



Ancient Kaua`i Mapping Project: Using GIS to locate and map ancient Hawaiian agricultural landscapes on Kaua`i

Erik Burton

Research

Abstract

GIS tools are used to develop a predictive model for identifying the primary agricultural complexes on Kaua`i, and to conduct a systematic aerial survey for transported landscapes. Comparisons are made to historical records, and place names are matched to elements of the ancient agricultural landscape. Results are recorded in a series of layers enabling spatial analysis and 3D visualization of the data in its environment. The resulting GIS layers and master model allows custom data views to be created by enabling selected layers, so that desired aspects of the agricultural landscape can be visualized. The resulting layers are discussed as individuals and also how they interact to provide a view of the ancient integrated agricultural landscape. Conclusions about the predictive model for agricultural complexes, the ethnobotanical surveys and the historical records are discussed.

Mo`olelo ho`opokole

Ua hana GIS no ke kukulu kumu alaka`i e wanana i na wahi mala `ai ma Kaua`i, a e alaka`i i ke kilo mokulele no na `aina loli `ia. Ua ho`okuku `ia me na palapala mo`aukala, a ua ho`olikelike `ia na inoa wahi me na mea `awe`awe`a o na mala kahiko. Ua kukulu i na lalani papa GIS i mea e wehewehe, a he ho`ike 3D i ua `ikepili nei. Hiki ke koho i na papa makemake `ia e ho`ike ai. He `olelo kuka ko ia nei no na papa kekahi i kekahi, a me ko lakou hana pu `ana ma ka `aina kahiko. Ua ho`oholo i hopena no ke kumu alaka`i wanana no na mala kahiko, na kilo kalailau, me na palapala mo`aukala.

Introduction

Study Location

Kaua`i is the westernmost (Figure 1) of the main Hawaiian Islands, nearly circular in form and approximately 25 miles by 35 miles. Its central massif, Wai`ale`ale, captures legendary amounts of rainfall as its peak of just over 5,000 feet punctures the trade wind (Ramage & Schroeder 1999) powered cloud layer passing overhead, forming the dominant weather pattern on Kaua`i. Like the other Hawaiian Islands, Kaua`i is generally wet on the north and east sides, dryer on the west and south sides.

Background

Ancient Hawaiian Agriculture

Ancient Hawaiians were master agriculturists (Handy *et al.* 1991) who developed and recognized hundreds of variet-

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Figure 1. Hawaiian Islands with Kaua'i as the westernmost of the major islands. Image generated with Google Earth.

ies of taro (*Colocasia esculenta* (L.) Schott), **ʻuala** (sweet potatoes, *Ipomoea batatas* (L.) Lam.), and **maiʻa** (banana hybrids, *Musa acuminata* x *balbisiana* Colla). Their agricultural practices were highly adapted for each particular microclimate, with appropriate cultivars used for a particular area or production requirement. Hawaiians were also distinguished for having extensive **loʻi** (pond field irrigation systems) that could produce immense quantities of taro (Handy et al. 1991).

Kauaʻi is ideal for taro production with its long, well watered valleys (Ladefoged *et al.* 2009). Pond field irrigation systems are best suited for islands with lots of bottom land that can be reached by irrigation ditches. Kauaʻi, as the oldest of the main Hawaiian Islands, is ideally suited for this type of agricultural development, as it possesses many long valleys with gentle slopes (Kirch & Rallu 2007, Ladefoged *et al.* 2009).

A review of the old maps stored in the Kauai Historical Society (KHS 2009), and online with the David Rumsey map collection (Rumsey 2009), produced few maps of inland agricultural complexes. The earliest and most detailed maps were created by the sugar plantations and focused on their coastal land holdings, while the interiors are marked unexplored and don't reflect even a rudimentary understanding of the topography.

After contact with European peoples, the Hawaiian population began declining precipitously and ultimately fell by perhaps as much as over 80% (Kamakau 1992, Kirch & Rallu 2007). The resulting cultural collapse, along with newly introduced foreign goods and customs, ultimately created something of a disconnect with the ways and knowledge of the people of old. By the time detailed maps were first being made (1840s), knowledge of the abandoned upland agricultural systems had mostly been lost to history.

The interior of Kauaʻi is mostly preserved from the impacts of development and industrial agriculture, with over 60% of the island classified as conservation land (The State of Hawaiʻi Data Book 2004). By looking at Kauaʻi in Google Earth it is evident that, due to the remoteness of much of its interior terrain, most of this conservation land was not utilized by modern agriculture or ranching, preserving it much as it was when abandoned by the ancient Hawaiians. Remnants of transported landscapes are still to be seen in these well preserved areas, along with earthen and rock walls that supported the agricultural infrastructure (Burton, personal hikes). A wide range of preservation levels exist, from sites completely overgrown in **hau** (*Hibiscus tiliaceus* L.) or bamboo (some of which is the ancient introduced **ʻohe**, *Schizostachyum glaucifoli-*

um (Rupr.) Munro), to places that look like they could have been abandoned just a few decades ago.

Pressures from a variety of sources including cattle ranching, industrial agriculture, feral pigs, goats and even illegal campers have led to the degradation of many readily accessible sites. Some plants left over from ancient Hawaiian agroforestry practices have become invasive and are growing unchecked (Figure 5), suffocating agricultural complexes, agroforestry remnants and native plant communities. Of these plants, **hau** and **`ohe** are the worst as they both form dense, difficult to penetrate thickets that allow for little else to grow under their canopies.

Historical records on the subject of inland agriculture are a bit vague. Handy et al. (1991) indicate that they would expect agricultural complexes to be found in a number of upland valley sites. In Ladefoged et al. (2009) a predictive model is presented that estimates which lands are best suited for pond field and dryland farming based on "climate, hydrology, topography, substrate age, and soil fertility". The efficiency of labor used for production of wetland taro compared to dryland agriculture is also explored.

Since terms about GIS and Hawaiian agricultural practices vary in their use, Table 1 is provided to indicate how they have been defined within this document.

Plants from Transported Landscapes

When the ancient Polynesians colonized Hawai'i, they brought their favorite plants (Abbott 1992) and began transforming previously untouched lands to meet their needs. Plants that still grow where they were planted long ago, and are visible in aerial imagery, include **`ohe**, **mai`a**, **hau**, **kukui** and Hawaiian **tī**. Although mango's were introduced in historic times, Hawaiians planted them on the lands that they were still using, and many remain today in lands that are now considered forest. Geo-referenced aerial photographs are studied in detail to map each of these residual transported landscapes:

`ohe

Schizostachyum glaucifolium is the Hawaiian **`ohe** (St. John 1978), and is a clumping variety (Figures 2, 3) that goes to seed once every 30 years. This species can occasionally form dense groves and appear to be a running variety (White 2003) as it has also reproduced by seed. It has extremely thin walls and long internodes, often used

Table 1. Definitions for technical terms used in this document.

Agricultural Complex
Hawaiians created a series of pondfield agricultural systems (similar to rice paddies) that were fed by a primary ditch pulling water from the stream and feeding a series of smaller ditches which in their turn supply the individual lo`i (agricultural pondfield). At the end of a system, the primary ditch typically returns the remaining water back to the river with each systems design adapting to local conditions.
Ancient Hawaiian Land Divisions and Tenure
Under the Ancient Hawaiians system of holding land, the king owned the island and allowed his subjects to use the land. Kauai was divided into five moku (districts) named Hale`lea, Ko`olau, Puna, Kona and Napali. These moku were further divided into ahupua`a (valley or watershed) which were individually managed by a konohiki (kings land agent) who allotted land to inhabitants (Kirch 1985) and ensured that the agricultural systems functioned productively.
Geographical Information Systems (GIS)
GIS programs allow users to navigate and view geographic information overlaid on a virtual globe of the world. Spatial analysis can be performed and custom maps can be created with a variety of data layers. Two GIS applications were used for this project: Google Earth (Google Earth) and Pictometry (Pictometry International Corporation).
Google Earth
Designed for use by a variety of skill levels, Google provides a GIS application that allows users with very little or no previous GIS experience to view and explore GIS layers while "flying" through a 3D landscape. The imagery resolution for Kauai is adequate to identify larger trees but not smaller plants such as bananas and tī. Custom data sets (layers) are easy to create and share.
Pictometry
Although the imagery available from Google Earth is useful, Pictometry has a much higher resolution package of 6-inch pixel geo-referenced aerial oblique imagery. Although it was developed primarily for Urban Planners, Pictometry provides up to 12 different views of a given area which makes it useful for conducting surveys of an ancient agricultural landscape. The extensive database of 15 Mb JPEG images are geo-referenced to the pixel, allowing users to measure and locate objects in the images with a variety of different tools including location, area, height, distance, elevation and bearing.



