing canoes, and racing canoes. With high demand for koa logs from over 77 Hawaiian canoe racing clubs and organizations, the KKCMA is the only forest designated for this purpose. The KKCMA has been added to the Kaʻū Forest Reserve.

The forest together with parcels along the northern and western boundaries are in the agriculture land use district. The surrounding agriculturally designated parcels are under a long-term lease for cattle grazing by Kapāpala Ranch. The southern and eastern boundaries of the KKCMA parcel are in the conservation land use district, protective subzone. A hog wire fence surrounds the entire perimeter of the KKCMA parcel, with an access road on the interior side of this fence. There is a single, mid-elevation cross road running north-south with an abandoned and non-functioning fence on the uphill (west) side. Before KKCMA was set aside for the management of koa canoe logs, the land had a history of grazing and occasional timber harvests. There is evidence of continual grazing below the cross road and feral cattle trails above the cross road.

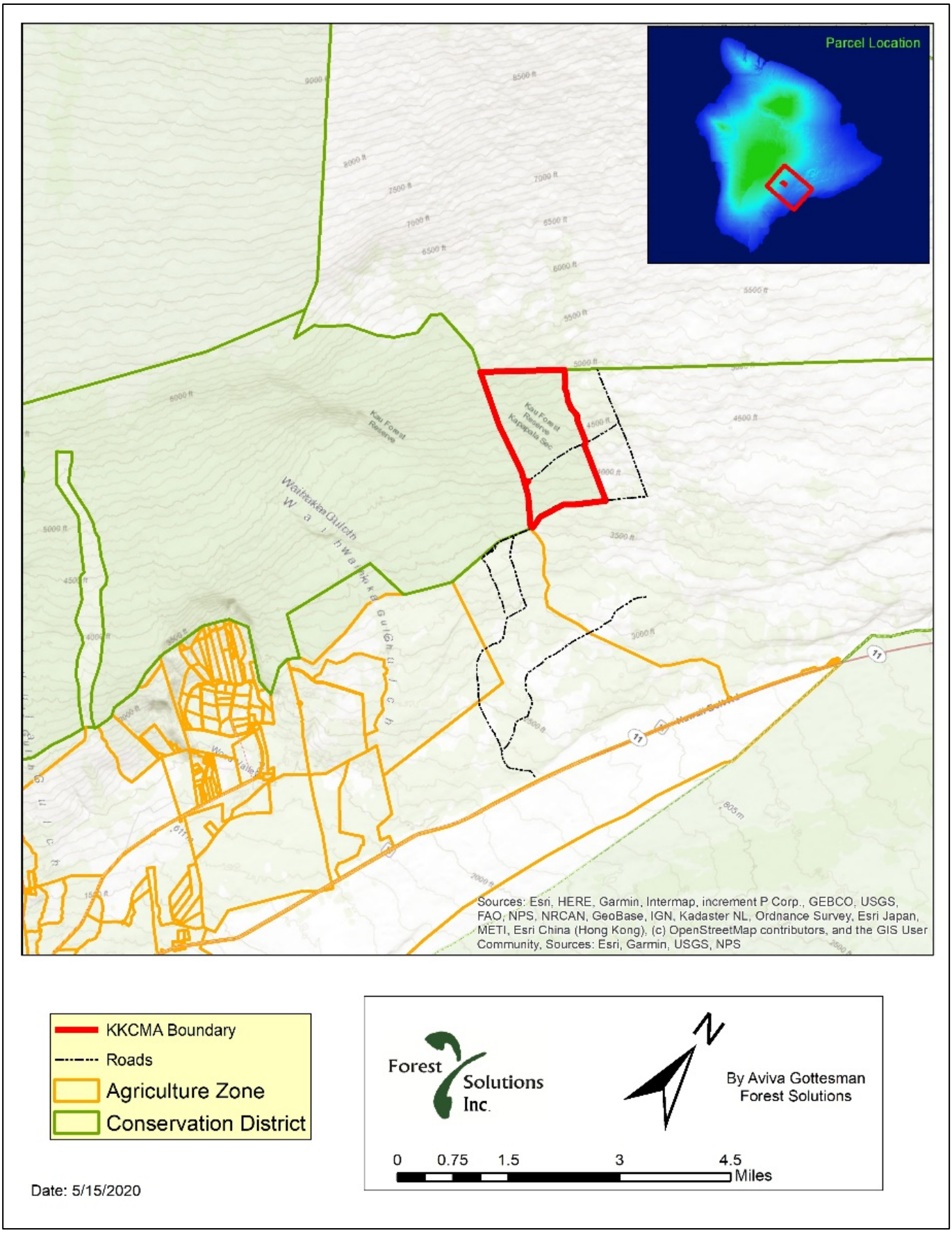

Figure 1: KKCMA TMK boundary and location on the island of Hawaii.

2.2. Ecological Description

The KKCMA is categorized in the ecological site description catalog as *Subhumid and Humid Low and Intermediate Mountain Slopes*. In the region of Kaʻū, KKCMA has an elevation ranging from 3,640 to 5,100 feet above sea level. The region has a mean annual rainfall of 63.5 inches (Rainfall Atlas of Hawaiʻi) with most of the rainfall occurring from November through March. Average annual temperature is 54 to 73 degrees F. The geology is comprised of basic igneous rocks (basalt) beneath weathered volcanic ash and cinders. The soils are mainly Keei and Kekake soils, ranging from very shallow to very deep, formed in volcanic ash over pahoehoe lava.

The vegetation at KKCMA is classified as *Montane Wet Forest* (Wagner 1999), with the lower portion (below 4,100 ft) presenting as an *ʻŌhiʻa/Uluhe* forest and the upper portion (4,100-5,100 ft) characterized as a *Koa/ ʻŌhiʻa Montane Wet Forest.* The lower forest canopy is characterized by groves of even-aged ʻōhiʻa (*Metrosideros polymorpha*) with a large component of uluhe ferns (*Dicranopteris linearis*) in the understory. Remnant, larger koa trees can be found in the upper region of the KKCMA, suggesting previous harvesting activities. Subcanopy species throughout the property include pilo (*Coprosma rhynchocarpa*), kōlea (*Myrsine* lessertiana), kawaʻu (*Ilex anomala*), kōpiko (*Psychotria hawaiiensis*), naio (*Myoporum sandwicense*), and ōlapa (*Cheirodendron trigynum)*. In the upper forest, hapuʻu ferns (*Cibotium glaucum*) form a dense understory, promoting shade-tolerant shrubs below. The ground cover in the lower forest is comprised of non-native grasses such as kikuyu (*Pennisetum clandestinum*) and meadow-rice grass (*Ehrharta stipoides*), while the upper forest maintains native understory biodiversity. The thick sward of alien grasses, lack of native understory and remnant cross-fence all suggest that the lower forest was once harvested and grazed intensively.

Many native bird populations are found at KKCMA. Non-native fauna includes a large population of feral pigs. The presence of cows was observed through excrement and evidence of browse throughout the parcel, especially in the lower forest, as well as sighting a cow inside the forest above the cross-road.

Figure 2. Scarified area of the forest with koa and ʻōhiʻa trees and a grassy understory.

2.3. Koa Canoe Log Description

There is a rich history and language around the various types of canoes traditionally made by the Hawaiian people. The three main types of canoes that the inventory is targeting through the identification of "canoe logs" are as follows[1]:

1. Fishing canoe (*ʻōpelu*): Present-day term for a short, thick hulled, wide bodied and heavy fishing canoe.
2. Racing canoe: The Hawaiian Canoe Racing Association (HCRA) has strict regulations regarding a racing canoe. There are separate races for koa canoes, non-koa canoes, and others, which demonstrates the importance for koa logs for building traditional koa racing canoes. The maximum length of a racing canoe is 45 ft according to the HCRA race rules.
3. Voyaging canoe: The largest type of koa canoes, first designed by the Polynesian people that arrived at the islands of Hawai'i.

Table 2. The minimum requirements of diameter and length for the three types of canoes this inventory is targeting.

Canoe Type	Minimum Canoe Width	Canoe length
	inches	feet
Fishing	24	10-20
Racing	36	30-45
Voyaging	40	40-60+

It is important to note that these size requirements are based off discussions with a variety of traditional koa canoe carvers. There are no official established sizing standards for the different canoes and these numbers are subject to change depending on the carver.

[1] The Hawaiian Canoe. Tommy Holmes. 1993. 2nd edition.

3. Methods

3.1. Variable plot field procedures

Throughout the entire forest area, variable plot sampling with multiple basal area factors (BAF) was used to maximize efficiency of data collection. This technique results in trees being sampled in proportion to their size, ensuring that cruising effort is focused on basal area and volume in proportion to their overall frequency and importance.

3.1.1. Plot layout

Using data collected in previous partial inventories, the forest was divided into four strata. The variable area plot layout included 106 plots distributed throughout the forest. Plots were distributed systematically throughout the four strata with the intention of refining preliminary (satellite imagery based) strata boundaries based on inventory observations and results.

3.1.2. Plot location in the field

A handheld GPS unit was used to locate plot center, which was considered achieved when the distance to plot was within 0-2 meters. Plot centers were monumented with blue spray paint and a center point stick, plot center located where stick and ground join. A photo of the plot was taken from 10m north of plot center. A relaskop was used to determine sampling trees starting at north and rotating clockwise (east). All trees counted and/or measured, regardless of species, were numbered with blue paint facing plot center. Paint was used to indicate diameter collection point with a small dot on the side of the tree that was determined to be the "uphill side".

