Annual Progress Report for "Kahanahaiki Vegetation Mapping Analysis"
Project Update: October 1, 2014 – September 30th, 2015

Evaluation of Three Very High Resolution Remote Sensing Technologies for Vegetation Monitoring in Makaha and Kahanahaiki Valleys

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Summary

This report serves to update the progress of this project from October, 2014 through September 30th, 2015. Support of this project was made possible by the Oahu Army Natural Resources Program, Research Corporation of the University of Hawaii, Pacific Cooperative Studies Unit, the Natural Resources and Environmental Management program at the University of Hawaii at Manoa, Resource Mapping Hawaii, Pacific GPS, USGS, Apollo Mapping and the support staff within these organizations.

The project study location was switched from Makaha to Kahanahaiki in upper Makua Valley for easier site access. Kahanahaiki has served as a model research site for a host of research. It is representative of many resources and challenges faced for management in the Waianae Mountain range of Oahu. Progress was made with respect to gear rentals, testing, field data collection, UAS exploration, imagery acquisition and classification training. Four aerial image missions were conducted under contract by ReMap HI and 3 UAS missions were conducted for research and development purposes. Weather was limiting and the missions served to be partially successful, capturing a portion of the desired image dataset. Imagery data was obtained from satellite, aerial and gigapan imaging platforms. Suitable World View 3 satellite imagery was collected for the study area and preliminary image processing occurred. Survey tools were used to collect field data during the Summer of 2015.

Study Site

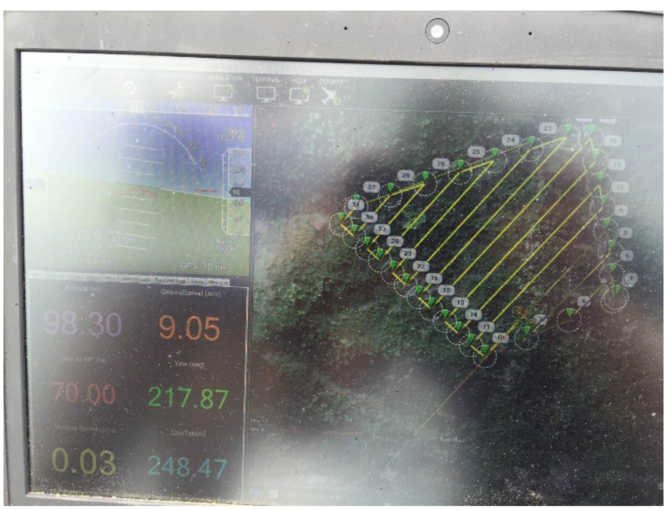
A site visit was conducted in Makaha Valley in early April and it became clear that the site is too remote for the scope of the project. Kahanahaiki in upper Makua Valley was chosen as an alternative study location and was approved by OANRP staff.

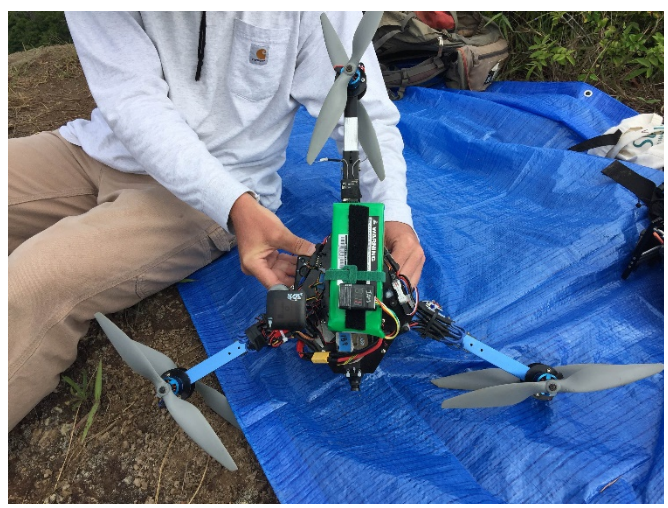
High Resolution Aerial

Under contract, Remap Hawaii flew on four occasions with the Cessna 206 fixed wing plane to capture high resolution imagery of Kahanahaiki and Makaha but faced challenges due to the difficult nature of weather in the area. Data collection was attempted after 10 a.m. in an attempt to capture imagery of the MUs when the sun was overhead and casting the least amount of shadowing. Incidentally, there were significant low level clouds during the flights and several missions were deemed to be unsafe to the pilot and crew. Partial imagery of upper Makaha was obtained and delivered (See Figure 1). Image resolution is high with significant potential for assessment and tracking change over time of vegetation.

Figure 1: Makaha subunit II image sample. The Kumaipo LZ and MU fence.