Figure 2. Clump of *Schizostachyum glaucifolium* (Rupr.) Munro in upper Wailua ahupua`a, Kaua`i, Hawaiian Islands. (The same clump is shown in Figure 2.) Photo by Erik Burton.



Figure 3. Clump of *Schizostachyum glaucifolium* (Rupr.) Munro in upper Wailua ahupua`a, Kaua`i, Hawaiian Islands. (The same clump is shown in Figure 2.) Photo courtesy of Pictometry International Corp.

as a water container. According to Handy *et al.* (1991), this variety was too soft for use in construction but was made into rattles for hula performances (**pu`ili**) & nose flutes (**ohe-hano-ihu**). Perhaps its most important use was for a quick and sharp knife. According to McClatchey (2010), Polynesians still recognize that this is among its most important qualities.

Lundstrom (2010) says that *S. glaucifolium* was used for musical instruments, tattoo needles, surgical scalpels and water containers. It will not root and grow from nodal cuttings but occasionally produces some seed. It does not flower gregariously and die, as many other bamboos do.

Another bamboo that I am seeing in enough quantity to merit mentioning is a thin, spreading taxa that forms massive and dense clumps (Figures 4, 5).

Mai`a

Musa acuminata x balbisiana hybrids are visible in Pictometry imagery, and I have found a number of them on my hikes. At least 80 varieties were planted (Handy *et al.* 1991) in old times for food and other purposes. Today about 40 variety names survive with fewer than 30 of them actually located (Kepler 2008).

All of these varieties (except for two) are seedless (Handy 1940, Kepler 2008) and rely up human intervention for es-



Figure 4. Thin spreading bamboo in Makaleha, Kaua`i, Hawaiian Islands. Photo by Kristar Burton.



Figure 5. Thin spreading bamboo in Wailua, Kaua`i, Hawaiian Islands. Photo courtesy of Pictometry International Corp.

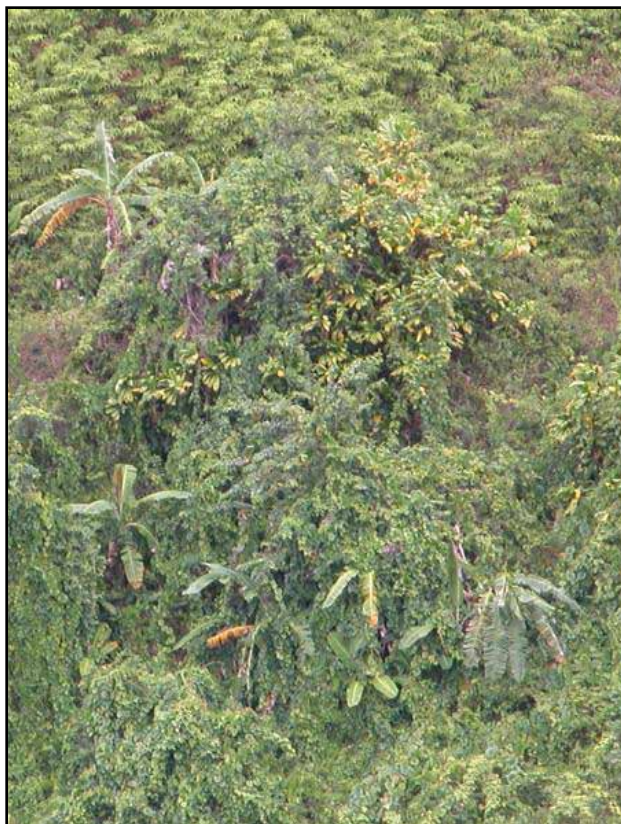


Figure 6a. *Iholena* bananas (*Musa acuminata* x *balbisi-ana* Colla) on the side of a hill in Wailua, Kaua'i, Hawaiian Islands. Photo by Erik Burton.

establishment of new plantings. Plants seen in the Kaua'i backcountry today (Figure 6a) are descendents of these ancient plantings.

Each of these varieties was selected because they had a unique feature or desirable trait. Some of these varieties were eaten raw while others were cooked before eating. In addition to roasting in an *imu* (underground oven) or on hot coals, a pudding-like dish called *piepiele* (Abbott 1992) was made from mashed ripe *iholena lele* bananas (Figure 6b) which were mixed with coconut cream, wrapped in *tī* leaves and steamed in the *imu*.

Traditional Hawaiian bananas are under assault today (Kepler 2008) as pigs are uprooting mature plants to eat the corms, banana bunchy top virus (Bunchy top 2006) has spread to most inhabited parts of Kaua'i and I have found corm borers infesting wild clumps – even in the remote interior. An effort to preserve and identify these unusual varieties has been started at the National Tropical Botanical Gardens (Limahuli). Identifying the varieties that are growing in the most remote parts of the island has proven to be a challenge, as some do not match any of the historical descriptions.



Figure 6b. *Iholena lele* bananas (*Musa acuminata* x *balbisi-ana* Colla) in Kaua'i, Hawaiian Islands. Photo by Erik Burton.

Hau

Another plant of many uses, *hau* (*H. tiliaceus*) was never left alone to grow out of control in ancient times. Instead, it was constantly harvested for its multitude of uses (Handy *et al.* 1991) including bark for rope, flowers for medicine, wood for starting fires and fishing net floats, skirts for hula, and booms for outrigger canoes.

Today the *hau* trees (Figure 7) are growing out of control and are consuming vast areas that were previously used for Hawaiian agriculture. Like running bamboo, *hau* spreads (Figure 8) and swallows up whatever other plants or agricultural structures are in the way. Left unchecked to grow at will, it will continue to transform the landscape of Kaua'i's remote areas.

As it stands today, reaching many of these remote areas is made difficult by the challenge presented in getting through dense stands of *hau* – often leaving me wondering “*hau*” the heck to get through or around it. As local Kaua'i lore has it, *hau* leaves even roughly resemble the island of Kaua'i including its major rivers and valleys (Wichman n.d.).



Figure 7. Hau (*Hibiscus tiliaceus* L.) bush and flowers in Kauaʻi, Hawaiian Islands. Photo by Erik Burton.



Figure 8. Extensive hau (*Hibiscus tiliaceus* L.) coverage in Keahua valley, Wailua, Kauaʻi, Hawaiian Islands. Photo by Erik Burton.



Figure 9a. Common mangos (*Mangifera indica* L.) on a trail in Wailua, Kauaʻi, Hawaiian Islands. Photo by Erik Burton.

Mango

With the early western explorers came many food plants new to the Hawaiians including mango trees. The common mango (*Mangifera indica* L.) (Figure 9a) was planted by the Hawaiians near their agricultural sites (Figure 9b) and these trees can still be seen today.

According to Morton (1987), “The earliest record of the mango in Hawaiʻi is the introduction of several small plants from Manila in 1824. Three plants were brought from Chile in 1825. In 1899, grafted trees of a number of Indian varieties, including *pairi*, were imported. Seedlings became widely distributed over the six major islands. In 1930, the Haden variety was introduced from Florida and became established in commercial plantations. The local industry began to develop seriously after the importation of a series of monoembryonic cultivars from Florida. But Hawaiian mangos are currently prohibited from entry into mainland U.S.A., Australia, Japan and some other countries, because of the prevalence of the mango seed weevil in the islands.”

