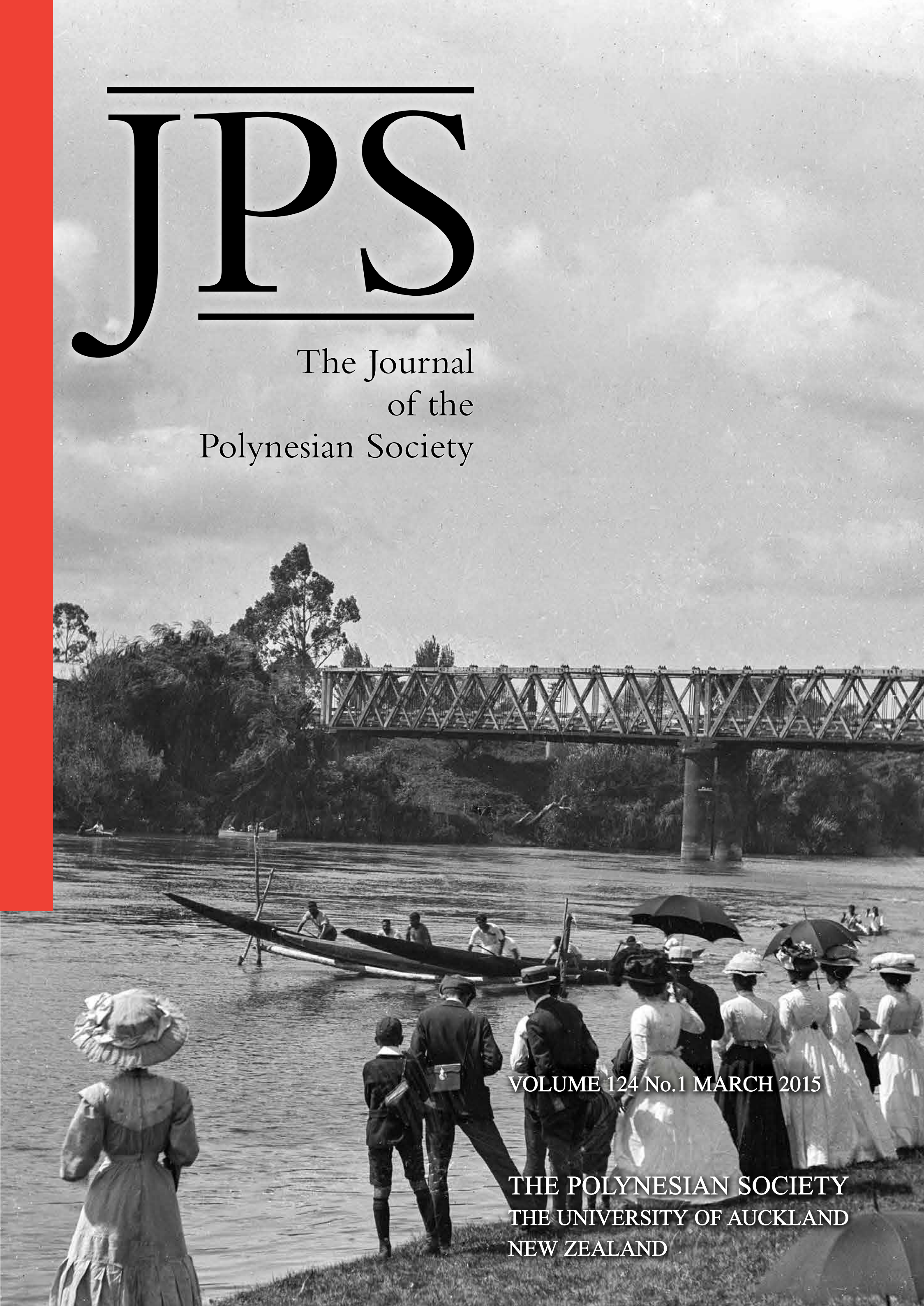

JPS

The Journal of the Polynesian Society

VOLUME 124 No.1 MARCH 2015

THE POLYNESIAN SOCIETY
THE UNIVERSITY OF AUCKLAND
NEW ZEALAND

TRACING THE RESILIENCE AND REVITALISATION OF HISTORIC TARO PRODUCTION IN WAIPI‘O VALLEY, HAWAI‘I

BENJAMIN D. JONES
University of Auckland

THEGN N. LADEFOGED
University of Auckland

GREGORY ASNER
Carnegie Institution for Science

Agriculture has always been important for Hawaiian subsistence. During the late prehistoric era the focus was on dryland production of sweet potato (*‘uala*; *Ipomoea batatas*) in vast leeward field systems and wetland production of taro (*kalo*; *Colocasia esculenta*) in more constrained windward pondfields (*lo‘i*). The infrastructure of both systems formed the basis for production after European contact, with the continuation of traditional agriculture and the eventual incorporation of new crops and ideas of how best to grow them. Commercial taro production continues today, with the revitalisation of pondfields in ancient settings. This revitalisation builds on both traditional notions of taro production and the effects of later introductions, such as rice (*Oryza sativa*).

On the island of Hawai‘i, Waipi‘o Valley was once a large highly intensified system for taro production (Fig. 1). During the mid-19th to early 20th centuries significant changes occurred (Olszewski 2000: 45). The traditional cultivation of taro in pondfields was being gradually replaced by introduced rice cultivation and later the commercial production of *poi* (a traditional Hawaiian food of boiled and pounded taro mixed with water) industry in the mid-20th century (Cordy 1994: 45, Lebo *et al*. 1999, Olszewski 2000). Today, wetland taro is grown in the valley, with an emphasis on revitalising the production capacity of a once intensively cultivated landscape (Bethel *et al*. 2001: 5, 7, 9, 31; Kubo *et al*. 2006: 6, McGregor 1995, 2007, Melrose and Delparte 2012: 61-62). Kirch (1997: 218) notes that Waipi‘o and other windward valleys are "…relics of once extensive complexes of ditches (*‘auwai*) and pondfields (*lo‘i*) that formed intricate grids across the alluvial bottomlands of most Hawaiian valleys". In this article we characterise the materialisation of a palimpsest landscape and document how Waipi‘o taro production changed during the historic era. We note the importance of pre-European contact wetland taro production, how this was transformed by the introduction of rice and the construction of paddies and how this in turn influenced Waipi‘o Valley's modern agricultural landscape.

Journal of the Polynesian Society, 2015, 124 (1): 83-109;
DOI: http://dx.doi.org/10.15286/jps.124.1.83-109

Figure 1. Southeastern oblique perspective of modern-day Waipiʻo Valley and a close-up of the lower valley showing taro pondfields. (Photographs courtesy of Melinda Allen).

In the early 1820s, missionaries William Ellis, Asa Thurston and their guide, Makoa, traveled through the valley and documented intensive agriculture in Waipiʻo (Ellis 1963, Lebo *et al*. 1999: 4). He noted various crops, including wetland taro, *maiʻa*/banana (*Musa* sp.) and *kō* or sugarcane (*Saccharum officinarum* L.) (Cordy 1994: 31, Lebo *et al*. 1999: 5). Taro was being grown in *loʻi*, with complexes often composed of multiple components, including the source (*poʻowai)*, the stream (*kahawai*), diversion ditches (*ʻauwai)* and plots or terraces enclosed by raised banks known as pondfields (*kuāuna*) (Silva 2002, 2004, Kirch 1977: 252-53).

Additional information is available from the time of the Great Māhele, between 1846 and 1855, when legislation creating alienable private property was put in place (Linnekin 1983, 1987). In her analysis of the rich taro lands of Keanae on Maui Linnekin (1983: 173) notes:

> In the Mahele, the king divided the lands of the kingdom among himself, the government and the chiefs. These three parts became known as Crown, Government and *Konohiki* lands…. Most of the small parcels awarded to the common people as tenants were taken from the *Konohiki* lands…. The Land Commission Awards (LCA) or *kuleanas* granted to native tenants were meant to establish the commoners' inalienable rights to the lands…[but] the acreage ultimately awarded to commoners was minuscule compared with the extent of Crown and Government lands….