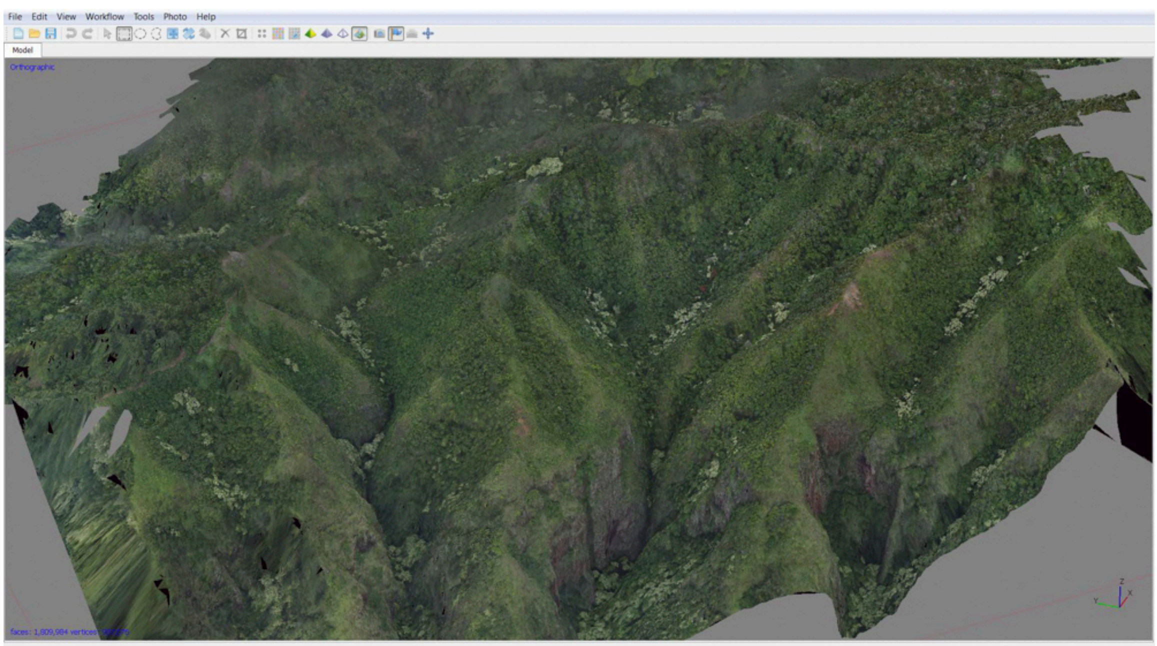
After four attempted flights the focus switched to an Unmanned Aerial System (UAS) and several site visits were conducted. UH Manoa Geography graduate, Charles Devaney was brought on for the UAS phase. Benefits of UAS include but is not limited to: cost effectiveness while delivering a quality sweet of image data products, reduction of risk, easier mobilization and the capability of flying safely below the cloud ceiling. A test flight was conducted with a DJI Phantom and GoPro Hero 3 camera. Resulting imagery showed potential. The flight mission was preplanned by Mr. Devaney to image Kahanahaiki subunits I and II and a flight was coordinated with favorable weather conditions. A Y-6 rotary Unmanned Aerial Vehicle (UAV) was prepped and flown by Mr. Devaney. It flew 3 out of 5 preplanned flight segments on autopilot after the initial launch (See Figures 2 and 3). Battery life was a limiting factor with 10 minute flights. The Y-6 mission was ended short due to significant compass errors and potential firmware issues complicated by possible interference from nearby communication towers at the Nike facility. It was safely returned to the launch point.





<u>Figures 2 and 3: Flight mission while the flight was underway and the Y-6 rotary UAV being prepped for launch.</u>

A fixed wing, Newskywalker UAV was identified as potentially a more suitable UAV for the mission. A launch and land location was identified and Troubleshooting and equipment testing were conducted. It was flown under conditions that started optimally with light winds and a high cloud ceiling. Weather moved into Kahanahaiki from the south with a low cloud ceiling. An entire MU dataset was collected and the fixed wing performed well on autopilot staying true to the planned flight. Line of site was followed, however approximately 50% of the image dataset of Kahanahaiki Subunits I and II was partially obstructed by low clouds. If a safe landing is achievable the fixed wing UAS shows great potential as battery life is expanded significantly. The Newskywalker flew on a single battery for 107 minutes with approximately 50% usage. The rotor and fixed wing UAVs were flown with a Sony Mirrorless camera delivering sharp, high resolution images. Two image deliverables were obtained from the Newskywalker, a 3-D image mosaic of subunit II and orthorectified tiles of the cloud free southern portion of the MU (See Figures 3 and 4).



<u>Figure 3: Screenshot of the 3D image data product of Kahanahaiki subunit II looking east.</u>

Figure 4: Sample image tile of Kahanahaiki subunit II.

World View 3 Satellite Imagery

In June 2015, Apollo Imaging delivered the first data set of 175km 2 capturing target MUs in the Waianae Mountains collected on May of 2015. The imagery of the leeward portion of the northwestern data set was cloud free. Much of the remaining target area was obstructed by cloud cover. Apollo mapping was contacted and agreed to continue to collect imagery of the area until an acceptable deliverable may be obtained. Data processing of the cloud free portion of the May data set was undertaken by Apollo Imaging, however the geoprocessing needs further work.

Orthorectification will be conducted to align Kahanahaiki and Makua with an accurate known base layer data set.

Gigapan

An effective protocol was developed for obtaining sharp, effective mosaics using a Gigapan Epic Pro mount, Canon 60D and Canon 100-400mm f4L lens. A 900 image mosaic was gathered from one of the main gulch vantage points to be used in the accuracy assessment (See Figure 5). Two other ridgeline locations were imaged in addition.