Many magnificent specimens of these mango trees remain today (Figure 9b) in both accessible and somewhat remote places. People are still harvesting and enjoying the fruit of these trees (Figure 9a), a gift from the past that just keeps on giving. Although mango trees were not introduced by Polynesian settlers, they were planted by Hawaiians during the early contact period. Further research is needed to determine the variety(s) or cultivar(s) of these plantings.

Hawaiian ti

Cordyline fruticosa (L.) A. Chev., (Figure 10) does not produce seed in Hawaii as it does not appear to produce viable pollen (Yen 1987). All plants have been propagated through vegetative cuttings such as a fly whisk discarded along the route of an ancient trail. Others were planted to consecrate special areas or around a home, planted in upland gardens (Kepler 1998) for util-



Figure 9b. Common mangos (*Mangifera indica* L.) in flower on a Kaua'i hillside, Hawaiian Islands. Photo by Erik Burton.

ity purposes, emergency food and in more recent times, **okolehao** (alcohol) production.

An indeterminately growing plant of 1,000 years and 1,000 uses (McClatchey 2010), **tī** was treasured by the Hawaiians for its many uses including medicinal, food containers for serving or steaming food in the **imu** (ground oven), leaves for weaving just about everything and even thatching houses. **Tī** was even used as a famine food or for a welcome treat (Abbott 1992), by slow baking the huge starchy roots until they turned into a sweet sugary mass.

During the U.S. era of alcohol prohibition, **tī** was planted for **okolehao** production. **Okolehao** (iron bottom) is a form of alcohol based on the sugar produced by baking the **tī** root (Abbott 1992). Different stories account for the name "iron bottom" including the idea that you need one

to be able to drink the strong drink that was produced. Another explanation is that some of the iron try-pots from the whaling ships were combined with an old gun barrel to create a still (Fornander 1916-1917).

Oddly enough, the aerial signature for **tī** plants is a yellow circle (Figure 11) as the dying leaves stand out from the surrounding green foliage.

Historical Records

The Great Mahele (historic land division) preserved a remarkable amount of place names for features associated with agricultural complexes, and related places claimed by Hawaiians during the years of 1848 to 1849. These records have recently been posted online (Ulukau 2011).



Figure 10. Hawaiian **tī** (*Cordyline fruticosa* (L.) A. Chev.) in Kaua'i, Hawaiian Islands. Photo by Erik Burton.



Figure 11. Hawaiian **tī** (*Cordyline fruticosa* (L.) A. Chev.) in Lumaha'i valley, Kaua'i, Hawaiian Islands. Photo courtesy of Pictometry International Corp.

Before 1848, all lands on an island were held by the **Ali`i`ai Moku** (lit. chief who eats the island) and apportioned to commoners through a **konohiki** who directed an entire **ahupua`a**. Whenever a new **Ali`i`ai Moku** would assume rule over an island, a **mahele** (division) was held and lands could be re-divided according to the new chief's wishes. The Great Mahele (Moffat & Fitzpatrick 1995) of 1848 transformed this ancient land tenure practice into our modern system of land ownership, effecting dramatic change to the Hawaiian lifestyle. After the Great Mahele, **konohiki** were no longer needed and so many found themselves destitute that a special act was passed to help them acquire some land.

In addition to the Great Mahele records, many old maps exist that have a number of agricultural features outlined and named. Most of these are maps of sugar cane and pineapple field systems in the early 1900's.

The Kauai Historical Society has extensive records on file including the unpublished work of Fred Wichman who collected so many place names for Kaua`i.

Summary

Hawaiians heavily modified their agricultural landscape to maximize production of food and other resources for a particular **ahupua`a**. Modern agriculture has greatly impacted these ancient systems in the more accessible areas; however, vast portions of the interior of Kaua`i appear to be largely untouched since they were abandoned by the ancient Hawaiians.

Easy to use GIS tools with decent imagery present us with an opportunity to record these ancient sites before they completely disappear. Using GIS tools to model their abandoned agricultural systems can provide a view into the extent of landscape modification for agricultural production during an ancient time of peak population.

Objectives

Building on the history presented above I set out in this project to achieve three objectives:

1. Develop a method of identifying the primary agricultural complexes within an **ahupua`a**.
2. Conduct a GIS based aerial survey of an **ahupua`a** detailing the location of plants from transported landscapes.
3. Develop a GIS model of information from the historical archives that can be used to compare with the results from Objectives 1 & 2.

Methods

Using GIS to visually analyze an ancient agricultural landscape requires the creation of data sets that are repre-

sented as GIS layers. For the three GIS layers being discussed, Agricultural Complexes, Transported Landscapes and Historical Records, the tools are the same but the approach is significantly different.

GIS Applications Used

For this project, I used two GIS applications: Google Earth, and Pictometry International's Electronic Field Study. Google Earth was used to house the GIS layers and visualize their relationship to the landscape. It was also used to create some of the GIS layers. Pictometry's Electronic Field Study was used to locate the transported landscapes, and analyze the agricultural complexes.

I used the freely available version of Google Earth, (Google Earth 2010) which, at the time of this paper, is in version 6.0.3.2197. In order to view the Google Earth imagery as clearly as possible, I used a large, high quality monitor in a darkened room. I also increased the resolution of the imagery being delivered from the Google Earth servers, by going into the menu under Tools, Options, and then increased the Terrain Quality to maximum by sliding the selection bar all the way to the right.

Google Earth has pulled together a variety of satellite images to "quilt" together their imagery database. These images have a varying degree of resolution depending on what you are viewing at the moment. Their imagery is delivered from their central servers and is subject to change at any time. The imagery quality available for Kaua`i during the time of this study was sufficient to identify larger trees, but not shrubs and smaller plants such as **ti**. (But for example, the imagery available for San Jose, California is sufficient to identify shrubs and smaller plants.)

Pictometry International Corporation's Electronic Field Study, version 2.7, Production release 1, Revision 14 (Pictometry 2010) was also used. It's database of 44,000 Geo-referenced images of Kaua`i average 6-inches per pixel, and allow me to systematically survey an **ahupua`a**, obtaining coordinates for trees and other objects in the landscape. Using the application, you can also determine the boundaries of an agricultural complex, measure the height of a cliff, and view an area from a variety of different angles. Electronic Field Study was designed for Urban Planners, and the Pictometry staff indicated that this project is the first time they have heard of their application being used for landscape surveys.

GPS Tools Used

A portable GPS unit (Garmin 60 CSX) was used for field visits to record locations of plants and other features. Data from the GPS unit was downloaded into the Garmin Map Source (Garmin 2010)(software version 6.14.1) application, reorganized, and then imported into Google Earth.



Figure 12a. Author's conception of an agricultural complex. Image generated with Google Earth.

Method for Identifying Agricultural Complexes

For the purposes of developing this GIS layer, I have defined an agricultural complex (Figure 12a), as a gently sloping or level area of land along a river or stream, that can be irrigated by an **auwai** (irrigation ditch), and containing remnants of transported landscapes.

To locate agricultural complexes, it is helpful to try and think like an ancient Hawaiian engineer. Handy *et al.* (1991) describe the construction and operation of **auwai**, along with some of the protocols associated with their communal use.

When constructing these new irrigated agricultural complexes, the ancient Hawaiians put considerable work into bringing water in as high as was practicable, maximizing the farmable area. The layout of each complex is different, yet they share some essential elements. Most are sup-



Figure 12b. **auwai** elevation measurement. Image generated with Google Earth.

plied by a primary **auwai** that uses a dam to pull water from the stream. This water is used to supply the small ditches and **lo'i** that make up the complex.

To locate the ancient agricultural complexes of an **ahupua'a**, I begin at the coast where the river or stream enters the ocean. There are usually some broad flat lands here and a **muliwai** (brackish pond) where the river or stream enters the ocean. As these lands are at the lowest elevation, they are some of the easiest to reach with an **auwai**.