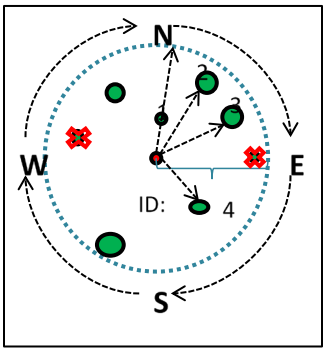

Figure 4. Variable area plot diagram.

Figure 3. Diagram of log measurements for koa trees.

3.1.3. Tree level sample collection

Two basal area factors (BAF) were used for each plot following big BAF methodology. A more inclusive BAF of 9m^2/hectare (39.204 ft^2 per acre imperial BAF) was used to measure basal area. Each "in" tree was counted and crown vigor was observed at species level. Detailed tree-level data were collected for all koa in the BAF 9m^2 plot. A more stringent BAF of

16m^2/hectare (69.696 ft^2 per acre imperial BAF), the "big BAF", was used to determine which ancillary, non-koa trees to measure.

3.1.4. Understory vegetation cover sub-plot

A 2-meter radius (12.5 m^2 area) fixed area plot was measured from the plot center to observe and record understory cover. All stems and plants under 1-meter (3.28 feet) in height were counted as groundcover or seedlings, while all stems taller than 1-meter were counted as shrubs or saplings. Individual plants were counted if there were less than 50 stems; if count was above 50 or in the case of grasses then percent cover was estimated.

3.1.5. Plot level data

The following data were recorded at each plot:

1. Latitude/longitude
2. Photo number
3. Basal area factors used
4. Limiting distances and results for borderline tree determinations (if any)
5. Tree count by species for all "in" trees
6. Average crown vigor by species for all "in trees"
7. Substrate and drainage
8. Understory cover type
9. Observations

Figure 5: Forestry technician Kairos Pacheco using a relaskop to determine plot basal area.

3.1.6. Tree level data (koa only)

Non-koa trees in the 16m plot were measured for DBH and height. All koa trees tallied in the 9m plots were measured, using a traditional descriptive log procedure which included:

1. Tree diameter using steel logger's tape (DBH)
2. Tree height using relaskop (Ht)
3. Tree form
4. Crown Vigor

Koa tree detailed measurements:

5. Tree diameter from relaskop (rel DBH) to calibrate relaskop data
6. Tree level deduction (applies to all logs) and deduction type (rot)
7. Small end log diameter using relaskop (SED)
8. Large end log diameter using relaskop (LED)
9. Log length
10. Log level deduction (mostly rot) and type

Live trees with 100% deduction (cull) were included in the data, since they occupy space in the forest, whereas dead cull trees and snags were not. If a down tree was salvageable it would be recorded; however, if damaged to the point where recoverable volume would have been minimal (vegetation growing upon them), then it was not recorded. In a few situations a large koa was growing out of a tall stump and measuring the DBH would have been dangerous, therefore the DBH was measured with the relaskop alone.

3.2. Defect recording

Defects were recorded according to Table 1. Tree level codes apply to the whole tree, where log level codes apply only to each log. Tree codes are simple for efficiency where log codes are descriptive. For example, a log with 35% defect on a standing dead tree – 15% overall would have a combined defect of 50% on that log. That is, the defects are additive.

3.2.1. Understory subplot data

Attributes collected in the 2-meter radius nested sub-plot:

1. Seedling count
2. Sapling count
3. Species and count or percent cover if over 50 individuals
4. Categorical understory assessment

3.2.2. Between-plot data collection

Taking advantage of traversing the forest, the location of canoe quality trees encountered between sample points were tallied and recorded on a handheld GPS. The location of young koa canoe trees were marked and recorded, while mature canoe trees were measured at DBH and length of first log.

3.3. Edge buffer cruise

A strip cruise was conducted along the existing roads to identify accessible trees for harvest, including mature canoe-log trees and young canoe log trees. The strip cruise took place within a 200-ft buffer along the roadsides surrounding KKCMA, as well as the upper and lower side of the road that crosses through the middle of the forest.

All koa trees with tree form 1 or 2 (Figure 5) that had a diameter greater than 20 inches were logged on a GPS and their diameter noted on a datasheet. These trees were grouped in four types:

Table 3. Koa canoe classes used for trees in the perimeter strip cruise (100% tally)

Koa tree diameter	Form class	Canoe class
30 inches or more	1	Canoe
30 inches or more	2	Potential canoe
20-30 inches	1	Young canoe
20-30 inches	2	Potential young canoe
less than 20 inches	Any	Not tallied

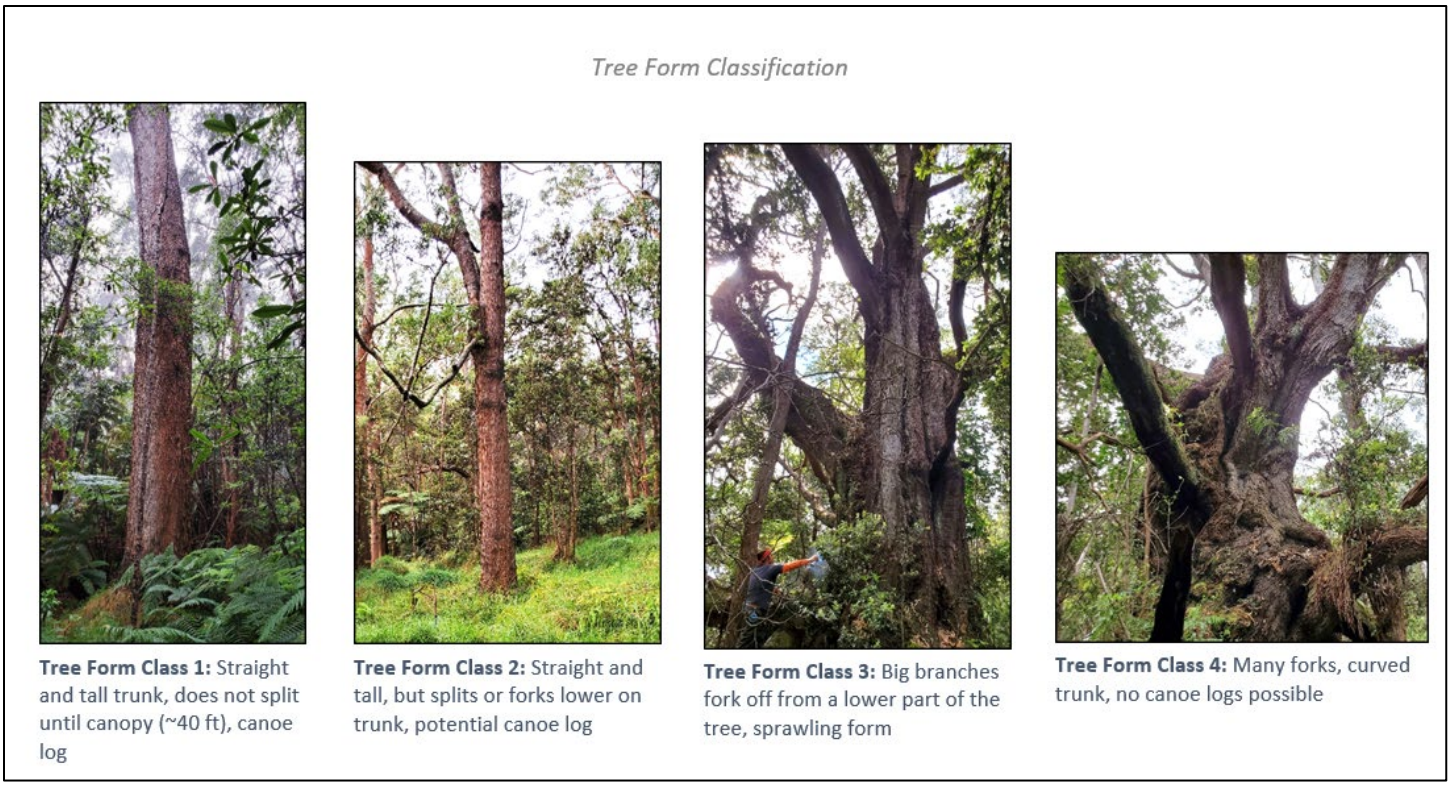

Figure 6: Koa tree form classification (1-4) used to determine canoe trees during the 100% tally strip cruise.

Dead, dying and all downed koa trees that met the requirements were tallied as well.

3.4. Data analysis

Data collected were analyzed using standard spreadsheet software. Plot level data were analyzed to obtain basal area per acre estimates. Tree level data (logs) were analyzed to obtain individual tree volume and basal area estimates, which were combined to obtain volume/basal area ratios (VBAR) in board feet per square foot.

Board feet were computed using the Scribner volume equation and cubic feet volume was computed using the SED (small end diameter) and LED (large end diameter) of each log together with its length to calculate a total volume using Smalian's formula. Although the analysis and results are discussed in Scribner board feet, they have also been summarized in International ¼ inch board feet (Table 5).

The individual log deduction (percentage) was included in each log volume calculation. The volume to basal area ratio is provided as additional information for future use in cruising KKCMA koa stands and as a guide for individual tree volume estimates using diameter.