Test classification using an object based approach and visual classification of a gigapixel image of upper Makaha collected in the previous reporting year was conducted in ArcGIS 10.0 (see Appendix 1).

Fig. 5: Mosaic of the east facing northern portion of Kahanahaiki subunit II.

Other Work

A Trimble Geo7XH was rented from Pacific GPS for a shared 6 week duration with OANRP. Karen Knowlen conducted an introductory training for this researcher and select OANRP staff. Training data of target species locations throughout subunit I of Kahanahaiki. Locations of ground markers to facilitate orthorectification of aerial imagery were also collected. The Truepulse 360 R laser rangefinder was integrated with the Trimble for obtaining GPS offsets. Early tests show error from 1-20m partially due to magnetic interference. Further investigation is required to develop a working protocol, however this combination of data collection shows much potential for mapping and rapid assessments from suitable vantage points (See Figures 6, 7 & 8)

Figures 6,7,8: Training data collection, orthorectification ground marker data collection and GPS offset exploration.

Appendix 1.

Object Based Image Classification of Gigapixel Imagery of a Mixed Mesic Forest

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Geography 762

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Term Project Paper

Abstract

Tropical island ecosystems are typically very vulnerable to invasive species due to high net resource availability and the poor ability of native species to compete for those resources. The invasion of Strawberry Guava (*Psidium cattleianum)* may have significant effects on Hawaii's water resources. Mapping the extent of Strawberry Guava in Hawaiian watersheds and monitoring landscape change is a key component to watershed restoration efforts. The Gigapan robotic unit allows a user to capture very high resolution digital images (<1cm) with billions of pixels from suitable ground locations. It is gaining use by researchers across many fields of science to capture site information from geology to ecology to complement field work; however it has yet to be fully utilized for vegetation mapping. Analysis of imagery has been limited to visual classification of imagery. Object based classification with eCognition was used to classify Gigapan imagery to separate *P. cattleianum* from a target area in Makaha Valley, Oahu, Hawaii. User's accuracy was low at 47% (n=30) due to a host of factors including the lack of a fourth NIR band, shadowing due to the sensor view angle, homogenous nature of the vegetation, spectral similarities among vegetation, and changes in the light levels during the image collection process. Object based classification may not serve to be the most optimal pairing with Gigapan imagery, however visual analysis and classification may serve to be an effective classification method to classify to the species level due to the very high spatial resolution of the imagery (0.8cm).

Introduction

The Hawaiian Islands are a prime example of ecological diversity and host an array of unique and rare species that have evolved within a myriad of environments (Gon, 2003; Sailer, 2003). A key ecosystem within the islands is the mesic forest, an area found in coastal, lowland, and montane areas of Hawaii that receives 1200 mm to 1500 mm rainfall annually (Wagner et al., 1998; Sailer, 2003). Although wet forests are credited with capturing the bulk of rain water, mesic forests significantly supplement groundwater recharge and buffer wet forested areas from degradation by land use change, ungulate damage, and fires (Sailer, 2003; Juvik and Juvik, 1998).

The mixed mesic forest of upper Makaha valley is an area of significant groundwater recharge (Mair and Fares, 2009). Unfortunately, much of the upper valley has been severely impacted by an array of human activities and the subsequent introduction of many invasive plant species (Juvik and Juvik, 1998; Takahashi et al., 2010; Mair and Fares, 2009). In addition to ecological impacts, non-native tree species threaten to negatively affect the hydrological services provided by native forests (Mair and Fares, 2009; Vitousek et al., 1987). Invasive plants such as *Psidium cattleianum* alter local water balances by changing vegetation structure, water storage characteristics, and rates of transpiration (Takahashi et al., 2010).

Vegetation monitoring provides the basis for understanding the intricate composition of an area on a forest to watershed scale. It can allow us to capture current forest dynamics and can be used to track changes in an area over time. The baseline data provided by vegetation monitoring can be very useful especially in areas that receive management through ecosystem restoration. Tracking changes over time can give natural resource managers insight on the forest composition and resource inventory and provide a means to assess the effectiveness of conservation practices and a measure for success of their efforts. Unfortunately, traditional "on the ground" vegetation monitoring techniques can be time consuming and costly and may vary in accuracy and consistency depending on observer bias (Congalton, 1991). Ground monitoring can also be damaging to sensitive ecosystems and difficult to accomplish in steep terrain.

New technology is changing the face of vegetation mapping and its efficacy in the form of remote sensing and GIS. Analysis of remote imagery can provide accurate and timely assessments of vegetation on a large scale at a set point in time (Bunting and Lucas, 2006). Remote imagery can easily be replicated and can provide an accurate visual key of an area (Bunting and Lucas, 2006).