In Waipi‘o Valley, the Great Māhele recorded "a minimum of 1529 fields of which 155 were not awarded to the claimants" (Olszewski 2000: 5). Production in the valley dramatically changed in 1881 with the arrival of rice and the establishment of two mills, marking this as a time when taro was being supplanted by rice as the main crop (see Emerson 1881, Olszewski 2000: 32). However, during the last decade of the 20th century there was a renewed interest in taro and the first *poi* factories were established. "Although no formal company name is listed with their operations, at least five other people were making *poi* for commercial markets between 1896 and 1901" (Olszewski 2000: 65). By 1914 a significant decline in rice production had occurred, with approximately 1128 agricultural pondfields recorded in the Valley, of which 273 were for rice and 855 for taro (Bishop Estate 1914). By the mid-20th century *poi* production had decreased, with the closure of the Waipi‘o Poi Factory in February 1959 (Honolulu Advertiser 1984: Section I: 20 cited by Olszewski 2000: 76).

WAIPI‘O VALLEY

Waipi‘o Valley is in the Hamakua District on the northeastern windward side of the island of Hawai‘i. Steep walls rise approximately 300 m above the valley floor near the ocean and 910 m at the back of the valley, forming a U-shape that is characteristic of the valleys on the relatively young volcanic islands of the archipelago (Figs 1 and 2). The valley floor was formed by alluvial and colluvial processes, with current annual rainfall in the area ranging from c. 2100 to 2600 mm (Rainfall Atlas of Hawai‘i 2011). A well-defined "A" soil horizon of moderate acidity has formed throughout the valley floor and this has not been depleted of bases to the extent of normal humic latosols, suggesting fertile ground for irrigated agriculture (Bethel *et al*. 2001, Petersen 1970). Palmer *et al*. (2009: 1452) note that the flow of irrigation water would have supplied a wealth of nutrients to sustain intensive wetland cultivation and suggest "…irrigation water, not weathering, could represent a source of nutrients in excess of crop requirements in irrigated Polynesian pondfields".

The geomorphology of the valley indicates the occurrence of high velocity, coarse-grained sediment discharge and transport, relatively steep channel gradients and frequent channel avulsions during storm discharges (Kubo *et*

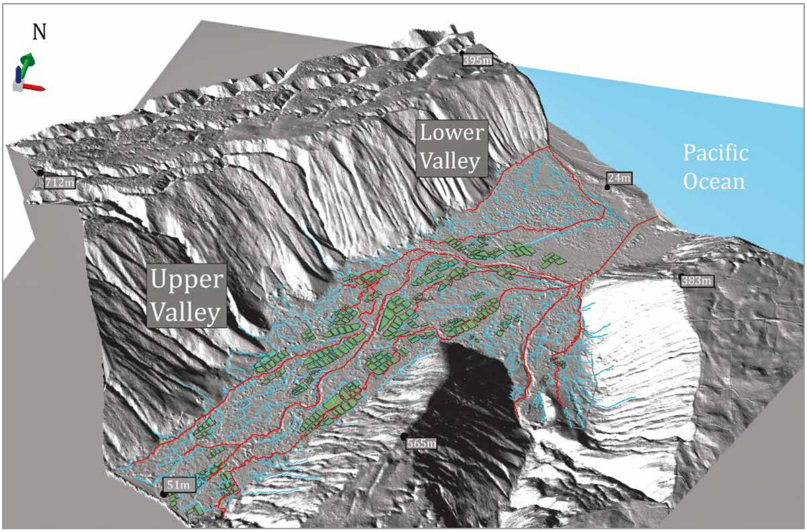

Figure 2. A three-dimensional representation of Waipi'o Valley. Terrace pondfields captured by a 2010 LiDAR survey are represented as green polygons, rivers as red, while blue lines are streams and possible *'auwai*. Tributary valleys feed into Waipi'o in the upper reaches of valley (not shown here), whereas the Wailoa and Hi'ilawe Rivers occur in the middle to lower valley, eventually flowing into the Pacific Ocean.

al. 2006: 17). The channel avulsions, flooding and tidal waves would have shaped the current surface record of Waipi'o and various flooding events are recorded between 1918 and 1973 (Kubo *et al*. 2006: 14). During this time it is estimated that approximately 44 hectares of taro land were destroyed by scour or deposition, rendering 30 *'auwai* (irrigation canals) sections unviable for agriculture. Tidal waves also have been recorded, with a large wave in 1946 destroying many homes and taro pondfields (Salmoiraghi and Yoshinaga 1974).

Waipi'o Valley features prominently in oral traditions; it was once the royal seat of power for high chiefs Līloa and 'Umi (Cordy 1994, Kirch 2012). The period of approximately A.D. 1600–1620 saw the rise of 'Umi the unifier, the son of Līloa, and as the title suggests, 'Umi both unified the different chiefly polities that existed within Hawai'i Island and introduced a form of structured agricultural production (Kirch 2012). Consequently, the oral history of Waipi‘o suggests complex spiritual, social and political aspects of Hawaiian life unfolded within the valley, a way of life that was dramatically changed in the historic period by the influx of new ideas and people (see McGregor 1995, Olszewski 2000). After Western contact, this included the development of the Hawaiian rice industry, a process that hinged on the immigration of Chinese labour for sugar plantations and the rice industry, available land and an expanding rice market both locally and abroad (Coulter and Chun 1937: 20-21, Olszewski 2000: 46). Chinese and Japanese immigrants came to Hawai‘i as indentured labourers and after their service some of them moved to Waipi‘o and subleased land from local Hawaiians and the Bishop Museum for commercial rice cultivation (Lebo *et al*. 1999: 9, McGregor 2007: 58, Olszewski 2000: 46). The rice industry in the valley was dominated by Chinese and to a lesser extent by Japanese and Hawaiians (Lebo *et al*. 1999: 9). Some Chinese immigrants inter-married with Hawaiians living in the valley, while others returned to their homeland or were lured away by economic opportunities in villages or towns (Lebo *et al*. 1999: 32, McGregor 2007: 59).

DATASETS

Our analysis of production change in Waipi‘o integrates three sources of geo-spatial data (Table 1). These include two historic survey maps of Waipi‘o and one modern LiDAR (Light Detection And Ranging) dataset. The first historic map was drafted by Wright in 1914 and depicts the 1846–1855 Land Commission Awards (L.C.A.), parcels given during the Great Māhele, and locations of 1914 *‘auwai,* streams and rivers. Wright’s 1914 map was

Table 1. Sources of geo-spatial data used in this analysis.

Dataset	Time period	Type	GIS format	Source
1	1846–1855	L.C.A.	Vector polygon	Wright 1914
2	1914	Stream network	Vector poly-line	Wright 1914
3	1914	Terrace pondfields	Vector polygon	Bishop Estate 1914
4	1914	Stream network	Vector poly-line	Bishop Estate 1914
5	2010	Terrace pondfields	Vector polygon	2010 LiDAR imagery
6	2010	Stream network	Vector poly-line	2010 LiDAR imagery

geo-rectified to a Transverse Mercator NAD1983 UTM Zone 5N projection using 12 common topographic features depicted on a modern U.S. Geological Survey (1995) topographic map. A second order transformation resulted in an RMS (Root-Mean-Square) error of c. 8.9 m. RMS error is as an accuracy indicator that measures the overall accuracy of the transformation by integrating residuals in both the easting and northing directions of all the GCPs (ground control points) (Gao 2009). Second order polynomials are regarded as the best alternative for a balance of accuracy and computation (Gao 2009) and were used in our analysis. The 1846–1855 L.C.A. parcels depicted on the 1914 Wright map were digitised and assigned attributes of claimant, L.C.A. number and plot number. The classification of crops within the L.C.A was taken from Olszewski (2000: 8-9). Olszewski (2000) synthesised claimants testimonies associated with the Land Commission Awards and corresponding evidence from the Great Māhele Land Court records, to create distribution maps to show the location of L.C.A plots that mentioned *lo'i*, *kula* and other sorts of associated data. As such her study provides a good indication of mid-19th century agricultural practices in the valley. The L.C.A dataset is important as it "peoples" the past, providing direct access to named individuals, and indicates how they managed their agricultural pursuits. These people are possibility the direct or indirect descendants of those still practicing and negotiating agricultural practices in the valley today.