3.4.1. Post stratification

Forest strata boundaries were updated based on field experience, changes in cover type, koa vs. other species' basal area, and koa diameter class distribution. GIS software was used to calculate strata area in acres, which was used to derive final cruise figures, presented in the results section.

3.4.2. Strip cruise data

Strip cruise trees were sorted by canoe class, recorded diameter was used to calculate individual tree volume (using VBAR) and volume for the entire surveyed area. The forest stand VBAR resultant from point

sampling, multiplied by individual tree basal area, resulted in volume estimates for each tree.

The KKCMA perimeter road is not entirely within the parcel (TMK) boundary. There are portions of the road that are within the adjacent Ka‘ū forest reserve. Trees that were later found to be outside of the KKCMA forest boundary and within the Ka‘ū forest reserve were removed from the dataset (136 trees removed from analysis but presented on map as “out of boundary trees”).

3.5. Community engagement

One aspect of this project was to collaborate with the Kapāpala Koa Canoe working group and provide opportunities for interested community members to participate in this inventory. One of two planned events was held on March 7, 2020. There were 19 participants and two Forest Solutions’ foresters at the event, conducted at KKCMA. The participants included University of Hawai‘i students, canoe club paddlers, canoe club association staff, cultural stewards, and canoe carvers and builders. Most of the participants were from the *Moku O Hawaii Paddling Association* (Big Island, HI), the *Keauhou Bay Canoe Club* (Kona, HI) , and *The Puakea Foundation* (Honolulu, HI).

Figure 7: Participants, including key stakeholders of the traditional canoe community, during the community engagement event participated in a roadside koa cruise for canoe trees.

A portion of the road buffer strip in the northwest corner was inventoried during this event, which also provided volunteers the opportunity to re-engage with each other and experience the forest firsthand. Many of the volunteers had not visited this portion of the forest before. Participants were enthusiastic about their experience and the quality of the Kapāpala Koa Canoe Management Area.

The second planned event was cancelled due to the COVID-19 pandemic and associated social distancing regulations.

4. General results

4.1. Results of the variable plot sampling

KKCMA contains just over 5.5 million net Scribner board feet of koa, approximately equivalent to 878,000 cubic feet (Table 3).

Table 4: Overall inventory results by strata for *Acacia koa* in KKCMA.

Strata	Basal Area		VBAR		Volume/ac		Acres	Total Scribner bf	Total Cubic ft
	Koa (ft^2/ac)	Other (ft^2/ac)	Scribner bf	cu. Ft	Scribner bf	cu. Ft			
K01	22.9	139	95	19	2,168	435	324	702,489	140,858
K02	20.8	135	187	31	3,878	650	386	1,496,898	250,716
K03	46.8	85	185	27	8,659	1,271	323	2,796,937	410,636
K04	25.4	127	96	14	2,450	366	207	507,064	75,801
Forest Level	**29.6**	**121**	**158**	**25**	**4,660**	**737**	**1,240**	**5,503,388**	**878,012**

The average koa basal area for each strata is between 20-25 ft^2/ac in all stands except K03, which has more than double the basal area at 46.8 ft^2/ac. Plot-level koa basal area data range from 0 - 157 ft^2/ac depending on the number of koa trees per plot (Figure 8). Strata K03 has the most koa basal area, with an average of 46.8 ft^2/ac, likely due to the four plots containing 117 ft^2/ac of koa.

Volume results calculated in International ¼ inch board feet are similar to Scribner bf at a total forest level volume of 5,389,936 BF. The strata vary slightly from Scribner bf with this calculation; However, the trend remains the same with K03 and K02 containing the most koa volume (Table 5).

Table 5. Results of koa volume by strata in International 1/4 inch.

Strata	Basal Area per acre	Volume (International 1/4 inch)		Acres	Total volume (international 1/4 inch)
		VBAR	BF/ac		
K01	22.9	71	1,626	324	526,792
K02	20.8	104	2,158	386	832,988
K03	46.8	236	11,045	323	3,567,470
K04	25.4	88	2,235	207	462,686
Forest Level	**29.6**	**176**	**5,207**	**1,240**	**5,389,936**

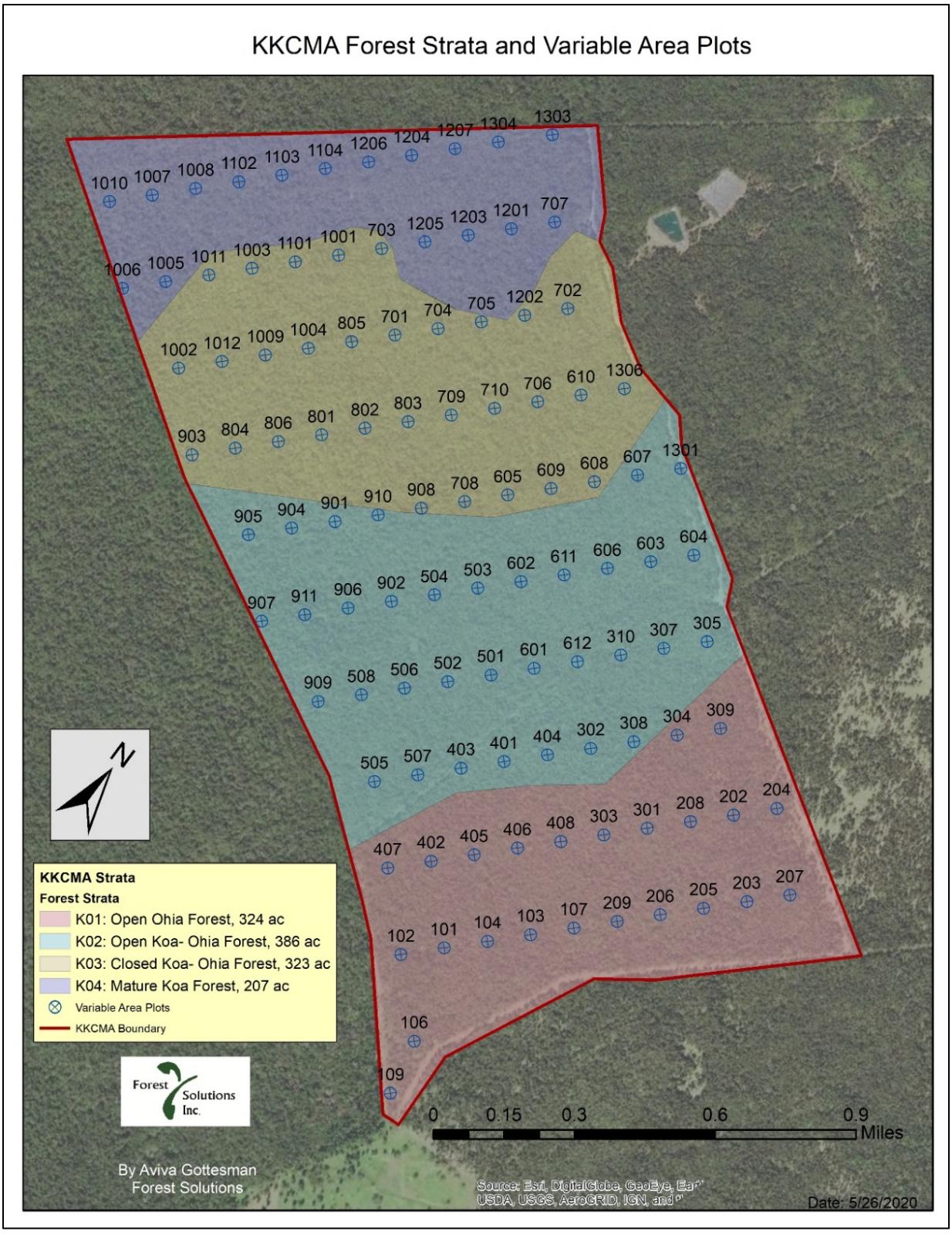

Figure 8: Variable area plots installed at KKCMA to conduct the forest inventory, included in the map are the newly refined forest strata: K01 (pink) is an open ohia forest, K02 (blue) is an open koa-ohia forest, K03 (yellow) is a closed koa-ohia forest, and K04 (purple) is a mature koa forest.

