Mango Trees as Cultural Indicators in the Limahuli Valley, Kauai

Torunn Stangeland

Research

Abstract

This paper describes the development of a new rapid method to age mango (*Mangifera indica* L.) trees using remote sensing data. The method is based on demonstrating that that crown width (CW) correlates positively with diameter at breast height (dbh). The data generated from this approach were used to assess the relative age of mango plantations in the Limahuli valley, Kaua`i, and to determine if the trees were planted in the latter half of the 1800s - a period of major social disruption on the island. Correlation between dbh and CW shows that these variables are positively correlated (R^2 = 0.7014). The freely available Google Earth and GPS Visualizer were used to visualize the position and size of trees. Using high-quality aerial photographs of the island, it may thus be possible to spot and map large mango tree canopies, and thereby provide a starting point to search for sites that were still populated by Hawaiians at the end of the 1800's. This method, in conjunction with aerial photographs or high-resolution satellite images, may be used to map and age human mango plantations and settlements in other regions, if combined with ground measurements and knowledge about tree growth at the site.

Introduction

Mango trees (*Mangifera indica* L.) belong to the plant family Anacardiaceae and originated in South-East Asia. These evergreen trees are long-lived; some individuals still bear fruit after 300 years (National Tropical Botanical Garden 2010). Mangos have been cultivated in India for more than 4000 years, mainly for the tasteful and nutritious fruit (Bally *et al*. 2009). The species spread to other parts of Asia, and by the beginning of the 16th century mango trees were gradually being distributed around the world (Morton 1987).

Mango trees have a relatively high growth rate; they may grow 2 m in height the first year. Once the trees start to produce fruits (after 2-4 years) their growth rate slows (Bally 2006). Cultivated trees usually reach 3-10 m in height at maturity. Wild trees can reach 30 m, and have a crown width of 30-38 m in favourable forest conditions. Age and growth of trees are difficult to determine, especially in the tropics were yearly rings from seasonal changes in growth cannot easily be observed in the wood. Tree growth does not increase linearly, but depends, among other things, on the crown's ability to photosynthesize and nutrient availability. Increment data must also be related to tree age or size (Brack 1997), and all tree species have increment curves specific to the species. Ostertag *et al*. (2005) found that the stem growth increment of mango trees in their study was 0.33 cm/yr; Sakihara *et al*. (2000) found mango trees around 50 year old to have a diameter at breast height (dbh) of around 50 cm, and trees more than 100 years old can reach a dbh of approximately 130 cm according to Bally (2006).

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Mango trees were brought to Hawaii from Rio de Janeiro in 1825 on the ship HMS Blonde (Bloxam 1925). Together with other introduced plants, three young mango trees were reportedly turned over to the priest and gardener Don Fransisco de Paula Marin for planting (Bloxam 1925; Staples & Herbst 2005). As far as we know Captain Cook was the first European to arrive on the Hawaiian Islands in 1778. In the following decades, many explorers and traders reached the islands bringing new plants, animals and merchandise. They also brought several diseases, to which the Hawaiian people had no immunity. By the end of the 1800s, the original population was reduced by 90% (Juvik and Juvik 1998). Measures were taken by the government to improve the health situation, and mango trees were widely distributed on the islands to improve the diet. In 1899, grafted trees of a number of Indian varieties, including 'Pairi', were imported. Seedlings became widely distributed across the six major islands (Morton 1987).

There are few written accounts of the Hawaiian people, but plants may be able to uncover and recite some of their history. In this study, we wanted to develop a method to use remote sensing to detect mango trees with large CW as markers for settlements. The position, dbh and CW of 39 mango trees from the coast and inland up the valley were measured in February 2010 and correlation between dbh and CW were calculated.

Figure 1. Common mango on Kaua`i, Hawaiian Islands. Photo: Erik Burton

Methods

Plant material

A voucher specimen (TS508) was deposited at the Herbarium of National Tropical Botanical Garden in Kaua`i (PTBG). The variety of mango collected has not yet been determined, but is commonly called 'Common Mango' on Kaua`i. It has medium-sized fruits with a dark purplish colour, and probably descends from the non-grafted cultivars first brought to Hawaii (Figure 1).