The second historic map was drafted in 1914 for the Bishop Estate, an estate established in the 1880s by Charles Reed Bishop in memory of his wife Bernice Pauahi Bishop, a member of the Kamehameha Dynasty. The map depicts taro, rice and empty terrace pondfields, and associated streams and *'auwai*. It was georectified using seven common features with the Wright map and produced an RMS error of 2 m in relation to that base map. The taro, rice and "unknown cultigen" plots depicted on the Bishop Estate map were digitised, as were the stream networks (both larger named and un-named streams) and *'auwai*. This map provides an indication of early 20th century agricultural activities in the valley and a good representation of the hydrology. The manual digitisation procedure identified 1128 labelled agricultural fields: 273 rice fields and 855 taro pondfields (Bishop Estate 1914).

The third dataset was LiDAR data recorded by the Carnegie Airborne Observatory in 2010. LiDAR is an active remote sensing system for acquiring elevational data. Energy is transmitted from an airborne instrument to the earth's surface, with response rates indicating both the height of any vegetation and the bare earth elevation (see Asner *et al*. 2007 and Ladefoged *et al*. 2011 for details of the LiDAR dataset). This 1.2 m resolution dataset was used to create a digital elevation model (DEM) depicting the under-vegetation "bare surface" of the valley floor and walls. The DEM was the basis for creating 16 different hill-shade models, each model using a set sun angle of 25 degrees and varying the cardinal point by 22.5 degrees. We used a principal component analysis (PCA) of the 16 models to derive information from the multiple hill-shades (following Devereux *et al.* 2008). Devereux *et al*. (2008: 474) found that the first three to five components usually contain a high percentage (typically over 99 per cent) of the information or variability in the original datasets. The Eigen values (a mathematical indication of the amount of information gained by each new component; see Gao 2009 for an in-depth explanation and the mathematical formula) for our analysis suggest that the first three components contained 99.55 percent of the information. The first three components were then merged into a multi-band image, with individual components corresponding to the bands shaded to the colours of red, green and blue (Fig. 3). This image was used to identify and digitise terrace pondfields, which we classified into two categories: (i)

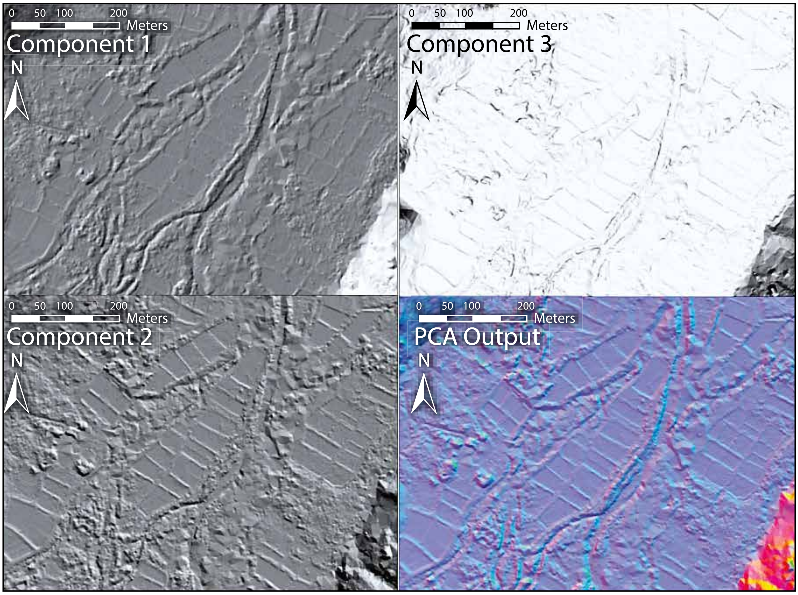

Figure 3. Results of the PCA analysis. The top left image emphasises a series of terrace pondfields in component 1. The bottom left image emphasises the same features visualised in component 2. The top right image emphasises the same features visualised in component 3, while the bottom right emphasises a multiband image of the merged components.

high confidence features that were easily identifiable because they contained at least four connected walls with high slope relief and internal, near-flat areas, and (ii) low confidence features that showed somewhat distinct wall morphology and flat surfaces, but due to the resolution and clarity of the data could not be conclusively defined as terrace pondfields. The manual digitisation procedure identified 363 high confidence and 64 low confidence pondfield features in the PCA raster coverage.

STATE OF HAWAIIAN WETLAND TARO PRODUCTION IN THE MID-1800S

Using Māhele records, in combination with the LiDAR DEM, illustrates the distribution of L.C.A plots, *kula* (open fields or land on the side of the valley) and *lo'i* (wetland terrace pondfields). Linnekin (1987: 21) noted in her analysis of Great Māhele data that "chiefs, local land supervisors and seniors within the family allocated land and water rights to their subordinates, they were conveying the right to utilize subsistence resources: the right to partake of the fruits of the land and water, not ownership in the Western sense". Spriggs and Kirch (1992) built on this notion in their investigation of early 19th century socio-political control of water and land in Kawailoa, Anahulu. Our analysis of the Waipi'o data extends Spriggs and Kirch's (1992) approach and documents a series of complex socio-political relationships in Waipi'o. We can observe the control of land and water by using the L.C.A geo-spatial dataset in combination with the hydrology depicted in the 1914 data. We used the 1914 hydrology data because a map of mid-19th century hydrology of the valley does not exist or could not be located. We focus on individuals specified in the L.C.A. data, their control of water at particular points along a stream and how water flowed from their land to other cultivators.

The 1914 hydraulic dataset was divided into five analytical units or systems (Fig. 4) which enabled us to communicate the complexity of how water moved between cultivators. Hydrology was classified as streams, diverted streams and *'auwai*. Streams and *'auwai* were depicted and labelled on the 1914 map, and diverted streams were depicted on the map, but were not labelled as *'auwai* or named streams. Identifying who controlled the water in a stream or *'auwai* at a particular point was determined by overlaying the L.C.A. coverage with the hydrology. The intersection of L.C.A plots and hydrology occurred in various ways and the five alternatives of connections, diversions, feeders, initial nodes and termination nodes are defined in Table 2. In Figures 5 through 10 the L.C.A. plots that did not connect to streams, *'auwai* or diverted streams were labelled 'NC' for non-connected and indicated in blue and those that were connected were labelled 'C' and are indicated in red.