Object of Study

Accurate and timely classification of remote sensing imagery is vital to the adaptive management process. Little work has been conducted with supervised classification of Gigapan imagery. The objectives of this research were:

1. To investigate the use of object based classification to classify *P. cattleianum* from gigapixel Gigapan imagery in subunit II of Makaha Valley.
2. Conduct a visual classification of the imagery for comparison
3. Assess the accuracy of the object based classification

Study Site

Upper Makaha valley is located on the leeward side of the Northern Waianae Mountain Range of Oahu. It is owned by the Honolulu Board of Water Supply (BWS) and is one of their key watersheds. Makaha valley has a diverse history of land management and some of the land use practices within the valley continue to have impacts on the forest community to this day (OANRP et al., 2010). Maintaining and improving the function of this watershed is of utmost importance for groundwater recharge and protected habitat of endangered native plants and animals (Townscape, 2009). Vegetation communities within Makaha valley have been described by Harmon (2006) and Suzuki (2006), who utilized fine resolution satellite imagery to document the highly invasive *P. cattleianum* throughout much of the valley. Native to Brazil, *P. cattleianum* was first introduced to Hawaii in 1825 and is now a dominant component of many Hawaiian environments from sea level to 1300m (Smith, 1985; Takahashi et al., 2010). Remnant native forest tree species including *Metrosideros polymorpha*, *Acacia koa*, and *Diospyros sandwicensis* are found within a portion of the upper Makaha valley (Harman, 2006). The most intact native areas within the valley were fenced with the recent completion of two subunits. Subunit I is about 85 acres and subunit II is about 35 acres in size (see Figure 1). Ground vegetation monitoring in subunit II was conducted in 2014 with the use of belt transects and survey plots (Oahu Army Natural Resource Program status report, 2014).

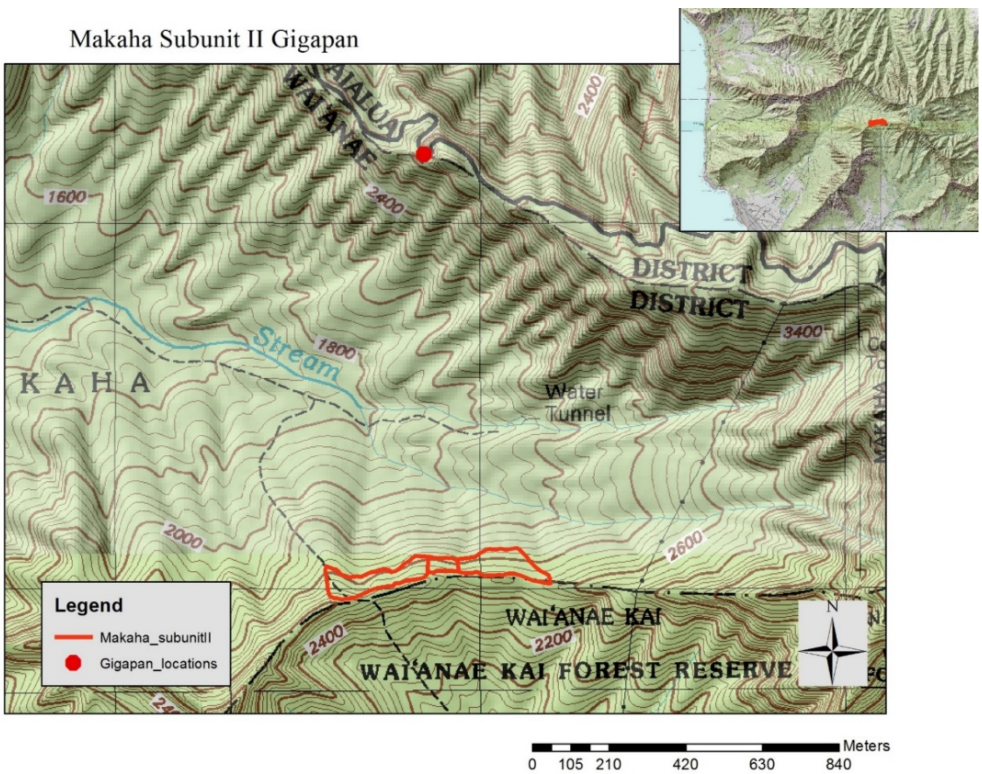

Figure 1. Topographic map portraying the back of Makaha Valley with Subunit II and the Gigapan location on the Ka'ala road.

<u>Object Based Image Analysis</u>

Traditionally, aerial photography has been used to obtain very fine (<1m) spatial resolution, however other platforms are becoming available (Bunting and Lucas, 2006). The advancement of hyperspectral satellite sensors has lent the opportunity for many studies of digital image analysis. The pixel based image analysis was the accepted methodology since the launch of Landsat-1 in 1972 (Blaschke et al. 2014). However there are limitations to this pixel based approach. Blaschke et al. (2014) point out, that once the spatial resolution is finer than the object of interest, objects are made up of multiple pixels so focus should be on the patterns that are created. A per-pixel approach with new high resolution sensors may decrease the accuracy of within class spectral variability (Blaschke et al. 2014, Hay et. al. 1996). Research in the 2000s started developing object based image analysis focusing on the color, tone, texture, patterns, shape, shadow and context of groups of pixel objects; development of these techniques represents a new paradigm in image analysis (Blaschke et al. 2014).

There have been multiple challenges that researchers have faced when seeking to map tree crown and canopy cover or tree density, including the understanding gap dynamics, and/or discriminating and classifying species (Bunting and Lucas, 2006). Canopy reflectance can be influenced by shadowing between crowns, reflectance contributions from non-photosynthetic material (e.g., primary branches) in the crown and the underlying soils and vegetation, and variations within and between species and growth stages as a function of foliar biochemistry, moisture content, internal structure and age of leaves (Bunting and Lucas, 2006).