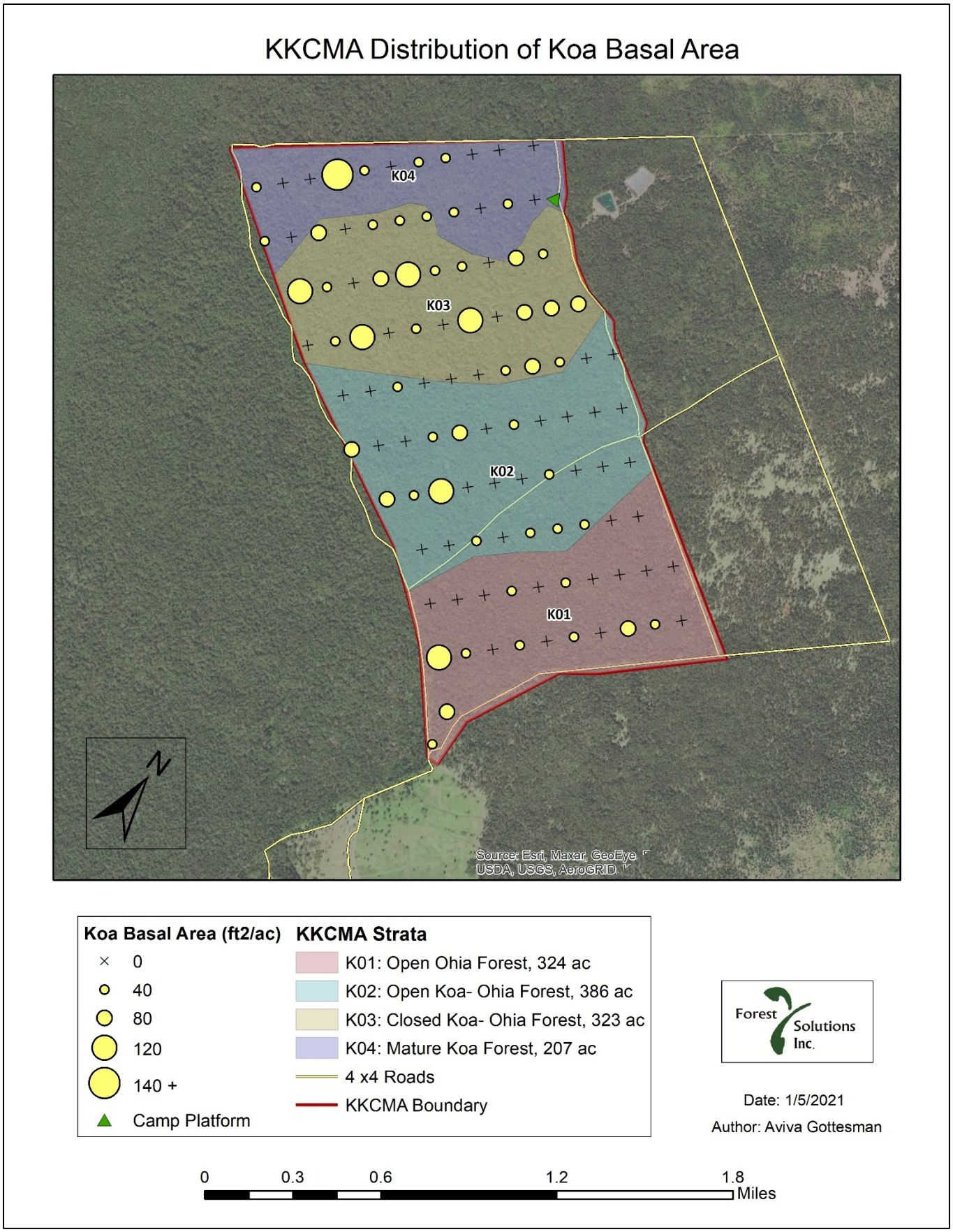

Figure 9: Distribution of koa basal area (ft^2/ac, yellow) by plot.

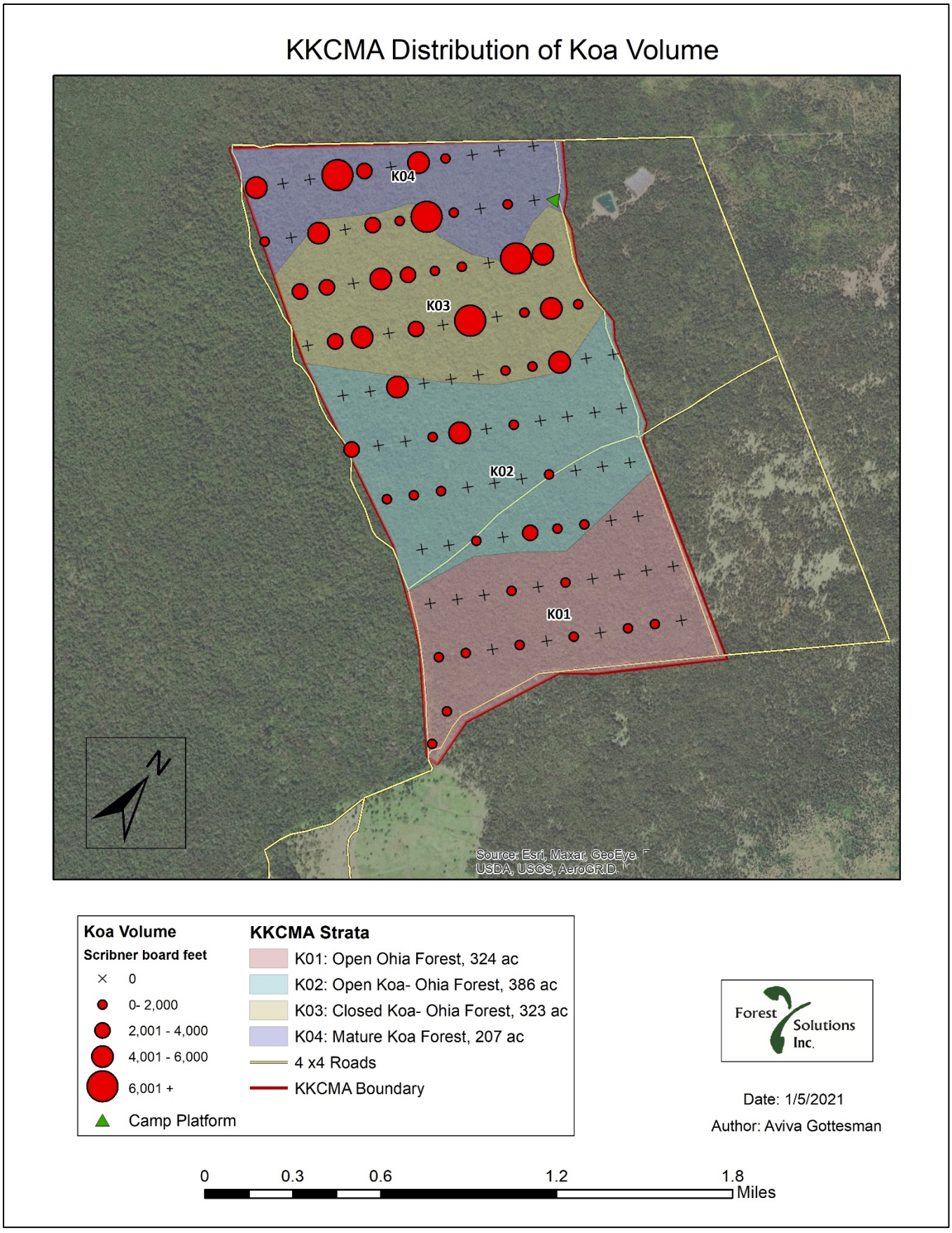

Figure 10: Distribution of koa volume (Scribner board feet, red) by plot.

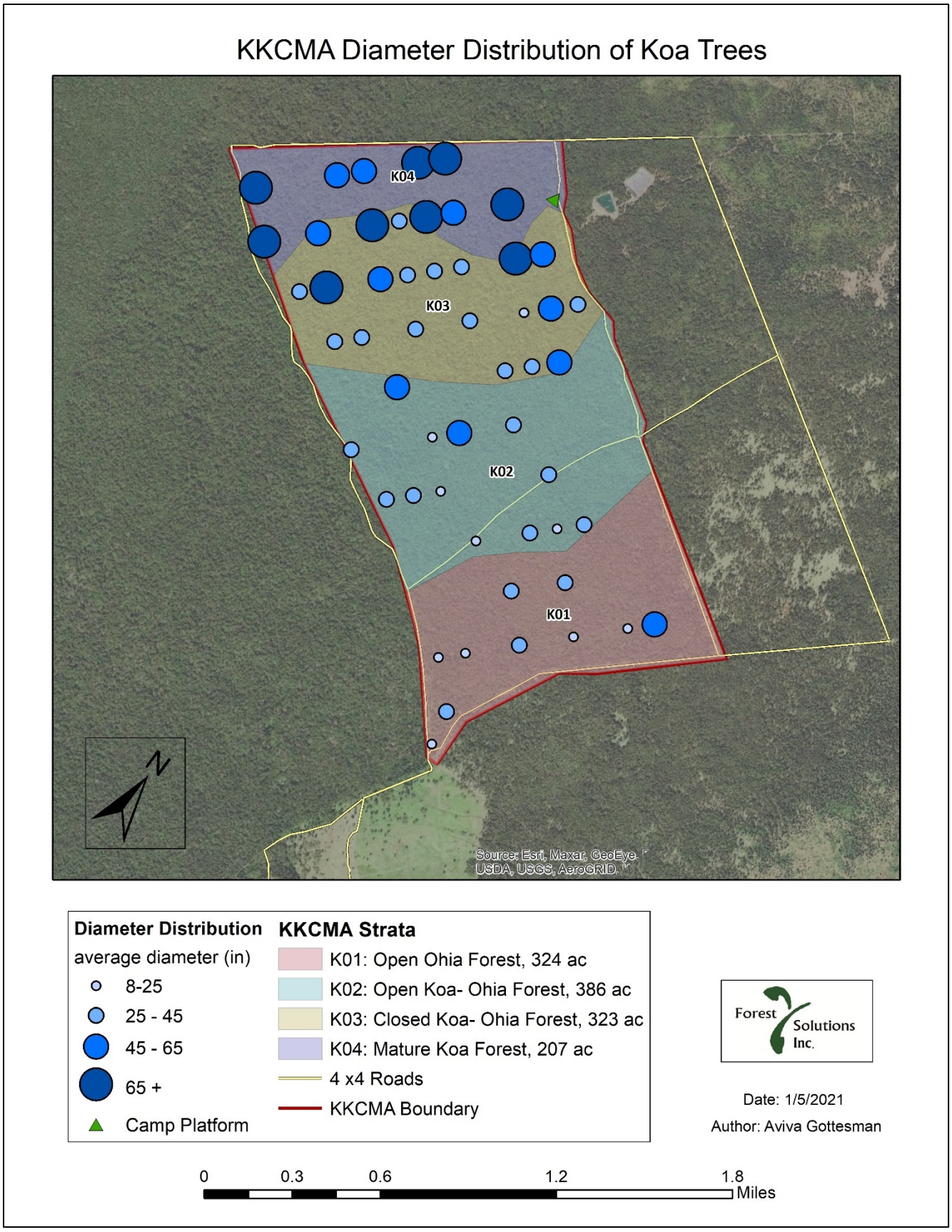

Figure 11: Distribution of the average diameter (inches) of koa trees by variable area plot.