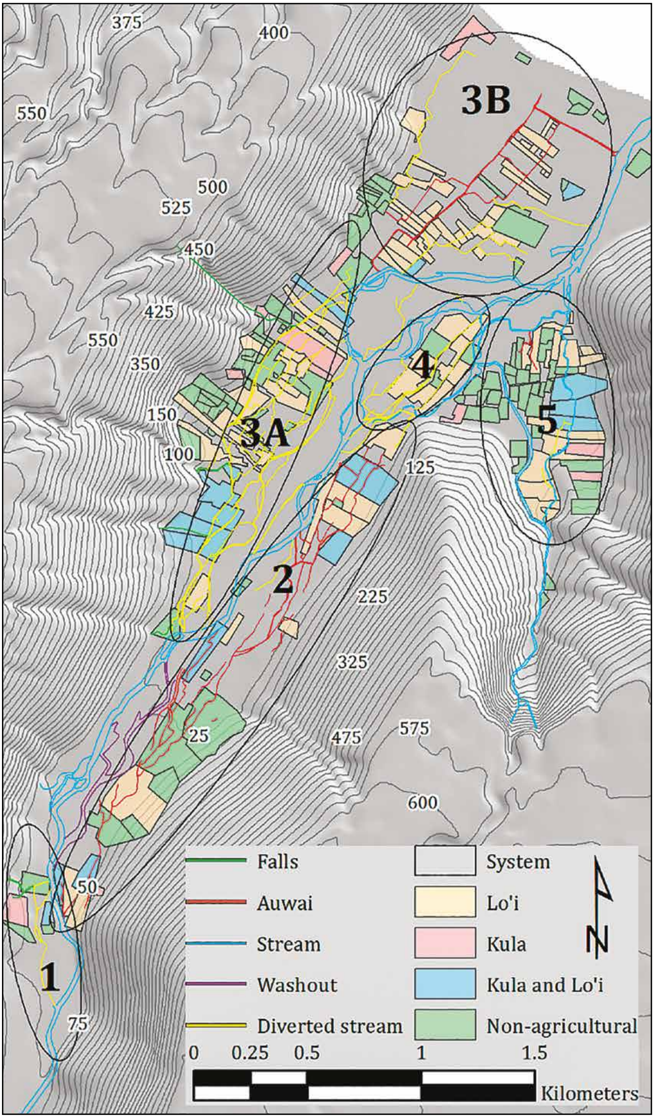

Figure 4. The analytical water system sections are displayed with the distribution of L.C.A agricultural land.

Table 2. This table describes the concepts behind the hydrological symbols.

Water flow symbology	Description
Connection	When two or more streams converge and/or when a stream or *‘auwai* runs through a L.C.A plot connecting that plot to the water network, and as such allowing it to be siphoned.
Diversion	When an *‘auwai*, stream or waterfall branches off into another direction.
Feeder/Drain	When an *‘auwai*, stream or waterfall is not connected and/or does not have an upstream tributary water source, but acts as a drain to direct water from an uphill point towards the main water network.
Initial	When an *‘auwai* or a stream brings a new source of water into the water network; a waterfall would be an example.
Termination	When an *‘auwai* or stream represents the last branch in a system's hydrological network, where water flows from upstream to downstream, then looping back to main river system, an L.C.A plot or simply flowing out onto the valley's surface.

Systems 2, 3A and 3B are particularly good examples of the relationships between cultivators (Figs 6-8). It is apparent that some people had greater access to water than others. For example, Kawahineainiu's water nodes in system 3A (Fig. 7) sequentially flow from individual to individual until the middle of the system, where one or two individuals, like Nakoko, control various hydrological nodes that feed water to multiple cultivators. This hierarchical pattern is further expressed by how W. Konohiki (perhaps an individual's name, but also the Hawaiian term for a lower ranked chief) is at the uppermost point in system 2 (Fig. 6). Further, it seems that some individuals who have total authority in one system are dependent on others in another system. Claimant Wailoa, while being at the top of the water access hierarchy in system 2, is lower in the hierarchy of system 3A (Fig. 7). Alternatively, this situation might reflect two individuals with the same name. Furthermore, some cultivators received water from multiple sources and/or individuals such as in systems 3A, 3B and 4 (Figs 7-9). While this might be considered costly in hydrologic terms, it suggests social factors were important, a situation noted by Spriggs and Kirch (1992) in their analysis of

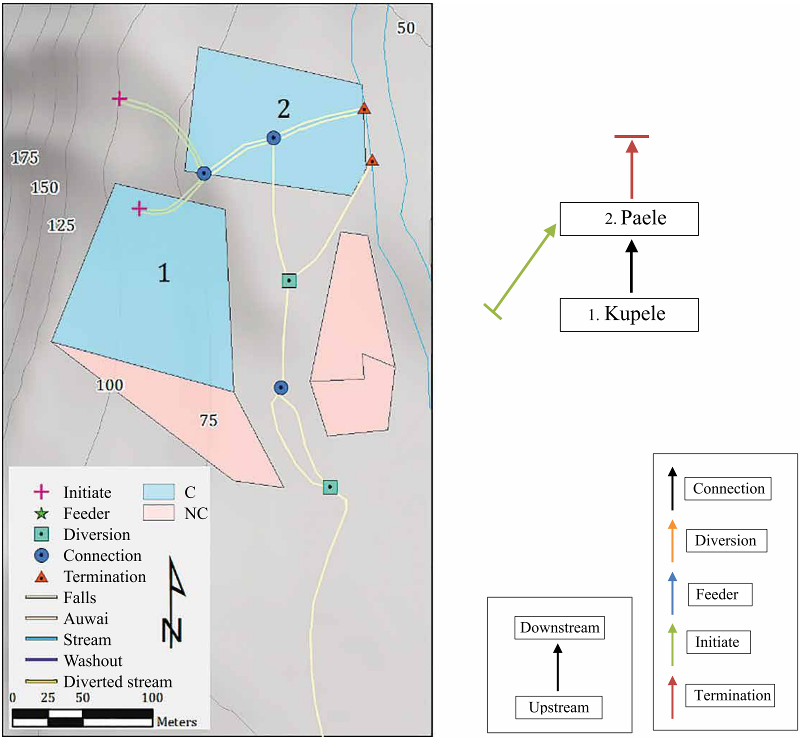

Figure 5. The map on the left and the diagram on the right illustrate the matrix of water flow between cultivators in system 1.

early contact period cultivation systems in Anahulu Valley. They suggest that multiple or secondary canals might be sub-optimal in hydrologic terms, but could represent a social "assertion of a newly acquired right to some of the land and water...[rather] than a required technical innovation" (Spriggs and Kirch 1992: 139). An example of this in Waipi'o is how Maka in system 3B (Fig. 8) was able to derive water from the main river system at multiple points, thereby circumventing the impact of Kaolulo, even though other cultivators were totally dependent on water from Kaolulo, who seems to be lower in the water access hierarchy of system 3B. These networks of water control demonstrate that water and land were contested and dynamic resources that were negotiated within social and environmental parameters.

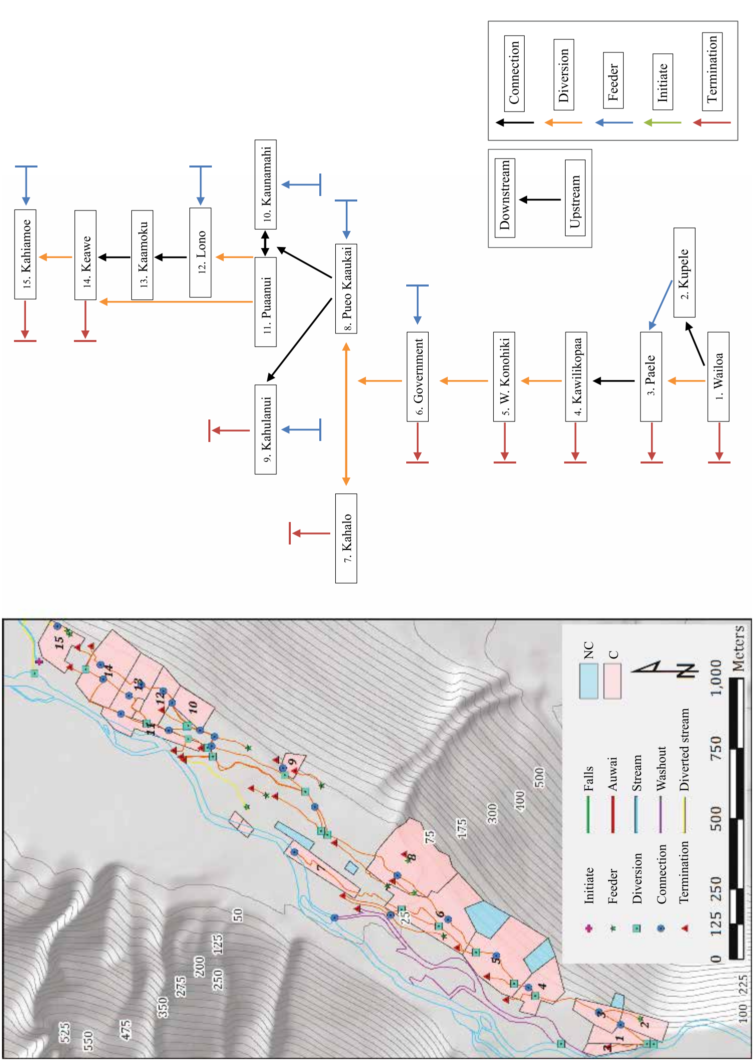

Figure 6. The map on the left and the diagram on the right illustrate the matrix of water flow between cultivators in system 2.