Gigapan System

Little work has been done mapping vegetation with the Gigapan system. This project will represent the first attempt to couple the Gigapan system with a laser rangefinder GPS and run through object based classification vegetation analysis. The Gigapan robotic unit allows a user to capture very high resolution digital images (<1cm) with billions of pixels (gigapan.com, Sargent et al. 2010, Stock et al., 2010). The technology utilized by the Gigapan robotic unit was developed by Carnegie Mellon for the Mars Rovers, Spirit and Opportunity to capture images of the red planet (gigapan.com). It is gaining use by researchers across many other fields of science to capture site information from geology to ecology to complement field work (Sargent R., Bartley C., Dille, P., Keller, J., Nourbakhsh, LeGrand, R., 2010). The TruePulse 360R is a laser rangefinder that can link to a GPS to obtain GPS offsets from up to 1,000m from its target location for non-reflective surfaces and 2,000m for reflective surfaces. The laser rangefinder will be mounted on the camera via the hotshoe and fired at each image location in the Gigapan mosaic allowing for georeferencing of the Gigapan mosaic.

Figure 2. The Gigapan Epic Pro, Canon 60D, and TruePulse 360R rangefinder setup used for image acquisition

Methods

Imagery was obtained of Makaha Subunit II on April 5th, 2015, between 12 and 1p.m. from a turnout on the Federal Aviation access road leading up to the summit of Mount Ka'ala. The vantage point has an elevation of approximately 850 meters, (see Figure 1) and is located at the UTM coordinates 04Q0586840, 2379164. The exact setup location is marked with pink surveyors flagging to allow for return to the same location. The Gigapan Epic Pro was mounted on a sturdy tripod and levelled using the bubble level on the device. A Canon 60D and a Canon 300mm f2.8L lens with a Canon 2x extender were mounted to the Gigapan unit and zoomed to its full extent (see Fig. 2). A Truepulse 360R laser rangefinder GPS was mounted to the camera on the hotshoe attachment oriented at the center of the scene.

The camera was set to aperture priority, ISO400, F5.6 with a shutter speed of 1/800. Focus was made with autofocus at the center of the scene then the lens was switched to manual focus. The top left and bottom right corners of the panorama were selected. The Gigapan unit was initiated to take the images of the study area starting at the top left corner panning from top to bottom. Once the unit had taken the images in a certain column it moved up to the adjacent row with a 30% overlap in between images. The unit took approximately 40 minutes to complete the panorama image capture.

Image post processing was conducted with Adobe LightRoom 5.0. A 10% level increase was applied to contrast, vibrance, clarity, saturation, sharpening and noise reduction of each image. The gigapixel panorama of the study site was put together using GigaPan Stitch 2.3.0307. Visual classification of a subset of the image was undertaken to be used for the classification accuracy assessment using visual cues, such as canopy shape, canopy size, canopy color, texture, bark and stem color and relationship to other objects (Jensen, 2007) (See Table 1). The Gigapan image was imported into ArcMap 10.1 and a subset of the panorama was selected and delineated by a polygon feature class. Ten vegetation species classes were identified by zooming and exploring the image and delineating polygon shapes, each with a separate feature class.

Table 1. Examples of visual cues used for visual classification of the imagery

	Visual Attributes					
Species	**Canopy shape**	**Canopy size**	**Canopy color**	**Canopy texture**	**Bark/ stem color**	**Relationship to other canopy objects**
Strawberry guava	Uniform relatively flat canopy surface	small	dark green	uniform texture	dark bark	Large monotypic stands
Ohia	irregular canopy with light dead branches	medium	dark green	irregular texture	grey bark with many dead branches	solitary well-spaced
Koa	Irregular canopy	large	light green	irregular texture	greyish white bark	solitary to clumped

An object based classification approach was applied to a subset of the imagery with eCognition Developer 9.0. The imagery was initially segmented at a relative scale of 120, shape 0.2 and compactness of 0.8 in order to create segments smaller than canopy objects. The image subset was then classified into a broad classification of two separate classes, Strawberry Guava and the other canopy components. This was achieved by applying various layer values from the Feature selection to the classification process tree. Levels were set for the Mean Brightness for

Layer 3 and Max diff. in addition to the Standard deviation level of Layers 1, 2, and 3. A nearest neighbor supervised classification was also run (see Fig. 6).

An accuracy assessment was conducted comparing the visually classified image with the object based classified image. This was executed by first exporting the classified eCognition data into jpg. format. A grid was laid over the image in Microsoft Powerpoint and 30 random points were generated with a random point generator tool. The points were plotted on the grid and inserted on the image (see Fig. 7). The two classified images were overlaid in Powerpoint and each random point was assessed to determine if the classification of Strawberry Guava was accurate by visual comparison.