Study area

Limahuli is a valley situated on the windward, northern side of Kaua`i; the northernmost populated Hawaiian island. The valley is narrow and extends to the sea, surrounded by steep mountain ridges ranging from 300 to 1000 m high. The Limahuli stream, one of the last pristine streams on the island, runs through the valley. The climate is wet tropical with an average precipitation of 200 mm / month in the lower part and up to 600 mm/month in the upper part of the valley (Juvik & Juvik 2008). The forest is dominated by introduced invasive species like *Schefflera actinophylla* (Endl.) Harms (octopus tree), *Casuarina cunninghamiana* Miq. (ironwood), *Coffea arabica* L. (coffee plants), *Clidemia hirta* (L.) D. Don (soap bush) and bamboo.

The valley is a part of Hā'ena ahupua`a. Ahupua`a, is a traditional Hawaiian resource management system recognizing the interconnection between the mountains and the ocean, and the role that fresh water play in linking the two. Lava-rock terraces for growing taro (lo'i kalo) were built here 700-1,000 years ago (National Tropical Botanical Garden 2010). Presently there are people living in the lower part of the valley, while in earlier times people were living much further up in the ahupua`a. In 1989, an archaeological survey and mapping project recorded 88 archaeological features in the lower part of Limahuli valley, mainly inside Limahuli Garden (Patolo & Cleghorn 1991). Limahuli Garden is now a part of the National Tropical Botanical Garden (NTBG), and the old terraces and taro patches have gradually been restored to demonstrate the old cultivation, land and water management system. Behind the garden and further up the valley is the Limahuli Preserve, donat-

ed to NTBG in 1994. It presently serves as a restoration site for preservation of native species.

No documented archaeological excavation has been performed here.

Ground searching and measurements of trees

Mango trees were flowering at the time of the study, and the reddish flowering crowns facilitated their detection from an elevated viewpoint high up in the Limahuli Garden. From this position, the distribution of the mango trees was noted for later measurements. For each tree, the GPS position was registered, trunk circumference at breast height (1.3m) and canopy width (CW) were measured. Trunk circumference (c) was subsequently converted to dbh using the standard formula d = c/3.14. CW was estimated by pacing the diameter of the canopy in two directions perpendicular to each other. These measurements were subsequently averaged (Brack 1997) and the data was entered into Google Earth and GPS Visualizer. A correlation test was run in Excel between dbh and CW.

Size, distribution and Google Earth mapping of trees

Trees with dbh >20 cm were measured, except a single small tree with a dbh of 0.11 cm which was also registered and recorded. Trees were sorted in five size classes based on diameter at breast height: I: <20 cm; II: 20-49cm; III: 50-89cm; IV: 90-149cm and V: >150cm.

Google Earth was used to visualize the position and size of the mango trees registered, and GPS Visualizer was used as the tool to convert data from the spreadsheet to Google Earth, saved as CSV (comma separated values) in a Notepad file (Hamilton *et al*. 2009, Oberlies *et al*. 2009).

Results

Registration of mango trees

In total, 39 individual mango trees were located and measured (Table 1), with 1, 11, 15, 7 and 5 trees in dbh classes I-V, respectively (Figure 2). A positive correlation (R^2=0.7014) between diameter at breast height and canopy width was found (Figure 3). I observed that a number of trees in the middle of the cluster had stunted growth of their crowns. Solitary trees supported larger and more circular canopies. The correlation may thus have been even more pronounced if the growth conditions had been similar, either in clusters or in the open.

The majority of trees (79%) were found within or close to the Limahuli garden in the lower part of the valley. Two trees were found close to the beach (Figure 1). A cluster of large, old mangos were found 10 km higher up in the

Table 1. Size class (based on diameter at breast height (dbh-cm), canopy width (CW-m), and position of mango trees in Limahuli valley, Kauai. Classes: dbh: I < 19 cm, II= 20-49 cm, III=50-89 cm, IV=90-149 cm, V>150 cm.