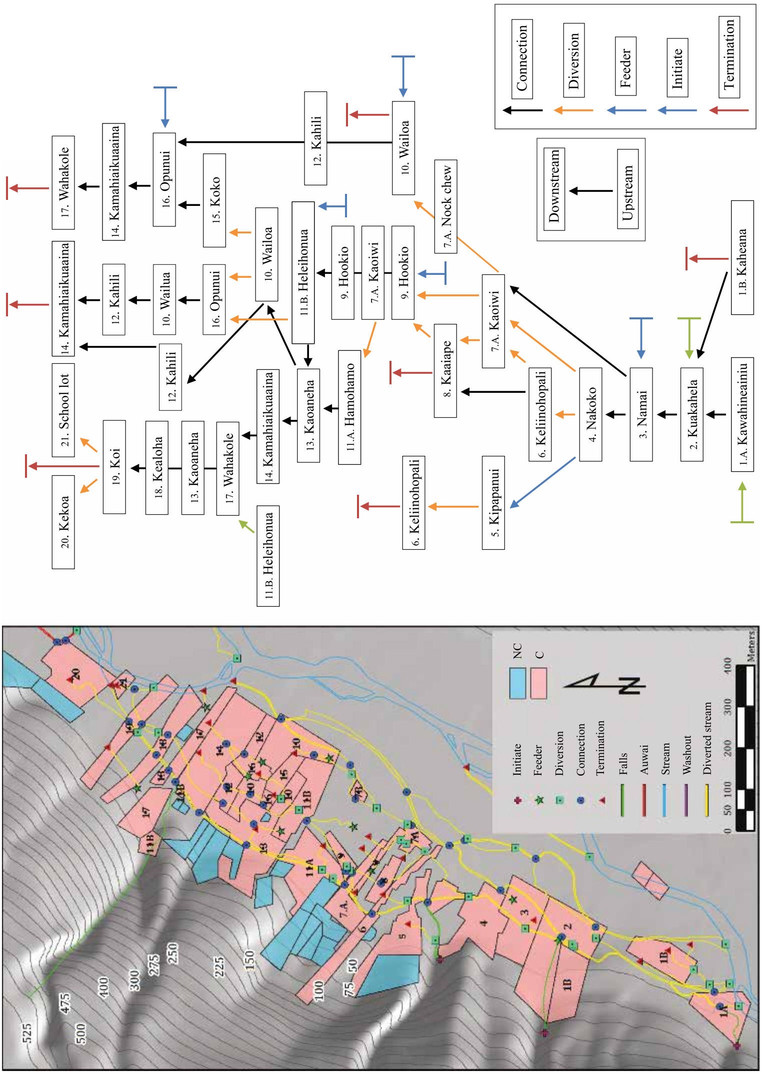

Figure 7. The map on the left and the diagram on the right illustrate the matrix of water flow between cultivators in system 3A.

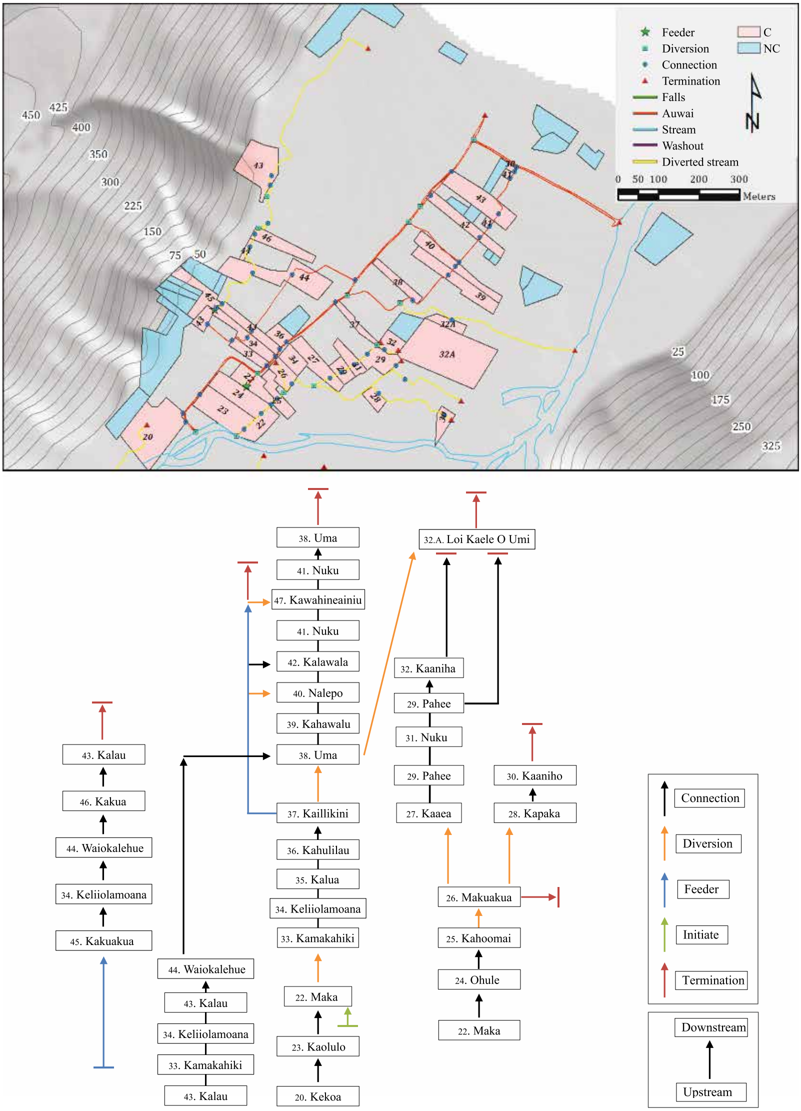

Figure 8. The map above and the diagram below illustrate the matrix of water flow between cultivators in system 3B.