Results

The TruePulse 360R laser rangefinder would not pick up readings at the survey location of the study site. The Gigapan Epic Pro and digital single lens reflex camera captured a subset of the area of interest as a panoramic image stitched together from 290 images, resulting in a single file 2.1GB in size (See Figure 3 and Figure 4). The distance from the vantage point to the center of Subunit II was measured using the ArcMap 10.1 measuring tool and determined to be approximately 1100m. The resulting gigapixel image had a spatial resolution of 0.8cm. This was determined using the following formula:

GSD=distance/focal length x CCD pixel size

Where GSD is the ground surface distance, the distance is measured from the camera to the survey location, the focal length is the length of the lens and CCD pixel size is the size of the camera sensor.

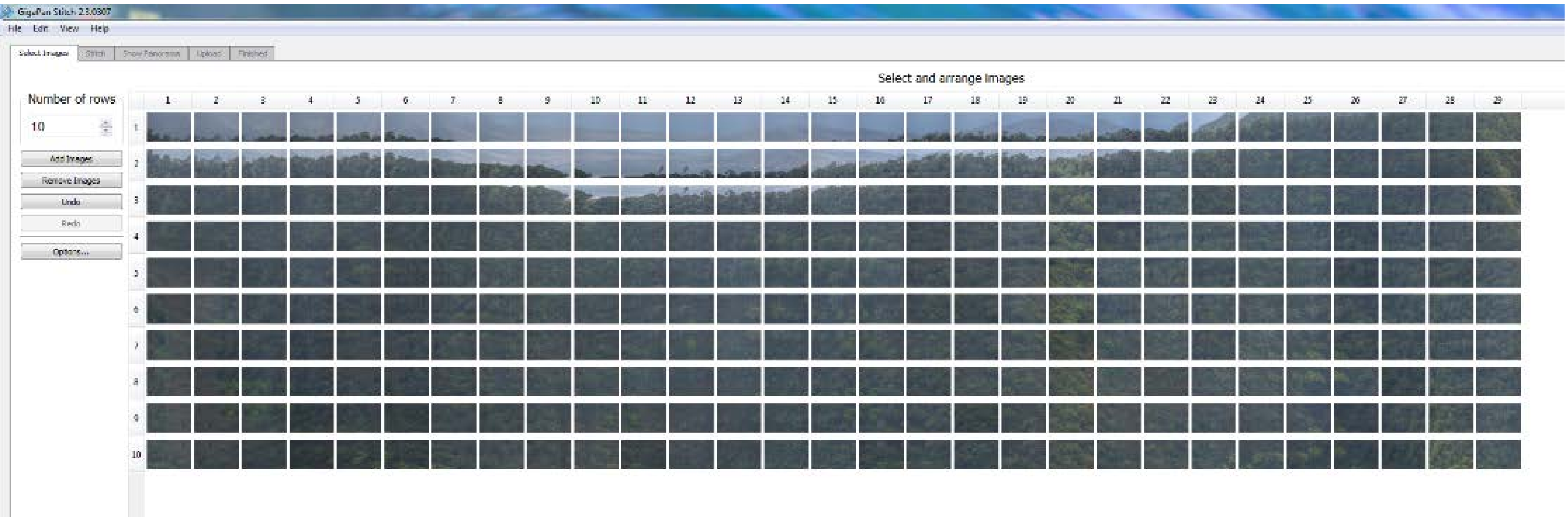

Figure 3. Individual 290 images prior to the stitching process

Figure 4. Gigapixel Gigapan mosaic of stitched images of the study site.

Visual classification of a subset of the target imagery was achieved for 10 canopy species due to the very high spatial resolution of the imagery. In order of abundance these included: Strawberry Guava, Koa, Ohia, Lemon Guava, Silky Oak, Toona, Tropical Ash, Eucalyptus, Coffee and Kukui (See Fig. 5).