Tree	dbh	CW	Size class	Latitude (N)	Longitude (W)
1	237	16.0	V	22.20870	159.57956
2	171	13.5	V	22.20870	159.57956
3	101	9.5	IV	22.20870	159.57956
4	166	18.0	V	22.21920	159.57652
5	30	7.5	II	22.21918	159.57654
6	76	12.0	III	22.21928	159.57672
7	162	20.0	V	22.21906	159.57533
8	84	12.5	III	22.21916	159.57533
9	96	12.0	IV	22.21911	159.57529
10	88	12.0	III	22.21919	159.57535
11	84	11.0	III	22.21910	159.57535
12	45	10.0	II	22.21909	159.57538
13	44	10.0	II	22.21908	159.57533
14	96	14.0	IV	22.21912	159.57538
15	94	15.0	IV	22.21887	159.57571
16	124	13.5	IV	22.21887	159.57571
17	33	8.0	II	22.21961	159.57634
18	127	13.5	IV	22.21951	159.57652
19	82	9.0	III	22.22030	159.58176
20	61	10.0	III	22.22063	159.58134
21	56	10.0	III	22.22058	159.57722
22	53	9.5	III	22.22046	159.57726
23	94	16.0	IV	22.22023	159.57674
24	49	11.5	II	22.22022	159.57674
25	23	6.5	II	22.22018	159.57680
26	59	9.0	III	22.22005	159.57669
27	151	14.5	V	22.22006	159.57660
28	23	6.0	II	22.22006	159.57660
29	32	7.5	II	22.22015	159.57645
30	81	12.5	III	22.22023	159.57642
31	33	8.5	II	22.22030	159.57622
32	29	8.0	II	22.22021	159.57628
33	30	5.5	II	22.21107	159.57848
34	63	8.5	III	22.20877	159.57913
35	11	3.0	I	22.21112	159.57913
36	62	12.0	III	22.21720	159.57690
37	66	9.5	III	22.21727	159.57678
38	64	12.0	III	22.21693	159.57629
39	63	10.0	III	22.21988	159.57626