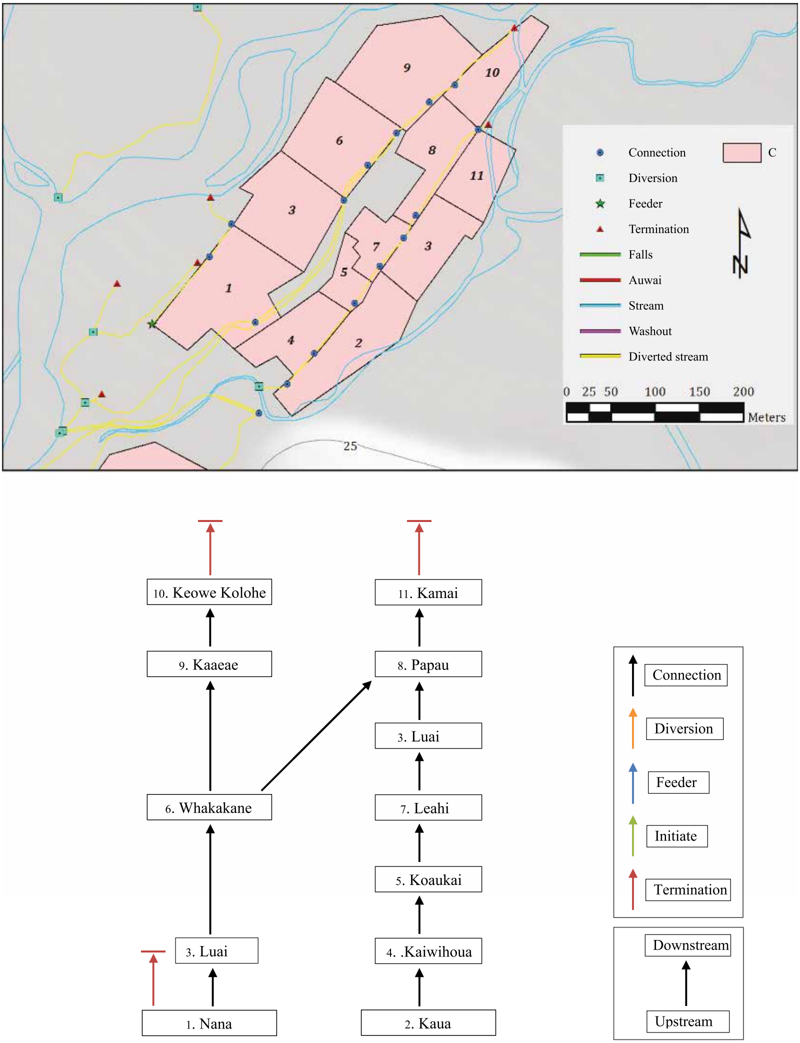

Figure 9. The map above and the diagram below illustrate the matrix of water flow between cultivators in system 4.

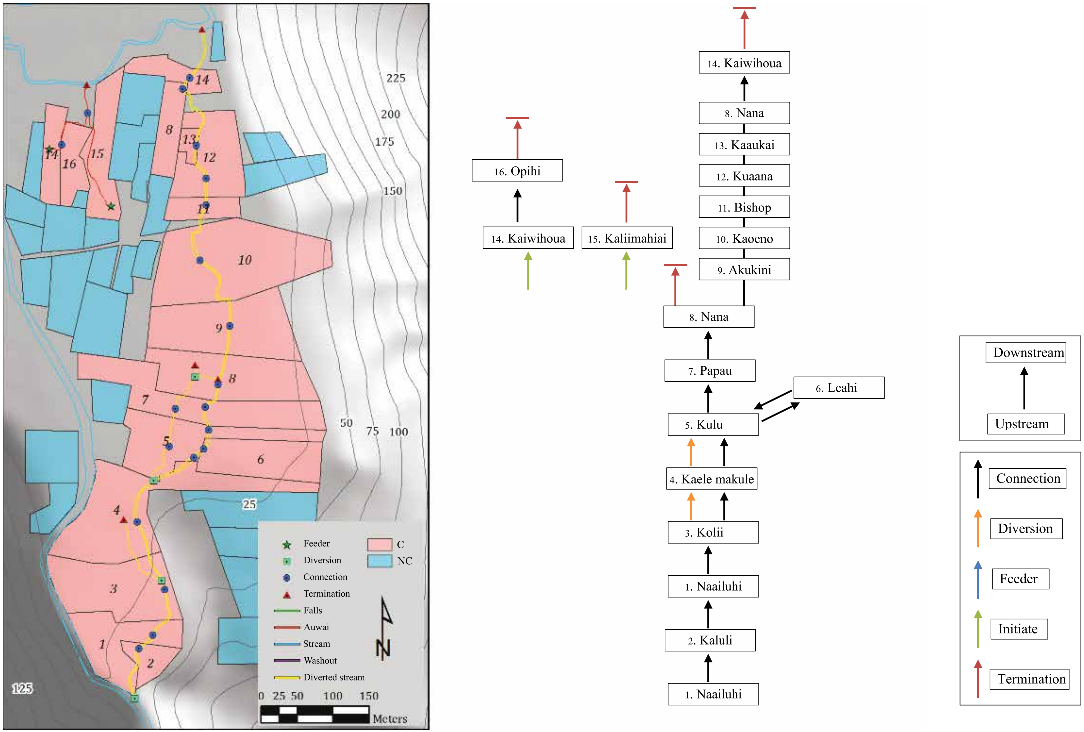

Figure 10. The map on the left and the diagram on the right illustrate the matrix of water flow between cultivators in system 5.

1881–1914: ARRIVAL AND DECLINE OF RICE PRODUCTION

During the late 19th century there was a shift from taro to rice production, as noted by the decrease in the number of taro *lo'i* from the 1529 recorded in the mid-1850s to 1128 recorded in 1914. Several hydrologic systems documented in the mid-19th century demonstrate how crucial the definition and control of L.C.A. grants were for subsequent agricultural practices. The possessors of L.C.A. land would have been able to define lease rights, which would have influenced the rice paddy cultivators who became prominent in the late 19th century, as much of the land at the time was leased (Lebo *et al*. 1999: 30, Olszewski 2000: 46) (Fig. 11). The social dimension of water use in the mid-1800s changed when rice was introduced, however, it was the previous definition of the L.C.A. that dictated where and how later generations leased and had access to land. The spatial patterning suggests that a disproportionate number of coastal L.C.A. plots were converted to rice, whereas the more inland L.C.A. plots were retained for taro production. It was these inland plots that had the greatest complexity of social relations in the mid-1800s and this probably made their conversion to rice production in the late 19th century more difficult. In addition, the status of the people who controlled the plots in the mid-19th century influenced later production strategies. For example, the land listed as owned by W. Konohiki was still extensively cultivated for taro in the late 19th century, and the L.C.A. recorded as "*lo'i o 'Umi* " (or pondfields of 'Umi which were presumably associated with 'Umi's chiefly descendants) were not used for rice production, even though it was surrounded by rice pondfields (Fig. 11).

The conversion of taro to rice production resulted in differential pondfield morphologies, distinctive to each practice. The geodatabase derived from the 1914 Bishop Estate map was used to calculate three metrics for the taro and rice pondfields. These metrics were statistically compared between the two classes of production. The first metric was simply the area of the pondfield, as calculated by the digitised polygon of each pondfield. The second metric was an index for the shape of the pondfield and was calculated by dividing the minimum bounded geometry of the pondfield width by minimum bounded geometry of the pondfield length. This produced an index that varied from 0.01 (for a long thin rectangle) to 1 (for a perfect square). For example a 20 m by 20 m pondfield would have a shape index value of 1, whereas a 30 m by 10 m pondfield would have a shape index value of 0.33. The final metric was the orientation of the pondfield as expressed in compass degrees derived from the longer side of the rectangle or square.

An independent two-sample t-test using a significance level of 0.05 was run to evaluate the null hypothesis that taro and rice pondfields had the same morphological attributes of area, shape and orientation. A Levene's Test for

Equality of Variances determined that the two populations had the same amounts of variability between scores. The resulting p-values suggest that shape and area were significantly different for taro versus rice pondfields, with taro pondfields being generally smaller and squarer than the rice pondfields (Table 3). The orientation of the two classes of pondfields were not significantly different, but a p-value of 0.07 indicates that rice pondfields were slightly skewed to the east in relation to taro pondfields. The results suggest that the morphology of the pre-existing taro pondfields were significantly altered when rice production began.

Undoubtedly Chinese and Japanese rice farmers had their own ideas and norms as to how to successfully carry out wetland cultivation. The rice cultivation re-worked the smaller taro pondfields into larger more rectangular plots. The bunds and barriers between the smaller fields were destroyed to create larger fields, possibly a response to different production requirements. The use of water buffalo for tilling, as has been documented in other valleys, would have been facilitated in these large plots. Other social and cultural imperatives also led to rice fields being larger in area. Olszewski (2000, citing Coulter and Chun 1937: 17-18) notes that Chinese rice production in Hawaiʻi used two types of organisational co-operative farming, *fun kung* and *hop-pun*. Both involved partnerships among several individuals, but scale differentiated the two. *Fun kung* involved one individual who fronted the capital costs of machinery and access to land, with others providing labour. *Hop-pun* involved equal partnership among individuals as a cost-sharing organisation (Olszewski 2000: 46). Olszewski (2000: 46) noted with "In the 1910 census data all individuals associated with rice agriculture in Waipiʻo are Chinese males (n=77; 29.1 percent of all males)". This large male labour force would have constructed and maintained the irrigation systems and paddies for rice production. These labour forces would have contrasted with those of traditional Hawaiian households involved in taro production at a household and semi-commercial level, which eventually evolved with the development of the *poi* industry in the early half of the 19th century and operating at a larger commercial level (Olszewski 2000: 53).