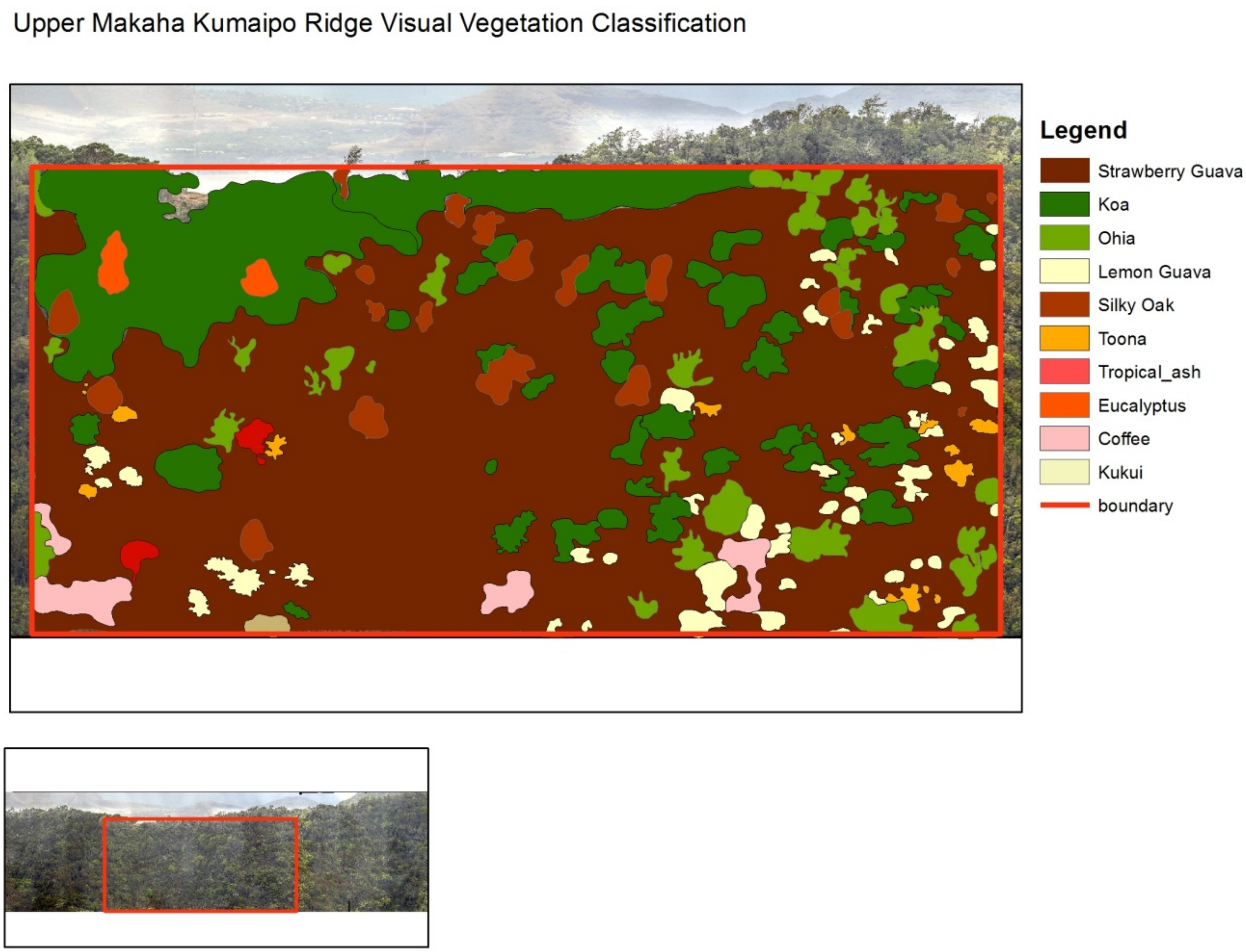

Figure 5. The classification of 10 species by visual classification in ArcMap 10.1

Object based classification of a subset of the scene yielded the image as seen in Fig. 7. The classification of Strawberry Guava is displayed in red and the other opaque polygons classified as not Strawberry Guava.

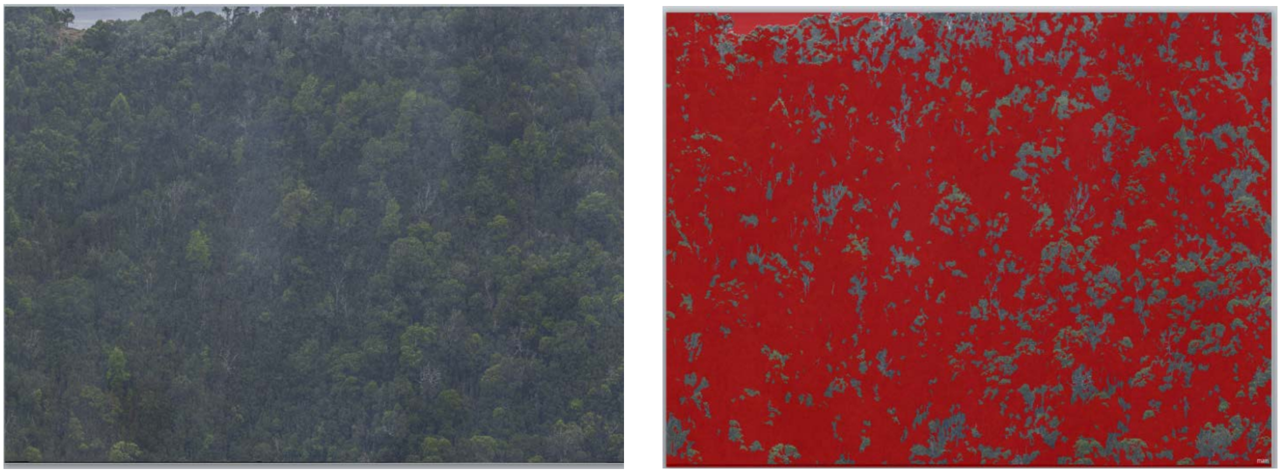

Figure 6. The subset image selected from the panorama for object based classification and the result of the supervised classification process to classify Strawberry Guava in eCognition with Guava as the red color.