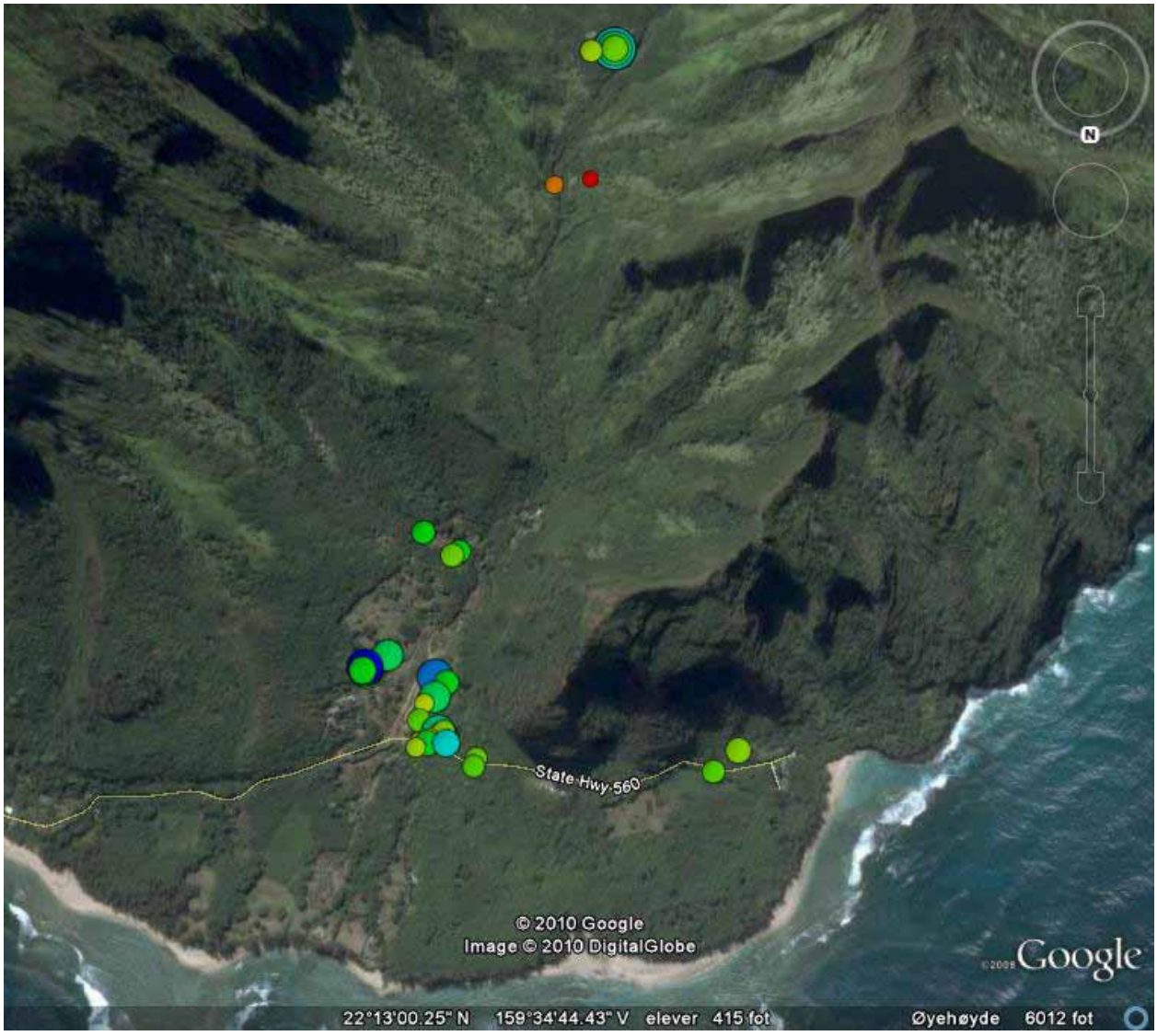

Figure 2. Common mango tree distribution in Limahuli valley, Kaua`i, Hawai`i. Each circle shows the distribution of an individual mango tree. The size of the ring represent diameter at breast height; the colors are coded after a color scale where red symbolises the smallest CW, yellow a bit larger, green intermediate and blue symbolizes the largest CW (Leydesdorff & Persson 2010). The size of the circle is correlated to the tree diameter at breast height.

valley, close to a stone wall and 5-10 m from the stream. A few smaller mango trees were found north of the cluster in the upper valley. Other species indicative of human settlements, such as Coffee, *Hibiscus tiliaceus* L. (**Hau**), *Cordyline fruticosa* L. (**Ti**), avocado and banana were also found in the area.

Registration of man-made structures and other plantings

All the trees within the Limahuli garden were close to numerous man-made terraces and stone walls. Around ten meters from the cluster in the upper valley there was a long stone wall, 0.5-1 m high, running parallel with the river about 10-20 meters from the water. The age and former use of the terraces are not yet known, as there have been no documented archaeological studies in this upper part of the valley.

Discussion

The main finding of this study is that a correlation between dbh and CW in mango trees was detected. Dbh is a common indication of tree age, when the growing conditions in the area, the increment and growth habit of the species is known. According to literature (Balley 2006, Ostertag *et*

al. 2005) we find it probable that the largest trees in this survey are more than 100 years old. It should be easy to detect the crowns of large mango trees on high resolution aerial photos or even satellite images, especially when the trees are flowering; like Jansen *et al*. (2008) detected sun exposed palm crowns in Panama.

Mango tree abundance in the Limahuli valley was highest in the more densely populated area 1 km from the beach. However, the largest mango trees (dbh: 171 and 237 cm) were encountered in the upper valley, which have long been abandoned by people. In the area close to the mango trees found in the upper valley (30 m from the trees), a registration was done of man-made structures and other domestic plants. It is therefore likely that the cluster of trees in the upper valley was planted in the latter part of the 1800's, since they have a much larger dbh than 130 cm which was the size Balley (2006) found that mango trees more than 100 years old could reach. According to local elderly people on Kaua`i mango trees were generally planted close to homesteads (pers. com.). Such old plantations may be used as indicators of earlier settlements. On Hawaii, they may thus indicate settlements of native Hawaiians after the big population decline in the nineteenth century. Five trees with dbh ranging from 124-166 cm are found in the Limahuli garden. These are also most likely planted in the same era. The fact that those in the upper valley are even larger may be a consequence of the rainfall gradient. The low abundance of mango trees found towards the sea may be related to the tsunamis of 50-60 years ago (Andrade 2008) or the fact that mango trees has low salt tolerance, or a combination of both.

Interviews of elderly people may be used to find out more about the possible age of the trees, and further archaeological studies should be carried out to find out more about the settlements.

The fact that there is a correlation between dbh and CW can be used to find old mango trees, using high resolution pictures or Google Earth. These trees might tell us at which places there were surviving Hawaiians at the end of the 1800's and give an indication as to where new archaeological expeditions ought to focus their attention. In this way, the distribution of old mango trees might show us a way to learn more about the history of the Hawaiian people through their connections to plants.

Conclusion

The current study suggests that there is good correlation between dbh and crown size in mango trees. High resolution satellite images together with free software, such as Google Earth and GPS visualizer can be used to identify the position of large mango trees and may thus be used to locate old settlements and thereby provide an indication for future archaeological excursions; not only on Hawaii, but also in other parts of the world.

The method may further be used to identify the position of any large woody plants that have a canopy that can easily be identified on aerial photos or satellite images, either to identify former human settlements or for other ecological objectives.

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