1914–2010: THE INFLUENCE OF RICE ON MODERN TARO PRODUCTION

The creation of larger, more rectangular rice fields during the late 19th century influenced the subsequent 20th century revitalisation of taro cultivation in the valley. We compared the pondfields documented in the 2010 LiDAR data with the 1914 geo-spatial datasets to establish relationships between rice and taro pondfields. The analysis focussed only on pondfields that overlapped at 40 percent or more (Fig. 12). An independent two-sample t-test with unequal variance indicates that the 1914 rice fields are not statistically distinct in terms

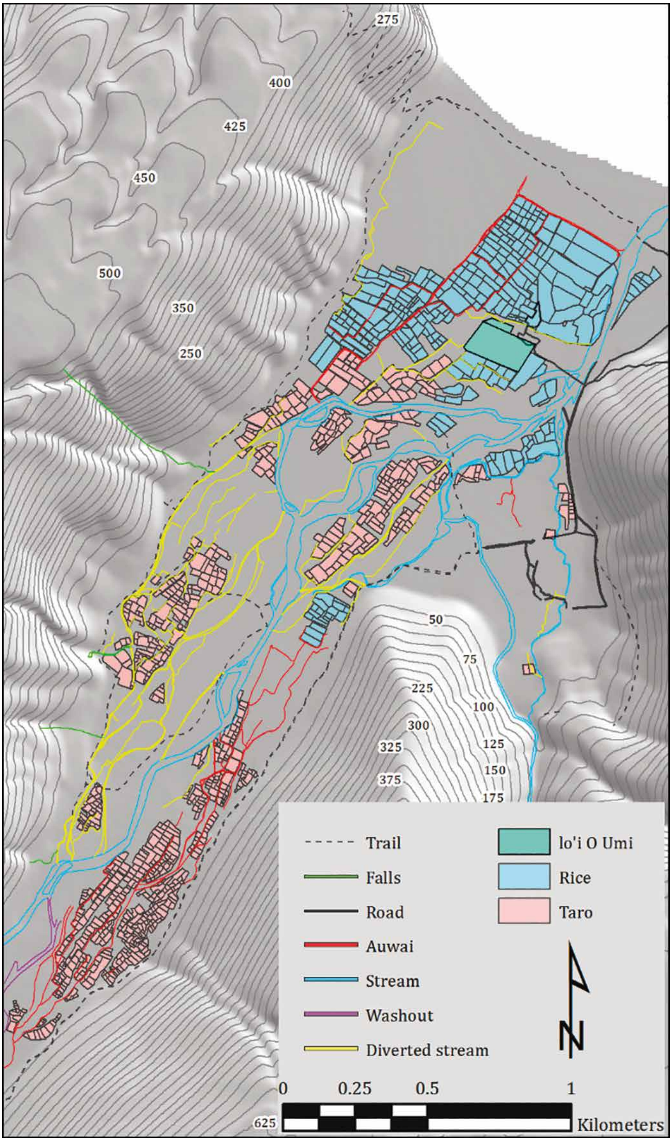

Figure 11. Distribution of taro and rice land in Waipi‘o Valley during the early 1900s.

Table 3. Statistical results for the independent two-sample t-tests comparing the difference between 1914 taro and rice fields.

Group statistics	Type	Number	Mean	Std. Deviation	Std. Error mean
Field Area	Taro (1914)	855	467.4	413.6	14.1
	Rice (1914)	273	1290.2	1432.4	86.7
Field Shape	Taro (1914)	855	0.7	0.19326	0.00661
	Rice (1914)	273	0.6	0.20863	0.01263
Field Orientation	Taro (1914)	855	87.7	46.6	1.6
	Rice (1914)	273	93.3	43.9	2.7

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	P-value (Sig. 2-tailed)	Mean difference	Std. error difference
Field Area	Equal variances assumed	168.466	0	-14.968	1126	0.001	-822.8	54.98
	Equal variances not assumed			-9.368	286.61	0.001	-822.8	87.84
Field Shape	Equal variances assumed	5.506	0.19	3.286	1126	0.001	0.04501	0.013
	Equal variances not assumed			3.159	431.161	0.002	0.04501	0.014
Field Orientation	Equal variances assumed	7.96	0.005	-1.759	1126	0.079	-5.6	3.2
	Equal variances not assumed			-1.814	482.879	0.07	-5.6	3.1

of area, shape and orientation in comparison to the 2010 taro pondfields (Table 4). This suggests that modern cultivators re-used some of the existing rice fields, rather than converting the fields back to their original pre-contact taro pondfield forms. In contrast, an independent two-sample t-test indicates that 1914 taro pondfields are statistically distinct from the 2010 taro pondfields in terms of shape, but not in terms of area or orientation (Table 5). The 2010 taro pondfields are more rectangular and tend to be larger relative to the smaller, squarer 1914 taro pondfields.

The historical process of transforming a landscape of predominantly taro cultivation to one of rice and then back to taro production was influenced by the configuration of the field structures. In 2012, Melrose and Delparte (2012: 61) noted "there are approximately 12 farmers in the valley actively producing taro and 3 to 5 main growers who produce most of the Valley's production". They go on to suggest that "for the farmers who grow taro, the motivations for continuing to farm go far beyond simple market value of the crop" (Melrose and Delparte 2012: 62). The analysis of the 2010 LiDAR data indicates that modern cultivators are not reconfiguring land to emulate traditional ideas of wetland taro cultivation; rather, rice cultivation has become incorporated into ideas about what modern wetland taro pondfields should entail. McGregor (1995: 165) suggests Waipi‘o is a cultural *kīpuka*, a rural Hawaiian community from which other Hawaiian communities can be "regenerated and revitalised in the contemporary setting". This reference to a *kīpuka*, an oasis of land surrounded by more recent volcanic flows, depicts Waipi‘o as a centre for the revitalisation and perpetuation of Hawaiian culture for future generations of traditional taro farmers (McGregor 1995: 196). "Waipi‘o as a traditional center for taro farming…[is training] a new generation of farmers steeped in the traditions of Waipi‘o and in protocol related to the cultivation of taro" (McGregor 2007: 82). The complex agricultural palimpsest of Waipi‘o is one template for economic and cultural revitalisation, and reflects the iterative performances of people's perceptions of traditional taro and historic rice cultivation.

* * *

The analysis of L.C.A. records from the Hawaiian Great Māhele documents early 18th century land use relationships and the importance of accessing and controlling water for taro production. Rice became a key cultigen for farmers by the 1880s and declined shortly after, with the last crop of rice in the valley around 1928 (Lebo *et al*. 1999: 19). During this time taro cultivation never ceased but it definitely declined and it is clear that rice cultivation re-worked the smaller and squarer taro pondfields into larger more rectangular plots.