After locating a candidate flatland along the river with Google Earth, I look for evidence of disturbances to the native landscape, including elements of transported landscapes, such as **kukui** trees (*Aleurites moluccana* (L.) Willd.), whose oily nuts

were burned for light. Next, I consult the Electronic Field Study imagery to see if there are any visual indications of the boundary of the complex. In many cases, you can see level, irrigable land running up to the base of a cliff, or to an abrupt bank in the hill.

With a general idea of the complex outline, I then conduct an elevation survey using Google Earth and the Electronic Field Study. In Google Earth, you can determine the elevation of an area by placing the cursor over it. The elevation will be displayed at the bottom of the screen, and change dynamically as you move the cursor around. With this tool, I determine the elevation of the river, just **mauka** (toward the center of Kaua'i) of the complex by moving the cursor from one side of the river to the other, noting the minimum elevation of the water level.

This gives you a beginning elevation for the water intake. Electronic Field Study also has an elevation tool; however, it measures canopy height. Google Earth's elevation tool measures terrain height, which provides a more accurate indication of a potential irrigation intake elevation.

With the intake elevation as a starting point, I use the Google Earth line tool to mark out the boundary of irrigable land, assuming a 2 foot drop for every 100 feet. This line (Figure 12b) provides an idealized view of the primary **auwai**, and marks the boundary of the agricultural complex.

Using Electronic Field Study's Area tool, I measure the complex three times, recording the average in the spreadsheet. In Google Earth, I use the Add Polygon tool to make an outline of the complex, and record the area measurement in the Description field. As the imagery in Google Earth is a little off of alignment, I rely upon elevation to guide drawing the boundaries of the complex. Although this is not as accurate as a ground survey would be, it is sufficient to provide valuable insight into the extent and nature of the ancient agricultural landscape. This process is continued up the **ahupua`a** (Figure 13), following each branch of the river and its streams until the indicators stop.



Figure 13. Agricultural complexes in Lumaha'i ahupua`a, Kaua'i, Hawaiian Islands. Image generated with Google Earth.

Method for conducting aerial surveys of transported landscapes

While I have noticed the indicator plants in the forest for some time, GIS provides the opportunity to record their locations. Pictometry is used to systematically explore an **ahupua`a**, from the valley floor to the top of the ridges (Figure 14), looking for remnants of ancient plantings. Coordinates for each tree or cluster of plants was recorded in Google Earth.

The following plants were included in the surveys: bamboo, bananas, **hau**, mango and **tī**. In order to determine what a plant looks like from the air, I start with one that I have already seen from the ground and take a look at it

with Google Earth and then in Electronic Field Study to determine its aerial signature.

In Google Earth, **kukui** trees are so easily seen, and plentiful, that I don't bother marking them. Some of the other transported landscapes can be glimpsed with Google Earth, but are much more visible in the Electronic Field Study imagery.

Beginning at the ocean, I use Electronic Field Study to systematically inspect the **ahupua`a**, including each of the side drainages, for the transported landscapes previ-



Figure 14. Bananas (*Musa acuminata* x *balbisiana* Colla), **tī** (*Cordyline fruticosa* (L.) A. Chev.) and mangos (*Mangifera indica* L.) in Wainiha ahupua`a, Kaua'i, Hawaiian Islands. Picture courtesy of Pictometry International Corp.

ously listed. As most areas have images available from each direction as well as directly overhead, great care is taken to determine the optimum viewing angle, as lighting can make things appear and disappear.

Once the ideal viewing angle is determined, the area or side drainage is explored from that angle, and the targeted species locations are systematically recorded, each in their own folder, and represented by a custom icon. This process is continued until the entire **ahupua`a** is explored.

Historical Reconciliation using GIS layers

Historical records were consulted for descriptions of ancient or historical agricultural systems. Further place names information was obtained from old maps, and especially from the unpublished manuscripts of Fred Wichman, that are on file at the Kauai Historical Society.

Using Google Earth, Tax Maps were converted into a layer using the Add Image Overlay tool. By temporarily making a Tax Map semi-transparent, I am able to align it with the Google Earth imagery. This is done for all of the Tax Maps

for the **ahupua`a**, and the image overlays are stored in their own folder.

One at a time, each of the Tax Maps is turned on, and any relevant features are traced with Google Earth Polygons or Lines. Hawaiian Land Claim Award parcel outlines, and old irrigation ditches are the main focus. When the Tax Map overlay is turned off, the drawing shapes remain, and each are placed in their appropriate folder.

Land Claim records from the Great Mahele were consulted (Ulukau 2011), and information for each Land Claim was entered under an envelope icon (Figure 15) which was placed in the related parcel outline. This was done for each Land Claim Award in the **ahupua`a**. Place Names mentioned in the Land Claim Awards (Figure 16), but not recorded elsewhere, were located and added to the Google Earth layer.

Results

The GIS layers are all combined to create a master GIS model for an **ahupua`a**. This allows a researcher to eas-



Figure 15. Hawaiian land claim award (LCA #10562.1 - Opu's moo kalo called Kamakapili & a large Loko adjoining called "Keaweloko") outlined in Ha'ena ahupua`a, Kaua'i, Hawaiian Islands. Image generated with Google Earth.



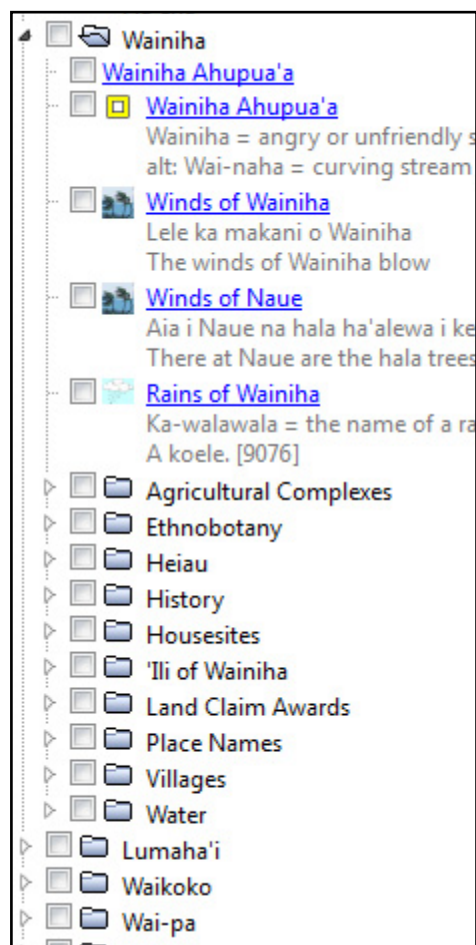
Figure 16 (above). Place names in Ha`ena ahupua`a, Kaua`i, Hawaiian Islands: **A)** Wa-wai-kapu Pali; **B)** Konohiki's pasture; **C)** Moo Kalo Maninihuanui; **D)** Sand hills back of beach; **E)** Kawaikapu pali; **F)** Kahau pali; **G)** Moo kalo called Keokeaihu; **H)** Pu`u-o-Ni`ihau; **I)** Pohaku-loa; **J)** Koie; **K)** Loi called Malupo; **L)** School - Grant #41:8; **M)** Aio's lois; **N)** Nakeu's lois; **O)** Kaluahonu; **P)** Lalaole's Koele moo; **Q)** Nuuanu land; **R)** Kalaelehua's lois; **S)** Moo kalo "Peekauai"; **T)** Loi "Koia"; **U)** Mako-hoa; **V)** Lae's land; **W)** Koele "Kapalaa"; **X)** Davida's loi "Pahole"; **Y)** Kiliili moo Piimoku's lois; **Z)** Na Anawaiakanaka; **AA)** moo Kapuakaiki/Kapuakaloiki; **BB)** Awana's lo'i; **CC)** moo "Kaahaolono"Kunihi's lois. Image generated with Google Earth.

Figure 17 (right). Main GIS model with layers organized into folders. Screen capture from Google Earth.

ily access data for a particular **ahupua`a** (Figure 17) and selectively enable the data to be visualized. By selectively enabling the data layers, a custom view of the ancient agricultural landscape can be created. This allows the data to be viewed from many angles in 3D, revealing things that were previously only understood by people who lived in an area for a lifetime.