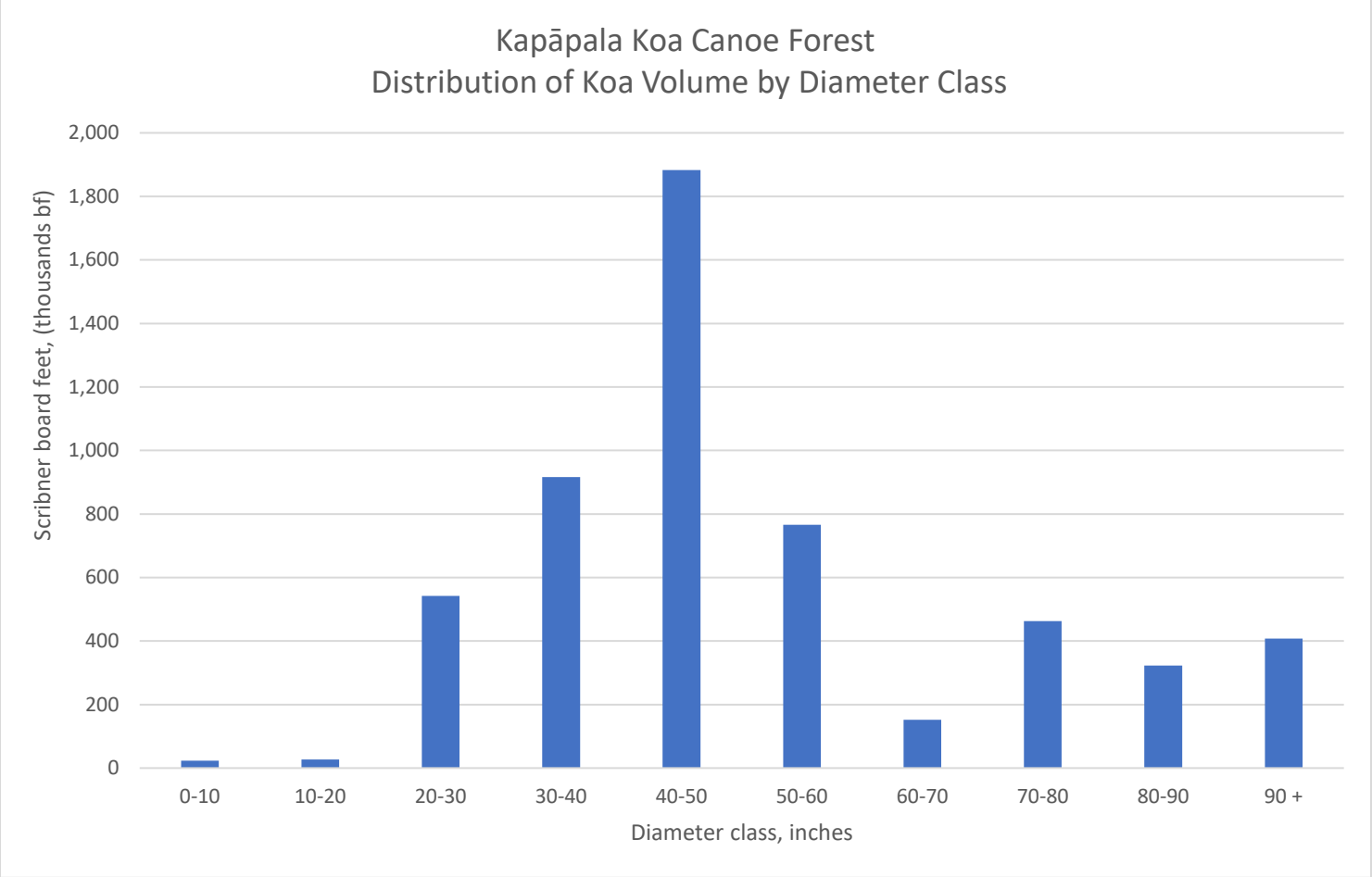

Figure 12: Distribution of koa volume (thousands of board feet) by diameter class (inches).

The highest volume of koa is in K03, where more plots contain trees, and the trees are larger in volume. Stand K04, has lower koa basal area; however, the trees are big and therefore the volume is represented with large symbols (Figure 9). K01 has very few high-volume plots owing to past harvesting and ungulate predation. Koa volume per plot increases with elevation along the four strata.

Across the entire forest, the average diameter of koa tree is 40 inches, therefore the large trees account for most of the koa basal area. The distribution of tree sizes (Figure 10) follows the same trend as the volume map (Figure 9), where the most koa is found in K03. As mentioned above, K04 has very large trees similar to K03. K01 and K02 have small to middle size trees.

4.2. Stratification

Strata K01 (324 acres) is an open ‘ōhi‘a forest composed mostly of ‘ōhi‘a with an uluhe (*Dicranopteris linearis*) and grass understory and a small component of younger koa trees. Strata K02 (386 acres, includes middle road) is an open ‘ōhi‘a-koa forest and has a similar basal area of ‘ōhi‘a as K01, though more koa trees are present in K02. The previous boundary between the two strata was along the roadside; though after observing the forest change through the variable area plots, the boundary was moved to below the road. Along the road there are many medium-aged koa trees, presumably arising from scarification of seeds during the road clearing. The switch from an uluhe shrub layer to hapu’u occurs where the new

boundary is placed. Strata K03 (323 acres) is characterized as a closed koa- ʻōhiʻa forest and has koa trees of all diameter classes.

Table 6: Diameter distribution (inches) of koa tree volume (Scribner board feet) by strata and across the property.

D-class (in)	Volume				
	K01	K02	K03	K04	Overall
0-10	1,133	22,590	0	0	23,723
10-20	17,585	8,303	925	0	26,813
20-30	242,471	161,097	138,598	0	542,167
30-40	175,533	431,410	309,321	0	916,263
40-50	265,768	569,847	1,047,707	0	1,883,322
50-60	0	303,652	358,136	104,329	766,117
60-70	0	0	0	152,037	152,037
70-80	0	0	400,654	62,463	463,116
80-90	0	0	134,300	188,235	322,535
90 +	0	0	407,296	0	407,296
Overall	**702,489**	**1,496,898**	**2,796,937**	**507,064**	**5,503,388**

The most prominent size class in K03 is the 40-inch size class, though many old-growth trees are present. K03 has double the koa basal area than the other three strata. It has the least ʻōhiʻa with an ʻōhiʻa basal area of 74.6 ft2/acre, but it has the most species diversity with a canopy species richness of 8 species (Table 5).

Strata K04 is a mature koa forest where there are only large koa trees above 50 inches. Like strata K03, K04 has high species diversity in the canopy with a species richness of 6 (Table 5). The koa trees in the variable area plots in K04 were mostly large, sprawling old trees that would not be suitable for canoes, though they contain a large volume of wood.

Figure 13: Mature koa trees with tree form 4, high percentage of rot, though still containing very high volume.