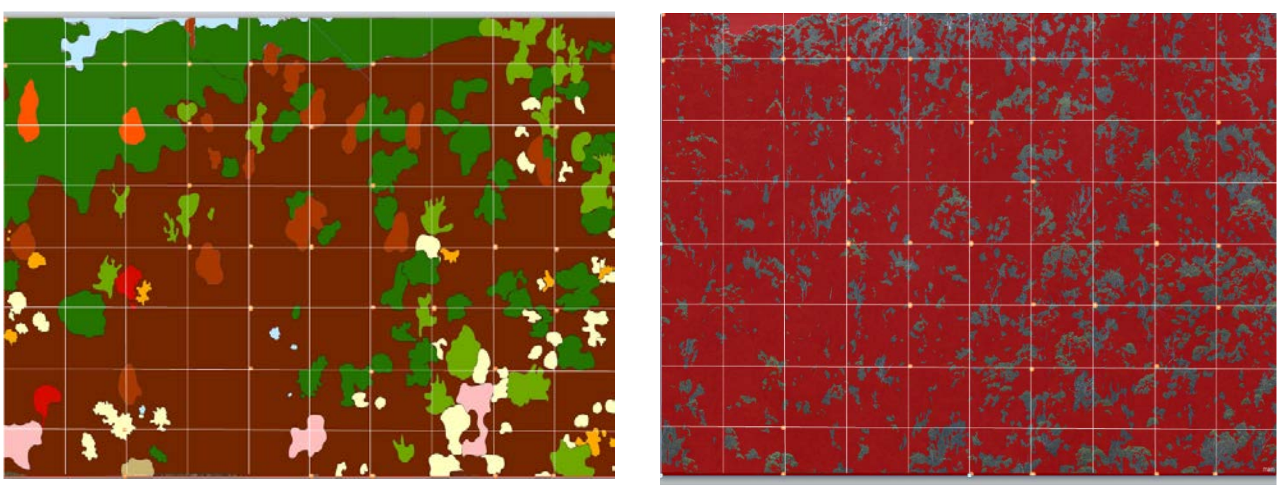

Figure 7. Grid overlay and random points used for the accuracy assessment of the image set

The overall user's accuracy was determined to be 47% accurate for classifying Strawberry Guava with object based classification. Visual classification was assumed to be 100% accurate.

Table 2. The accuracy matrix of assessment results.

	Producer (Visual)					
User (eCognition)	Class	Psicat	Other	Total	%	
	Psicat	8	5	13	43%	
	Other	11	6	17	57%	
	Total	19	11	30		
	%	63%	37%		47%	

Discussion

The TruePulse 360R laser rangefinder was meant to enable georeferenced points for the center of the images taken during the panorama, however the distance was greater than the 1,000m range and would not register at the survey location. It may have been even greater than the estimated 1,100m determined with the ArcMap measuring tool due to a difference in elevation from the vantage point to the study location. This tool may serve to be a very useful compliment to the Gigapan system under 1,000m but needs further testing. The ability to have georeferenced points for each image in the mosaic would be a great benefit to assist in incipient species location for management as a process to orthorectify this type of very high oblique imagery has yet to be determined.

Initially, the goal was to capture the entire subunit II in a mosaic of images to be created into a gigapixel panorama. However a subset of the unit was chosen to create a manageable dataset. This served to be an effective and efficient method that allowed for a workable dataset.

The low accuracy of the object based classification method may be attributed to a host of factors with the first being the nature of the image incident view angle. It is a very high oblique and the image may be subject to substantial shadowing that complicates the classification process. The high resolution is a benefit for visual classification and serves to be useful during the object based process, however this is a result of the combination of hundreds of images that may take a while to capture. In this case it took nearly 40 minutes to cover just half of the scene of upper Makaha Valley. The cloud cover was relatively uniform which was beneficial however the light levels did fluctuate during the data collection and the scene was brighter as the sun emerged from behind the clouds. This complicated and led to errors in classification as much of the preliminary segmentation was based on reflectance values. The file size is also effectively quite large as a gigapixel file making for time consuming post processing.

Perhaps the greatest drawback to Gigapan imagery and the specific equipment used for this study was the limiting factor of only three available bands, RGB. The lack of a fourth NIR band was a hindrance in the object based classification process as several of the classification algorithm rely on this NIR band to run a NDVI vegetation index sequence. eCognition offers manual classification techniques that allows for a higher classification accuracy but this lends to the question, at what point is it simply more effective to conduct visual classification?

Visual classification of the Gigapan image served to be very effective even to the incipient invasive species level. The very high spatial resolution and this researcher’s familiarity with the region and its associated species helped to facilitate this. There were two tropical ash trees that were easily identified within the scene and have high potential to spread throughout the area, potentially causing further detriment to the Makaha watershed. This highlights perhaps the greatest utility of the Gigapan system with vegetation mapping and monitoring for managers to detect incipient invasive species in target areas and visually track landscape changes over time. It has strong potential as a watershed management tool but classification may serve to be limited to visual analysis. The Gigapan system will serve to be a very useful tool if images can be georeferenced with the TruePulse system incorporated with a Trimble GPS unit to assist in ground location of these problematic incipient invasives. The assumption that the visual classification of the imagery was 100% needs to be made clear and may not be 100% accurate. An assessment of this accuracy needs to be conducted with the incorporation of a compliment of ground control plots.

Conclusion

Object based classification and high oblique Gigapan imagery may not be an optimal pairing as displayed by the low accuracy (47%) to map the simple classification of Strawberry Guava in upper Makaha Valley, Oahu. Visual Classification may serve to be more reliable to the trained observer but this is not quantifiable without ground control points. Gigapan may not be a suitable tool for quantitative mapping but has potential for monitoring change and has high potential to assist in incipient invasive species detection. A methodology for locating specific points in the image on the ground needs to be developed.

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