A few notes on data accuracy

The **ahupua`a** boundary outlines were obtained from the State of Hawaii GIS website and reflect the state of the boundaries around the time of the Great Mahele (1848). These **ahupua`a** boundaries changed over time with increases or decreases in populations, changing political leadership and other factors. These GIS layers are not considered to be accurate by modern surveyor's standards, but can still serve to help us understand the ancient Hawaiian agricultural environment. The data layers produced from this study are only aerial surveys, detailed ground surveys are required to obtain a truly accurate view of what remains on the ground.



Results are presented for three general classes of layers: agricultural complexes, aerial ethnobotanical surveys for plants from transported landscapes, and historical reconciliation using GIS layers.

Agricultural complexes

Figures 18 and 19 illustrate examples of agricultural complexes from Kaua'i.



Figure 18. Agricultural complexes in Wainiha ahupua`a, Kaua`i, Hawaiian Islands. Image generated with Google Earth.



Figure 19. Agricultural complexes in Lumaha'i ahupua`a, Kaua`i, Hawaiian Islands. Image generated with Google Earth.



Figure 22. Survey results for hau (*Hibiscus tiliaceus* L.) in Ha'ena ahupua'a, Kaua'i, Hawaiian Islands. Image generated with Google Earth.



Figure 23. Survey results for mango trees (*Mangifera indica* L.) in Ha'ena ahupua'a, Kaua'i, Hawaiian Islands. Image generated with Google Earth.

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Historical Reconciliation using GIS layers

Combined Layers

An example of mapping of historical results about sites is illustrated in Figure 25.

Examples of combined data layers are presented in Figures 26 and 27.



Figure 26. All layers displayed for Wainiha and Ha'ena ahupua'a, Kaua'i, Hawaiian Islands. Image generated with Google Earth.



Figure 27. All layers displayed for Wainiha ahupua'a drainages, Kaua'i, Hawaiian Islands. Image generated with Google Earth.

Discussion

Many times while doing this work I will get “chicken skin” when working on particularly interesting places, and in these moments I am transported (in my imagination) back in time to when these places were full of people and activity. I can almost see the farmers working in their plots, children jumping into their favorite swimming holes, women pounding out **kapa** (bark cloth), people on the trails bringing mountain products to trade with their family at the seashore, and enjoying special places discovered during a lifetime. To experience these places and not be moved would be unusual. As lovely as these remote places are today in their overgrown state (Figure 28), what wonders there must have been to see during the main times of occupation.

In taking a look at the data produced by these surveys, it is easy to be overwhelmed by a cloud of icons and shapes projected over a moving 3D image of Kauai. GIS tools allow you to turn on these layers individually or all at once and view them from just about any angle. This kind of dynamic visualization can be helpful in developing an un-

derstanding of the layout and spatial relationships of the agricultural landscape.

A discussion follows of each of the three focuses of this study: agricultural complexes, ethnobotanical surveys and historical records.

Agricultural Complexes

The number of agricultural complexes predicted by this GIS model point to a time of large populations. The model is actually a bit conservative, as it does not attempt to account for the many minor taro patches formed in the side drainages seen during my field visits. By outlining all of the main agricultural complexes within an **ahupua`a** (Figures 18, 19), the extent of development begins to take shape. The complexes certainly do form the “slowly ascending stairway of steps, broad in the tread and low in the rise” as mentioned in Handy *et al.* (1991). Google Earth allows you to “fly” up the valley, viewing each complex as it sits in its unique area of riverbed geography. The data from the historical layers coordinate nicely with the terrace areas (Figure 29) in the lower portion of Ha`ena ahupua`a.

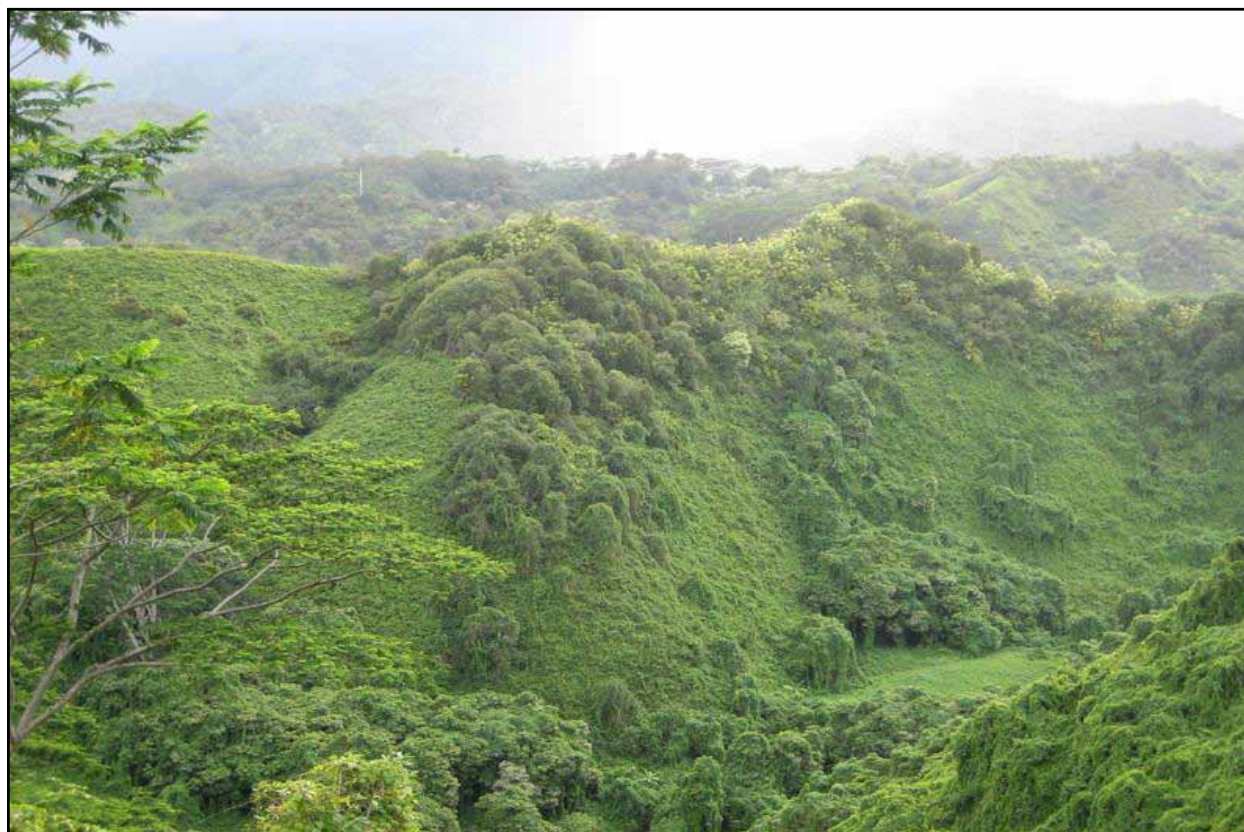


Figure 28. Kawi valley in Wailua ahupua`a, Kaua`i, Hawaiian Islands. **Ti** (*Cordyline fruticosa* (L.) A. Chev.) covers the twin-peaked hill while **ho`i** (*Dioscorea bulbifera* L.) smothers **mai`a** (*Musa acuminata* x *balbisi* Colla) plants and **kukui** (*Aleurites moluccana* (L.) Willd.) trees. An old agricultural complex is present in the meadow by the stream. Everything you need for a nice upland garden area. Photo by Erik Burton.



Figure 29. Agricultural complexes in Ha`ena ahupua`a, Kaua`i, Hawaiian Islands, with land claim awards and place names layers. Image generated with Google Earth.