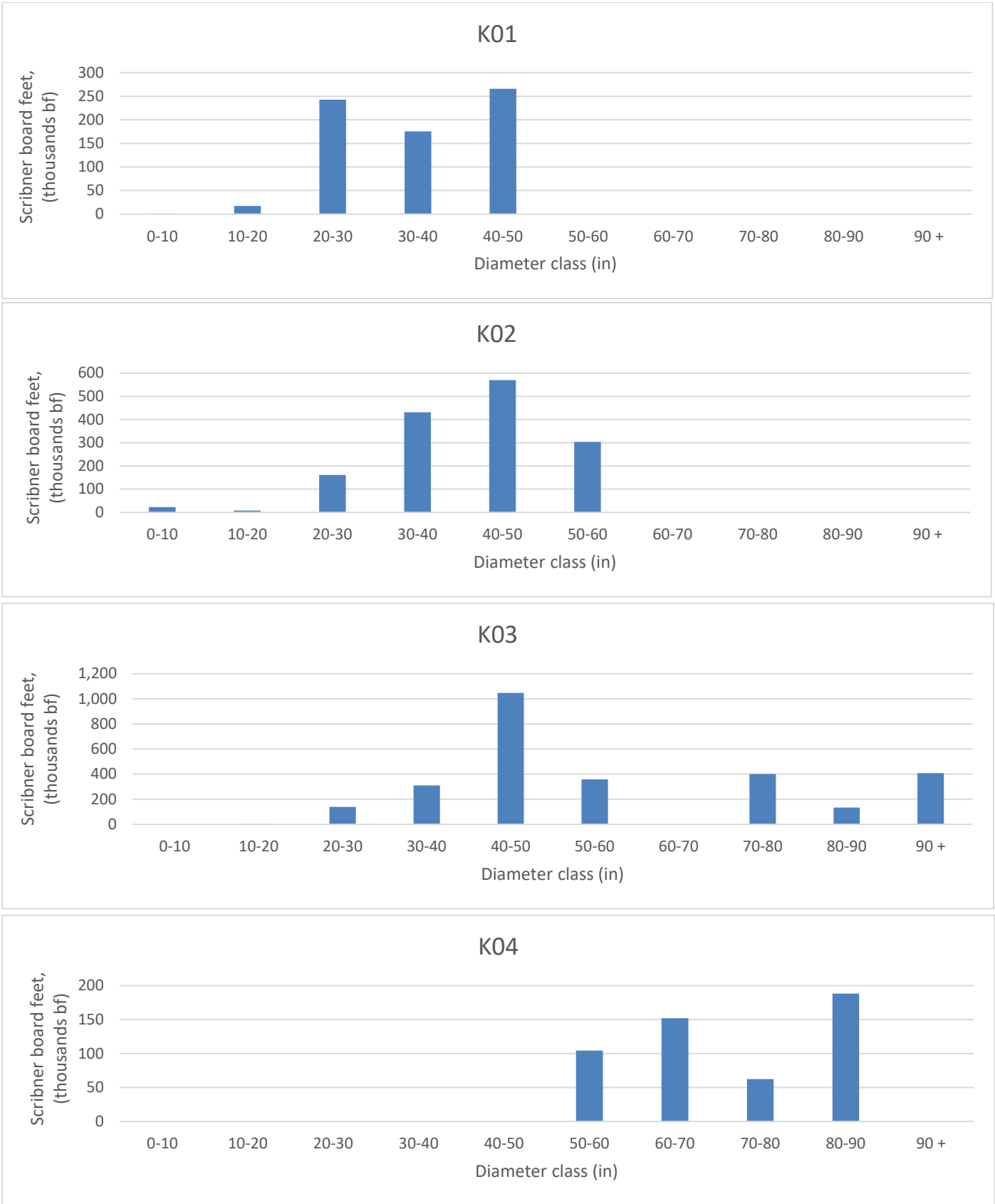

Figure 14. Diameter class (in) distribution in thousands of board feet by strata.

Table 7: Basal area (ft2/ac) for all tree species measured in variable area plots.

	Basal area (ft^2/ac)								
Strata	**koa**	**ʻōhiʻa**	**ōlapa**	**kōlea**	**kawaʻu**	**pilo**	**naio**	**kōpiko**	**Total**
K01	22.9	127.4	0.0	0.0	11.4	1.6	0.0	0.0	162
K02	20.8	121.1	1.2	0.0	12.7	2.3	0.0	0.0	156
K03	46.8	74.6	2.5	1.3	6.3	15.2	2.5	1.3	132
K04	25.4	115.3	6.9	4.6	0.0	2.3	4.6	0.0	152
Overall	**28.9**	**109.6**	**2.7**	**1.5**	**7.6**	**5.4**	**1.8**	**0.3**	**150.3**

4.3. Canoe log results from variable plot sampling

Of the 5.5 million board feet of koa in the Kapāpala Koa Canoe Forest, over 1 million board feet could be canoe logs and a further 1.5 million board feet are young canoe logs (Table 6). The remaining 3 million board feet are logs that are too small in diameter or too short in length.

Table 8. As seen in section 2.3- The minimum requirements of diameter and length for the three types of canoes this inventory is targeting.

Canoe Type	Minimum Canoe Width	Canoe length
	inches	feet
Fishing	24	10-20
Racing	36	30-45
Voyaging	40	40-60+

Based on the dimensions of the fishing, racing, and voyaging canoes, the requirements for a “canoe log” were created to establish a dataset describing the quantity of these types of logs in the forest. The dimensions seen in Table 9 are slightly generalized requirements based off the actual canoe types. This is to allow flexibility in the interpretation of the definition of a canoe log because different canoe carvers have different definitions. There is not one universal definition for the types of canoes, therefore the canoe log definition in the following analysis is more flexible. **The canoe log definition for this analysis is closest to the racing canoe dimensions.**

In the variable area plots, each koa log was measured with a small end diameter (SED), a large end diameter (LED), and length. For these calculations, canoe logs are defined as having an SED equal to or greater than 24 inches, and LED equal to or greater than 35 inches, and a minimum length of 25 feet. Young canoe logs are defined as anything with an SED greater than or equal to 20 inches and a minimum length of 15 feet.

Table 9. Canoe log minimum requirements of diameter and length.

	Minimum SED (in)	Minimum LED (in)	Minimum length
Canoe	24	35	25
Young Canoe	20		15

Table 10: Percent of logs recorded in each stratum categorized by canoe logs, young canoe logs, or N/A (not applicable for canoe).

	K01	K02	K03	K04
Canoe Log	12%	29%	18%	0%
Young Canoe Log	15%	26%	32%	17%
Non-Canoe Log Volume	73%	45%	50%	83%

Table 11: Volume (Scribner board feet) of canoe and young canoe logs predicted in each stratum according to the variable area plot sample.

	K01	K02	K03	K04	Total Forest
Canoe Log	82,335	434,380	517,012	0	1,033,727
Young Canoe Log	109,896	384,882	887,220	83,759	1,465,757
Non-canoe Log Volume	510,259	677,637	1,392,704	423,304	3,003,904

Out of the total canoe log volume, 49% of the volume is estimated to be held in even larger logs with an SED greater than or equal to 30 inches and a length of 30 ft or greater.

Based on the log measurements from the variable plot sampling, strata K02 and K03 have the most volume of canoe logs. K03 has over 534,000 board feet of canoe logs and K02 has almost 453,000 board feet of canoe logs. K01 has significantly less canoe logs, with 113,606 board feet in the strata (Table 7). No canoe logs were sampled in K04, therefore no volume is estimated in the strata, it is likely that there are some logs in this strata that were simply not captured by sampling. It is likely that K04 has less canoe logs because the koa trees are sprawling wide with many branches, perhaps due to competition with other native species present. There may also be a substrate or wind driver due to the higher elevation, keeping the trees short and stout. Under the dark conditions of this late seral stage forest (K04), it is uncertain if a new generation of canoe trees will be able to grow without management actions.

The young canoe volume by strata reflects the canoe volume and follows a similar trend with K03 having over double the volume of young canoe logs than K02, which in turn has over three times the volume than strata K01. Eighteen percent of the logs sampled in K04 were considered young canoe logs, resulting in almost 90,000 board feet of young canoe logs.

It is interesting to note, that out of the 80 koa trees that were carefully measured within our 106 sample points, we sampled two that may have a voyaging canoe log on them. One was measured in K03 with a diameter of 39.4 feet, an LED of 41.3 in and an SED of 38.6 in. The other was in K02 with a length of 41.8 ft, an LED of 37.4 and an SED of 31.5 in.

Figure 15: A canoe log in a variable area plot that was measured and recorded for volume calculations.

Figure 16: A young canoe tree found and measured in a variable area plot.