With all layers enabled (Figure 27) a view of a very busy ancient agricultural landscape is presented. Primary agricultural complexes by the main river, side drainages filled with *tī*, mango, bananas, *kukui* and hau bush. It is easy to see a group, perhaps a family unit, farming some *lo`i* fed by the main *`auwai* for the agricultural complex as well as utilizing a side drainage for all their forest resources. Instead of heading to the very back of the valley to collect needed forest plants, they simply farmed the nearest side drainage. In the case of a larger drainage, its own side drainages may have been allocated to certain groups or members within the family. On Kaua`i's wet north shore (the area of focused study for this project) most of these side drainages have year round streams and would have been quite productive as evidenced by the quantities of plants remaining (Figure 27).

The agricultural complex prediction maps developed from this study match up nicely with the maps provided by Ladefoged *et al.* (2009) which were based on "climate, hydrology, topography, substrate age, and soil fertility". Neither of our models account for the many minor terraces constructed in the side drainages that I have seen during my hikes. Apparently, just about everywhere conditions were ideal, *lo`i* were constructed and taro was planted.

Aerial surveys for plants from transported landscapes.

This was one of the more interesting sets of layers to create as it had the most direct contact with the people of old

without any human point of view filtering the raw data. The Pictometry package was very helpful as you can easily view the same area from many different viewpoints, using the different lighting conditions to reveal otherwise hidden plants, like *tī* and banana, tucked into ravines and under the tree canopy.

It was surprising to see just how many of these Hawaiian introduced plants were still growing in these drainages. After intensively studying hundreds of pictures, patterns begin to emerge that demonstrate a willful intent indicating human intervention, such as in the case of *tī* plants consistently situated at the very tops of drainages and along ridges.

`ohe

Finding 46 clumps of *`ohe* just in the *ahupua`a* of Lumaha`i was impressive. *`ohe* was used for so many things that it is easy to see why so many clumps were planted - such a useful resource should be close at hand! The groves of thin green *`ohe* (Figure 30) that have eaten up big parts of the side drainages and the valley floor need to be identified. Growing unchecked, they are consuming large areas and erasing possible evidence of ancient planting practices.

What is this thin stalked variety planted in these different areas and what was it used for? Ground truthing these different varieties would provide some interesting data for



Figure 30. This spreading bamboo in a Wainiha ahupua'a drainage threatens to consume ancient plantings on Kaua'i, Hawaiian Islands. Photo by Erik Burton.

comparing to the descriptions of "Hawaiian bamboo" (Abbott 1992, Handy *et al.* 1991).

Mai'a

What was most notable from the study results for **mai'a**, was the lack of plants considering the other planting activity. During my field visits, I would often find 2 to 3 times as many plants as were visible in the aerial imagery. Many of these others are hidden under the forest canopy or in other inconspicuous areas. Pressures on banana plants that could account for their low numbers include feral pigs who knock the plants down to eat the starchy corms and corm borers. Banana bunchy top virus is established on Kauai but so far seems to be sticking to the coastal areas which are impacted by people.

Identifying which varieties are planted in these areas could provide insight into their intended purpose. Certain plant cultivars had symbolic importance to the ancient Hawaiians and were sometimes planted for what they represented (Abbott 1992) instead of for food or utility purposes.

Hau

Ever since the Hawaiians stopped living in the old ways, **hau** has been on the run with nobody to check its growth (Figure 31). Usually a much trimmed clump near the side



Figure 31. Hau (*Hibiscus tiliaceus* L.) smothering kukui (*Aleurites moluccana* (L.) Willd.) trees on Kaua'i, Hawaiian Islands. Photo courtesy of Pictometry International.

of a river (Handy *et al.* 1991), **hau** is now left alone to grow (Figure 32) out of control. Although it is not currently considered an invasive species, it is probably just a matter of time.

The groves identified from the GIS surveys extend far inland and closely track the agricultural complexes identified in the surveys. This is especially true in Lumaha'i where they cover almost every agricultural complex (Figure 33) extending into the furthest upland reaches of the **ahupua'a**.

Mango Trees

The data from the surveys show mango trees planted primarily in the lower parts of the valley where the majority of Land Claims were awarded (Figure 34). As mango trees were introduced with the coming of Westerners, perhaps this grouping of trees in the lower valley reflects the greatly reduced populations that had moved down to prime lands in the lower valley.

Locally these mangos are referred to as the "common mango", they all seem to flower around the same time (January-March) and can primarily be found near old habitation sites near the coast. I would expect that ground truthing would show the bulk of these trees to be the same variety with just a few near the coast being other cultivars planted in more recent times. As it stands now, the fruit of many of these trees are still harvested and enjoyed by locals and visitors alike as they grace many a park trail (Figure 35).



Figure 32. Hau (*Hibiscus tiliaceus* L.) covering an agricultural complex in Lumaha'i ahupua'a, Kaua'i, Hawaiian Islands. Photo courtesy of Pictometry International.



Figure 33. Hau (*Hibiscus tiliaceus* L.) in dark green and agricultural complexes in light green show the close association between the two in Lumaha'i ahupua'a, Kaua'i, Hawaiian Islands. Image generated with Google Earth.

Most of these trees are now over 150 years old and have developed large trunks and high canopies. It can be a bit frightening hiking in old mango groves when the ripe fruit are falling silently from great heights. Although not as big and dangerous as a falling coconut, you still don't want to have one bonk you on the head.

Hawaiian **ti**

ti is the most populous of the plants mapped in these surveys. After intensively studying hundreds of high resolution photos of side drainages filled with Hawaiian introduced plants, I am left marveling most at the **ti**. For exam-

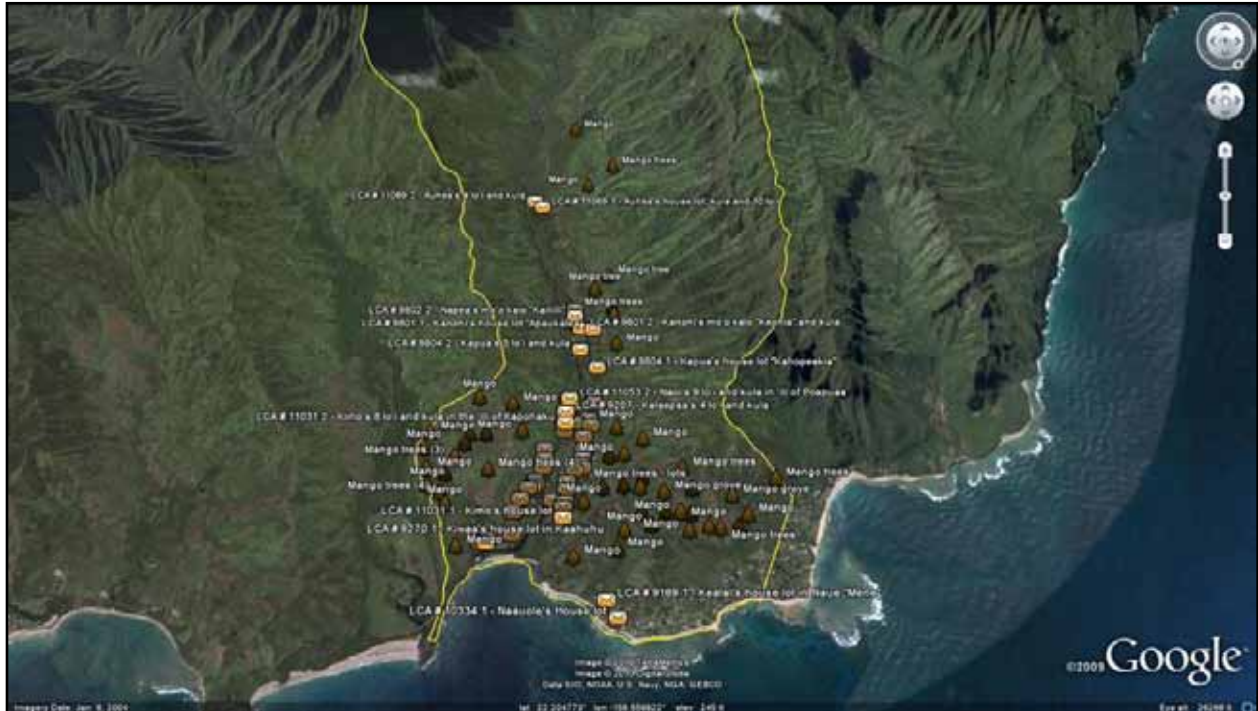


Figure 34. Mango trees (*Mangifera indica* L.) and land claim awards in lower Wainiha ahupua`a, Kaua`i, Hawaiian Islands. Image generated with Google Earth.



Figure 35. Mature mango trees (*Mangifera indica* L.) line a section of old road in laim awards in lower Wailua, Kaua`i, Hawaiian Islands. Photo by Erik Burton.

ple, some side drainages had a few **tī** plants in the lower and mid sections yet had remarkable concentrations of them right near the very top including a few planted right at the highest point (Figure 36). The pattern varies with some side drainages having very few **tī** plants and some that have a few at the very top with no dense concentrations.

The plantings seem to follow a very conscious pattern and are often grouped with other Hawaiian introduced plants like **kukui** trees, bamboo (Figure 37) and bananas.

When considering the **tī** plant's presence in these patterns, I had difficulty coming to terms with the possibility that each and every plant was put there by humans and is still growing exactly where it was planted. Perhaps it is just Mother Nature and her violent storms that have uprooted **tī** plants, broken them into little bits and scattered them in tight groups at the tops of drainages where they sprout and form the plants we see today? If it was Mother Nature doing this, I would expect to see a more general disbursement and not tight groupings of plants in a predictable pattern. There are more examples on Kaua`i of intentionally planted groups of **tī** in unusual places. An example is Figure 28, showing two peaks and the saddle between covered in **tī**. In upper Wailua ahupua`a is a ridge (Figure 38) with a large patch overlooking an overgrown agricultural complex. During my hikes in the field, I have found **tī** marking old trails and planted on sheer rocky cliffs (Figure 39) next to waterfalls. If these **tī** plants



Figure 36. *Ti* (*Cordyline fruticosa* (L.) A. Chev.) plantings show up with dying yellow leaves at the top of a drainage in Lumaha'i ahupua'a scattered among *kukui* trees (*Aleurites moluccana* (L.) Willd.), Kaua'i, Hawaiian Islands. Image generated with Google Earth.

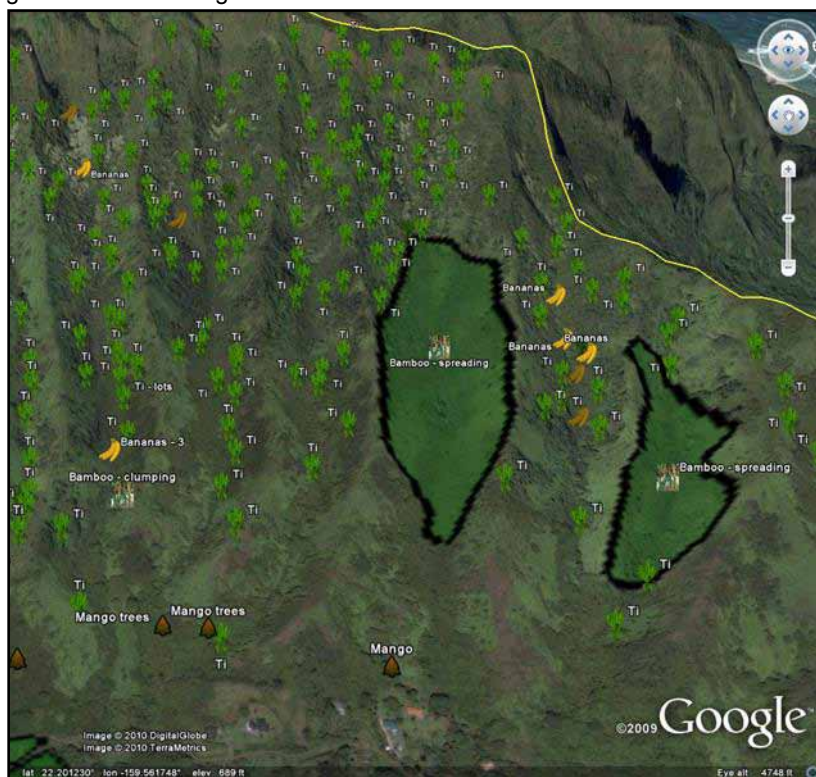


Figure 37. Side drainages in Wainiha, Kaua'i, Hawaiian Islands, planted with *tī* (*Cordyline fruticosa* (L.) A. Chev.) bananas (*Musa acuminata x balbisiana* Colla), *kukui* (*Aleurites moluccana* (L.) Willd.), mangos (*Mangifera indica* L.) and bamboo. Image generated with Google Earth.

were not planted by Mother Nature but instead were put there by a human hand, what was their purpose?

Assuming, as Bennett (1931) says, just as they did not build houses on land that could be used for taro production, the large populations of old must have had *kula* lands elsewhere for planting the other plants needed for everyday life. In looking at the geography around the agricultural terraces, the only other land is the side drainages where all the Hawaiian introduced plants were found! Supposing that these drainages (Figure 29c) were the *kula* lands for people during the ancient times of high populations, how were they apportioned?

Agricultural activity greatly benefits from the presence of water and most of these side drainages have perennial streams. Considering how methodical the Hawaiians were in dividing up other lands, it seems logical that individual side drainages would be worked by a specific group of people, perhaps an extended family or working group. If this was the case,



Figure 38. **Ti** (*Cordyline fruticosa* (L.) A. Chev.) plants cover part of a ridge in Wailua ahupua`a, Kaua`i, Hawaiian Islands. Photo by Erik Rohlfss.

the plantings up in the higher parts of the drainage could be accounted for in several ways.

Perhaps population pressures justified planting all parts of the drainage and as populations declined, later generations harvested the easier to reach plants, not replanting as there was so much to pull from.

Another possibility that comes to mind is the spiritual role of **tī** in accompanying prayers and sanctifying an area (Abbott 1992). Is it possible that each year, a **tī** plant was taken to the top of the drainage and planted as part of a prayer to the gods for successful harvests that year? After many years the plants would accumulate at the top of the drainage with a few especially brave souls taking their plant(s) to the uppermost reachable part of the drainage, getting it that much closer to the gods. This idea does account for this planting pattern being present in the minor drainages that lack prodigious quantities of **tī** but still have a few strategically placed plants at the very top. Some of the large drainages have several (Figure 40) branches that are themselves quite large and have **tī** going to their

tops. Could these also have been held by separate family groups and represent their individual prayers?

Another idea is that these plants could have been planted to demonstrate bravery. A flag rots over time whereas a **tī** plant is both long lasting and easy to see.

If you consider the ancient lifestyle pattern of living near your taro patch and periodically heading up into the mountains to tend your gardens and collect forest resources, it would have been quite a monumental trek for these people to have to proceed to the upper valley of the larger **ahupua`a** like Wainiha which is twelve miles long. Heading up the side drainages for these resources would have been much more convenient.

Considering that **tī** was used for so many things, including just about every spiritual function, and that it needs human intervention to create new plantings, further research could provide some interesting insights into ancient agricultural practices.



Figure 39. Ti (*Cordyline fruticosa* (L.) A. Chev.) planted on sheer rocky cliffs next to a waterfall in Makaleha, Kaua'i, Hawaiian Islands. For scale, the top of the falls is about 60 feet up from the stream bed. Photo by Erik Burton.

Historical Reconciliation using GIS layers

Working with these GIS layers was very interesting as a number of the identified agricultural complexes situated in the lower parts of the valley had names preserved during the Great Mahele. Some of these from the finished historical data layer are described as follows:

One interesting example is the very long (Figure 41) agricultural complex that runs along Powerhouse road in lower Wainiha. From the Kauai Historical Society's collection of place names (Fred Wichman) comes the name Ka-pa-loa, the long fence or alternatively Ka-pa-lo'i, the elongated food bowl. Considering the shape of the agricultural complex, my bet is on the name Ka-pa-lo'i as the complex is certainly elongated and would have produced much taro.