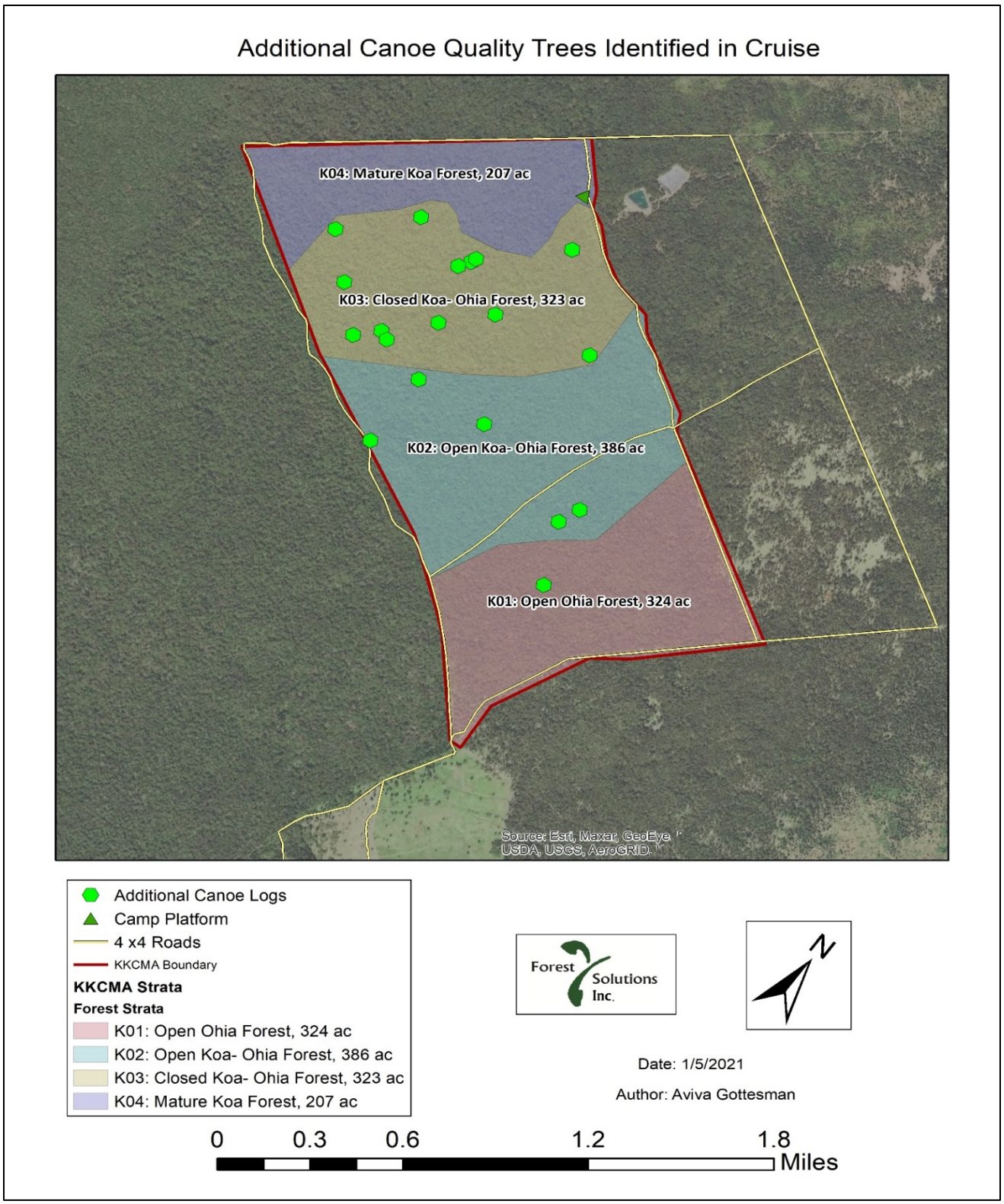

Figure 17: Canoe logs recorded in variable area plots and additional/extra canoe trees found walking between plots, although more are surely present that were not located in the sample.

In addition to the variable area sampling, several canoe logs were found walking from one plot to the next. These were marked on the GPS as additional data for mapping and potentially for future management. They can also be visited by canoe builders to refine the definition of a canoe log based on actual field conditions and then potentially to re-run inventory figures above (Figure 16).

4.4. Cruise Statistics

Table 12: Cruise statistics by strata. The last line for overall statistics is for the entire forest, it is not an average of individual strata.

Stats	Standard Error		
	BA/ac	VBAR Scribner	Cruise
K01	29%	18.2%	34.3%
K02	26%	21.4%	33.3%
K03	15%	9.9%	18.2%
K04	37%	11.2%	39.0%
Overall ($SE_{80\%}$)	**16%**	**11.0%**	**19.1%**

This cruise was designed to obtain a forest level error of less than 20% with a confidence of 80% on koa volume. Our actual results came in just under the allowable error at 19.1%. Stands that had higher koa stocking were naturally less variable and thus present lower error estimates.

5. Roadside buffer analysis

5.1. Results of the 100% tally around the edge of the forest

Results of the 100% roadside tally are based on a separate data collection methodology and data analysis methodology compared to the variable area plot results. These results OVERLAP with variable plot cruise results and should be considered a subset of the overall forest inventory that happens to be located near an existing road.

All koa trees with tree form 1 or 2 that had a diameter greater than 20 inches were tallied and organized by size and form class.

Table 13. Koa canoe classes used for trees in the perimeter strip cruise (100% tally)

Koa tree diameter	Form class	Canoe class
30 inches or more	1	Canoe
30 inches or more	2	Potential canoe
20-30 inches	1	Young canoe
20-30 inches	2	Potential young canoe
less than 20 inches	Any	Not tallied

A total of 479 koa trees were recorded along the roadsides of KKCMA within 200 feet of the road. There were 20 canoe logs accounting for just over 35,000 board feet of volume, and 192 young canoe logs equaling over 105,600 board feet. Trees with tree form class 2 were marked as potential canoe (51) and young canoe (216) logs, to provide additional mapping of koa trees for future management purposes (Table 10).

K02 and K04 had the most canoe logs in this cruise, which could partially be a result of those strata containing more roads and edges. K04 had no canoe trees within the variable area plots because the largest trees were over-mature with short, stout first logs. The koa trees along the roadside in K04

Tree Form Class 1: Straight and tall trunk, does not split until canopy (~40 ft), canoe log

Tree Form Class 2: Straight and tall, but splits or forks lower on trunk, potential canoe log

Figure 18. Canoe trees (class 1) and potential canoe trees (class 2) were defined based on the above criteria.

may have a better canoe form likely due to their younger age, exposure to more light, and/or less competition for resources along the road.

Additionally, along the middle road in K02 there are many canoe and young canoe logs (Figure 18). These two regions of KKCMA have a history of logging, which presumably scarified the soil and resulted in a healthy cohort of straight, large koa trees. Along the eastern and western side of the forest, there are very few straight koa trees because they either have grown heavy limbs due to excessively open conditions or they have evidence of animal browsing damage (stripped bark, cat-faces) from early growth stages. Only trees that fit the koa canoe log criteria were included the count.

Table 14. Basal area and volume of canoe and young canoe trees found during the 100% tally on the roadsides. Potential canoe trees and potential young canoe trees are included as supplemental information.

Row Labels	Tree Count	Basal Area (ft^2/total area)	Volume (scribner bf)	Volume (ft^3)
Canoe	20	224	35,213	5,571
Young Canoe	192	671	105,616	16,713
Potential Canoe	51	508	80,070	12,658
Potential Young Canoe	216	760	119,729	18,944
Grand Total	**479**	**2,163**	**340,628**	**53,886**

Table 15. Strip cruise results of canoe and young canoe trees by strata.

Strata	Canoe	Young Canoe	Potential Canoe	Potential Young Canoe	Grand Total
K01	1	11	1	34	47
K02	9	109	37	111	266
K03	1	27	2	27	57
K04	9	45	11	44	109
Grand Total	20	192	51	216	479

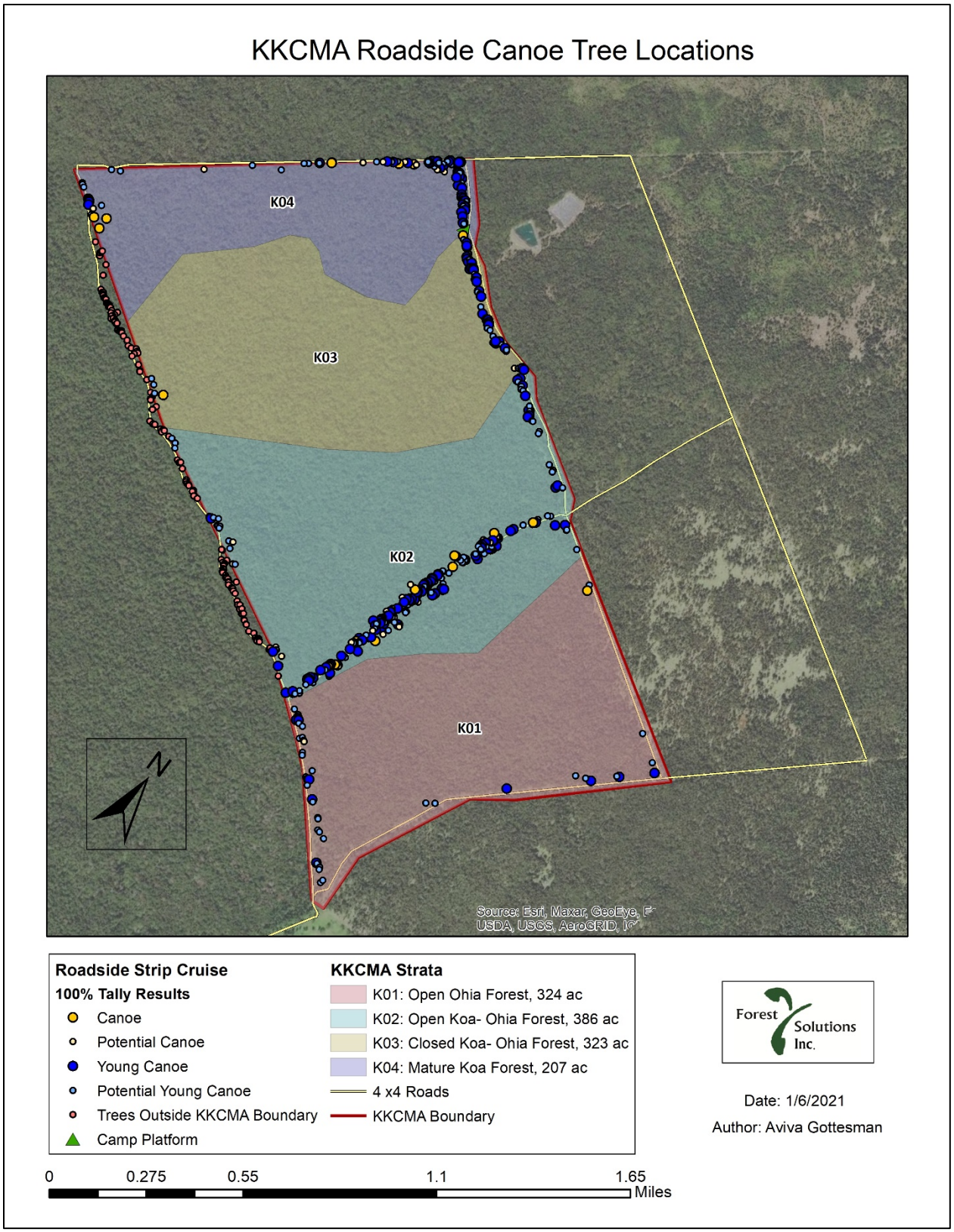

Figure 19: Marked location of canoe and young canoe logs along roadsides at KKCMA. Potential canoe and young canoe trees included.

6. Forest Health

Figure 20: Koa seedlings found between plots in K02.

The greatest threats to forest health at KKCMA include:

1. **Ungulates**: Feral cattle, sheep, goats, and pigs are harmful to the forest as they eat the young seedlings of native forest trees and shrubs. Cattle also compact the soil due to their size, making it difficult for new seedlings to emerge through the seed bed. Additionally, the high feral pig population is weakening the native hapuʻu tree fern population, providing a ready vector for weed seeds and constantly uprooting the thin soil.
2. **Invasive species**: The lower portion of the forest contains several invasive species including: banana poka (*Passiflora tarminiana*), morning glory (*Convolvulaceae sp*.), poha berry (*Physalis peruviana*), Japanese anemone (*Anemone hupehensis*), and an unidentified ivy. Although these invasives are a serious threat, the forest is in good shape considering that it is available to the public and receives regular traffic.
3. **Fire and Flood risk**: There is low risk of fire as the forest is wet year-round. Flooding risk is also minimal due to the prevailing slope and lack of streams nearby greatly reducing the risk.

6.1. Seedling results

The majority percent cover recorded in K01 and K02 for the groundcover level was meadow rice-grass (*Ehrharta stipoides*), kikuyu grass (*Pennisetum clandestinum*), and ferns (various species). In K03 and K04 the percentage of grass decreased, and more bare ground was exposed because of increased hapuʻu ferns, higher stocking (see basal area tables), and pig wallows. Common species in all strata includes ʻōhelo (*Vaccinium sp*.), uluhe (*Dicranopteris linearis*), and abundant maile (*Alyxia stellata*). Unique species found in the understory includes akala (*Rubus hawaiensis*), Hawaii sedge (*Carex alligata*), iʻo nui (*Dryopteris wallichiana*), maʻohiʻohi (*Stenogyne microphylla*), Hairgrass (*Deschampsia nubigena*) and ʻalaʻala (*Peperomia sp*.).

Table 16: Groundcover species richness by strata. Percent native does not mean percent cover of natives, it refers to percent of species richness that is native.

Strata	Species Richness	Percent native Species
K01	15	80%
K02	15	87%
K03	15	87%
K04	16	88%
Forest Level	23	83%

Seedling regeneration for ʻōhiʻa, kawaʻu, and ōlapa is substantial, while koa seedlings were only present in K04 plots. On an anecdotal level, occasional koa seedlings were observed during the inventory in the other three stands, though few were in the subsample plots.

Table 17: Key seedling stems per acre by strata for all native species.

Strata	Kawa'u	Koa	Kōlea	Kōpiko	'Ōhi'a	Ōlapa	Pilo
K01	13	0	0	0	13	134	13
K02	19	0	0	57	123	38	85
K03	31	0	10	0	197	94	62
K04	0	265	19	0	379	701	303

Table 18. Understory groundcover stems per acre by strata for all native species.

Strata	Akala	Hawaii Sedge	Hapu'u	I'o Nui	Maile	'Ōhelo	Uluhe	'ala'ala	Ma'ohi'ohi	Hairgrass
K01	0	0	40	13	362	362	0	134	0	54
K02	0	19	104	0	720	95	0	47	28	0
K03	21	42	62	0	842	197	21	62	0	0
K04	38	19	0	19	587	871	0	38	0	0

6.2. Sapling results

Table 19. Species richness for shrubs and saplings by strata.

Strata	Species Richness
K01	**4**
K02	**7**
K03	**9**
K04	**8**
Forest Level	**13**

Notable native species in the shrub level were kanawao (*Broussaisia arguta*), pāpala (*Charpentiera obovata*), akala (*Rubus hawaiensis*), ohelo (*Vaccinium sp.*), and hapu'u. Saplings included: kawa'u, koa, kōlea, kōpiko, 'ōhi'a, ōlapa, and pilo. All saplings and shrubs recorded in the subplots were native species. K02, K03, and K04 had around double the species richness of K01 (disturbed), corroborating the dynamic nature of the mature upper forest compared to the lower elevation, highly impacted forest.

Table 20. Shrub stems per acre by strata.

Strata	Akala	Hapu'u	Kanawao	'Ōhelo	Pāpala
K01	0	161	0	0	13
K02	0	208	0	0	0
K03	10	239	31	83	0
K04	19	133	0	114	0

Table 21: All sapling species found in subplots, in stems per acre by strata.

Strata	Kawa'u	Koa	Kōlea	Kōpiko	'Ōhi'a	Ōlapa	Pilo
K01	0	0	0	0	40	0	67
K02	19	0	9	9	38	9	85
K03	10	0	21	0	83	10	42
K04	0	19	19	0	114	95	95

'Ōhi'a seedlings and saplings increase along the elevation gradient, which could be attributed to multiple things such as an increase in coarse woody debris which provides more nurse logs for 'ōhi'a regeneration. The other native forest species are regenerating within K01, K02, and K03. K01 has the least amount of native forest trees, with only pilo and 'ōhi'a saplings in the subplots. Surprisingly, the only strata with koa sapling regeneration was K04, which has an average of 19 koa saplings/acre. This could potentially be storm related regeneration, resulting in a large even-aged population rather than consistent recruitment over time. Typically, koa regenerates in openings or areas of scarification and disturbance, not in a shady, mature environment. Perhaps the lower strata have more ungulates eating the koa seedlings as it is more open in the lower forests and therefore easier for animals to navigate.

Figure 21. Evidence of ungulate browse (potentially sheep) on multiple young koa saplings found in K03 not far from the camping platform.

7. Conclusion

The principal result of this inventory is that the KKCMA property contains 5.5 million board feet (bf) of koa, where 1 million bf are estimated to be canoe logs and 1.5 million bf of young canoe logs. The canoe logs are few and far between; however, they are big and represent a large percentage of the overall koa volume.

The trees that are present are large and there is almost no regeneration from the understory due to the presence of both cattle and pigs. These animals have been and remain the biggest threat to forest health, with evidence arising from all canopy levels on the damage from feral animals, and not only to the koa regeneration. The large koa trees in the upper elevation forest are not abundantly regenerating, they are mature to over-mature and far from the desired tree form of a canoe log except those located along the roadside. Based on the variable area plots, most of the canoe and young canoe logs are in K02 and K03. However, the 100% tally found the most canoe trees along the middle road (K02) and along the upper northern slope (K04).

On the forest level, the property is well stocked with an average basal area of 150 ft^2/ac for all species. The kikuyu grass and meadow rice grass, although non-native, continue to keep other invasive populations to a minimum, and appear to indicate a lack of overstory and mid-story stocking rather than being casual agents in themselves. In the future, forest management practices will greatly influence forest health at Kapāpala and will determine the state of koa canoe resources over the next 10-20 years. To access the canoe trees that are readily available in K03, roads will need to be developed inside the forest. However, more roads will increase traffic which could potentially increase the presence of invasive species and damage the pristine habitat in the upper portions of the forest.

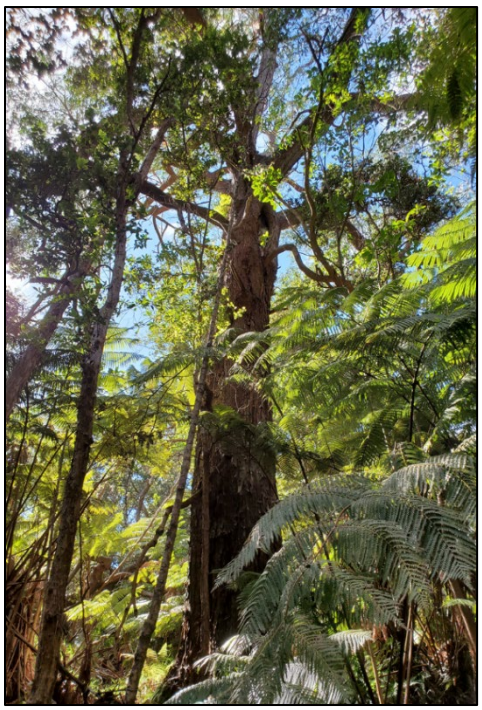

Figure 22: A canoe tree growing in a dense forest canopy.

It would be difficult to successfully plant koa and to maintain abundant natural regeneration with the continued presence of browsing ungulates, such as sheep and cattle. If ungulates remain in the forest, there will still be koa to harvest for many years; However, the resources will diminish over time and future generations will not be supplied with the amount and quality of koa that is present on the landscape today.

In conclusion, this inventory demonstrates that the KKCMA property contains many available canoe logs, as well as abundant young canoe logs to be harvested in the next 10-20 years. Both along the roadsides and deep in the forest, the property contains koa trees with the proper size and form to be canoe logs. With minimal management activities, such as improved fencing and ungulate removal, there could be koa canoe logs available for future generations.