The names of a few side drainages emerged from the Land Claim documents that do not appear on the old



Figure 40. Ti (*Cordyline fruticosa* (L.) A. Chev.) and kukui (*Aleurites moluccana* (L.) Willd.) plants in branching drainages in lower Wainiha ahupua'a, Kaua'i, Hawaiian Islands. Photo courtesy of Pictometry International Corp.

maps. One example of a drainage name is: `ai-kahi, place of food (Figure 42). Some tidbits from the Land Claim Award testimonies reveal interesting things about daily life at the time of the Great Mahele including that orange trees were a much valued asset as they could be sold to California buyers – one of the few cash crops for individual farmers at the time. The Land Claim records detail several battles with the **konohiki** of the **ahupua'a** who is trying to claim the trees of one of the inhabitants. These were no laughing matters. Shortly after the Great Mahele process was completed, **konohiki** lost their jobs and many had to depend on the charity of their former charges.

Names of individual taro patches, groups of patches and agricultural complexes came out of the Land Claim Awards and were able to be generally located on the map – many of these not appearing on any other maps such as names for side streams, pasture lands, cliffs and minor irrigation ditches.

Conclusions

At the beginning of this paper I posed three objectives and will now address if they were achieved and what was learned.



Figure 41. Ka-pa-loa, the long fence; or alternatively, ka-pa-lo`i, the elongated food bowl. An agricultural complex in lower Wainiha ahupua`a, Kaua`i, Hawaiian Islands. Image generated with Google Earth.



Figure 42. Ka-pa-loa, the long fence; or alternatively, ka-pa-lo`i, the elongated food bowl. An agricultural complex in lower Wainiha ahupua`a, Kaua`i, Hawaiian Islands. Image generated with Google Earth.

1. Develop a GIS model to predict the location and extent of Agricultural Complexes within an ahupua`a.

Based on my hikes to a sample of the predicted areas, the model for agricultural complexes is preliminarily accurate and the resulting GIS model can be used to predict the presence of abandoned agricultural complexes. The outlining of all of these complexes to the most inland extent of the **ahupua`a** provide a good idea of how far inland an **ahupua`a** was developed for agricultural production.

Note: When Pictometry completes imaging the island of Kaua`i, agricultural complex area measurements can be completed for each **ahupua`a** on Kaua`i.

2. Conduct a GIS based aerial survey of an ahupua`a detailing the location of plants from transported landscapes.

The plant surveys are labor intensive but provide a fantastic view of ancient Hawaiian planting practices that is otherwise unavailable. These side drainages were an important source of the valuable materials needed for everyday life. Being able to view these detailed plant surveys with the other layers provides a valuable view of the ancient agricultural landscape of an **ahupua`a**.

3. Develop a GIS model of information from the historical archives that can be used to compare with the results from Objectives 1 & 2.

The confusing amount of information contained in the old records was much easier to understand once it was rendered into GIS layers and viewed with the other layers. Names of individual **lo'i**, **auwai**, **loko** (fishponds) and **kula** lands began matching up with features identified

in the other layers. Combining these layers and viewing them in a 3D terrain model (Google Earth) helps an overall picture of ancient land use patterns (Figure 43) begins to emerge.

These new layers were added to my master GIS model (Figure 44) which consists of a variety of other layers shedding light on ancient Kaua'i.

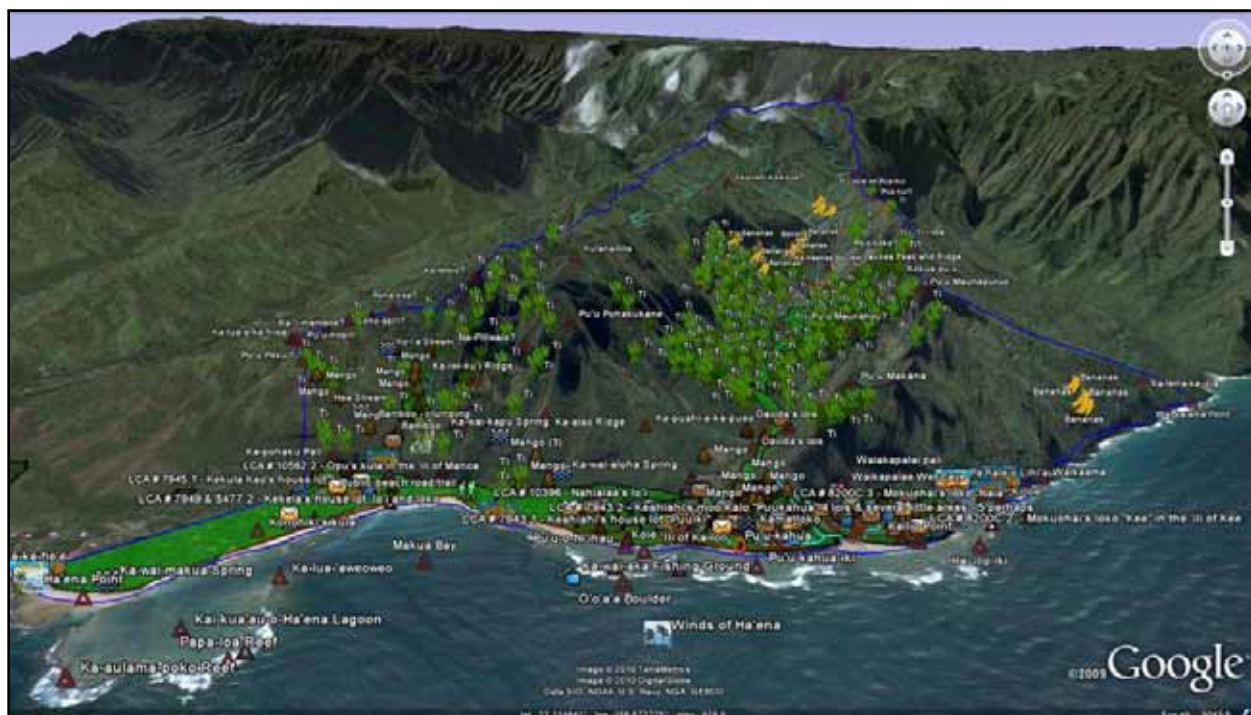


Figure 43. All layers for Ha'ena ahupua'a, Kaua'i, Hawaiian Islands. Image generated with Google Earth.

Acknowledgements

I would like to recognize the Hawaiian people for their achievements in maximizing sustainable agriculture in a variety of environments and conditions. We have much to learn from the people of old and their descendents.

Randy Wichman provided countless hours of consulting and direction to help improve my understanding of Kaua'i's ancient cultural landscape. His personal knowledge of ancient Kaua'i is not only singularly remarkable, his willingness to share and open demeanor suite him well for his role in leading the Kauai Historical Society.

My thanks also go out to Angela Kepler and Frank Rust for inspiring me about the wonderful group of bananas found in Hawai'i and their potential to tell us about the past. Her pictures of wild banana plants and old mountain gardens inspired me.

Kawika Winter provided invaluable advice and insights into plants, planting practices and help with what is **pono**.

He is a remarkably tolerant and patient sounding board for my crazy ideas.

Will McClatchey encouraged me to write this paper. "A scientist is somebody who shares information". Not only is his level of knowledge and passion for the subject remarkable, his enthusiasm is infectious.

Fred Wichman's wonderful books of Kaua'i legends were my initial inspiration to begin GIS mapping of ancient Kaua'i. His unpublished masterwork of Kaua'i place names kept at the Kauai Historical Society is an amazing resource for anybody interested in ancient Kaua'i.

My sincere thanks to those who hike Kaua'i's remote interior and share amazing photos with me, their contributions have materially contributed to this project.

My gratitude also goes out to all those who have collected and preserved the fragments of Hawaiian history that we do have.



Figure 44. Ancient Kauai Mapping Project - all layers. Image generated with Google Earth.

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