The bunds and barriers between the smaller fields were destroyed to create larger fields with different management and production requirements. The loss of taro pondfields and the rise of rice signals an altered scale of production, with the cultivation of rice introducing different water requirements and technologies, such as the use of water buffalo for ploughing. The analysis of the 2010 LiDAR data indicates that late nineteenth and early 20th century rice production influenced future taro cultivation. The taro pondfields

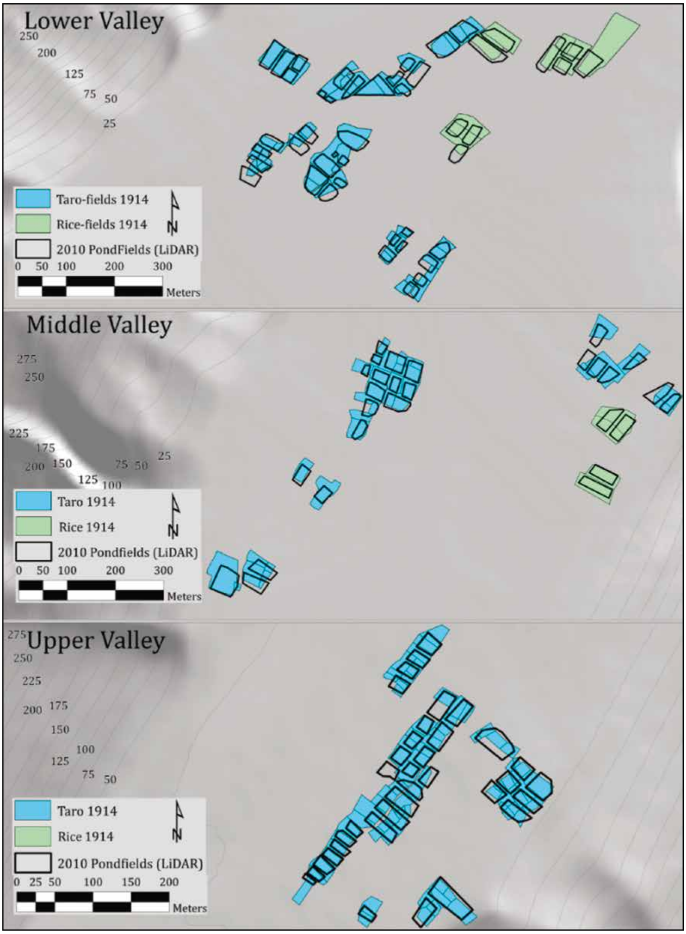

Figure 12. Modern taro pondfields in relation to 1914 rice and taro pondfields.

Table 4. Statistical results for the independent two-sample t-tests comparing the difference between rice fields in 1914 and taro fields in 2010.

Group statistics	Type	Number	Mean	Std. Deviation	Std. Error mean
Field Area	Rice (1914)	14	1909.2	1415.0	378.18
	Taro (2010)	13	1185.0	461.8	128.07
Field Shape	Rice (1914)	14	.5367	.20209	.05401
	Taro (2010)	13	.5002	.18525	.05138
Field Orientation	Rice (1914)	14	99.7	43.50752	11.62787
	Taro (2010)	13	70.2	41.96029	11.63769

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	P-value (Sig. 2-tailed)	Mean difference	Std. error difference
Field Area	Equal variances assumed	1.111	.302	1.758	25	.091	724.3	411.9
	Equal variances not assumed			1.814	15.926	.089	724.3	399.3
Field Shape	Equal variances assumed	.254	.619	.489	25	.629	0.748	0.748
	Equal variances not assumed			.490	24.998	.628	0.746	0.746
Field Orientation	Equal variances assumed	0.066	.799	1.795	25	.085	16.5	16.5
	Equal variances not assumed			1.798	24.958	.084	16.5	16.5

Table 5. Statistical results for the independent two-sample t-tests comparing the difference between taro fields in 1914 and taro fields in 2010.

Group statistics	Type	Number	Mean	Std. Deviation	Std. Error mean
Field Area	Taro (2010)	108	689.3	584.4	56.23
	Taro (1914)	181	558.7	511.8	38.0
Field Shape	Taro (2010)	108	0.62	0.17	0.016
	Taro (1914)	181	0.68	0.17	0.013
Field Orientation	Taro (2010)	108	83.9	45.3	4.4
	Taro (1914)	181	89.7	46.4	3.4

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	P-value (Sig. 2-tailed)	Mean difference	Std. error difference
Field Area	Equal variances assumed	.001	0.994	1.990	287	0.48	130.6	65.7
	Equal variances not assumed			1.924	202.2	0.56	130.6	67.9
Field Shape	Equal variances assumed	.454	0.501	-3.005	287	.003	-0.06	0.02
	Equal variances not assumed			-3.032	231.5	0.003	-0.06	0.02
Field Orientation	Equal variances assumed	.001	0.980	-1.037	287	0.301	-5.8	-5.6
	Equal variances not assumed			-1.043	229.6	0.298	-5.8	-5.6

documented in the 2010 data were similar to the 1914 rice fields, and larger and more rectangular than the taro pondfields mapped in 1914. By analysing the social relations depicted in the Māhele Land Commission Awards and documenting the historic conversion of taro to rice and back to taro we are able to understand the changes in, and resilience of, agricultural production in this iconic windward Hawaiian valley.

ACKNOWLEDGEMENTS

We thank Mara Mulrooney, Melinda Allen, Laura Dawson, Seth Quintus, Jim Bayman and Mark McCoy for their help and valuable comments. Gerald Z. Yonashiro and the State of Hawai'i DAGS Survey Division provided maps and advice on Waipi'o Valley. The LiDAR dataset was collected by the Carnegie Institution for Science. The research was funded by grants to Ladefoged from the Royal Society of New Zealand Marsden Fund (09-UOA-171) and the University of Auckland.

REFERENCES

Asner, G.P., D.E. Knapp, M.O. Jones, T. Kennedy-Bowdoin, R.E. Martin, J. Boardman and C.B. Field, 2007. Carnegie Airborne Observatory: In-flight fusion of hyperspectral imaging and waveform light detection and ranging (wLiDAR) for three-dimensional studies of ecosystems. *Journal of Applied Remote Sensing*. doi: 10.1117/1.2794018.

Bethel, Jennifer, Marrisa Furfaro, Phylis Maike-Ganileo, Nilka Julio, Kimberley Mills, Kenneth Roberts, Stephen Roberts, Ellyn Tong, Luciano Minerbi and Wiwik Bunjamin, 2001. Waipi'o Valley Towards Community Planning and Ahupua'a Management Phase II: Department of Urban and Regional Planning. Unpublished report, Planning Practicum, University of Hawai'i, Honolulu, available at http://www.durp.hawaii.edu/Library/Document%20pdf/Waipio%20Report%20Fall%202001%20opt.pdf

Bishop Estate, 1914. Map of Waipi'o. Map No. 570. Honolulu, Hawai'i. On file, Surveys Division, Department of Accounting & General Services, Honolulu, Hawai'i.

Cordy, Ross, 1994. *A Regional Synthesis of Hamakua District, Island of Hawai'i. Kapolei: Historic Preservation Division*. Department of Land and Natural Resources, State of Hawai'i, Honolulu.

Coulter, John W. and Chee Kwon Chun, 1937. Chinese rice farmers in Hawaii. *University of Hawai'i Bulletin* 16(5): 70.

Devereux, B., G.S. Amable and P. Crow, 2008. Visualisation of LiDAR terrain models for archaeological feature detection. *Antiquity* 82: 470–79.

Ellis, William, 1963 [1827]. *Journal of William Ellis: Narrative of a Tour of Hawaii, Or Owhyhee: with Remarks on the History, Traditions, Manners, Customs and Language of the Inhabitants of the Sandwich Islands*. Honolulu: Advertiser Publishing.

Emerson, J.S., 1881. Map of the Valley of Waipi'o, Hawaii, Showing Estate of C. Kanaina & the Crown Lands. Hawaiian Government Survey. Registered Map No. 912. On file, Surveys Division, Department of Accounting & General Services, Honolulu, Hawai'i.

Gao, J., 2009. *Digital Analysis of Remotely Sensed Imagery*. New York: McGraw-Hill.
Honolulu Advertiser, 1984. Big Island Faces Crises: Poi Lacking, February 21, 1984, pp. I20; Reprint of May 10, 1959.Kalena, Silva, 2002. Mahiʻai ʻAna i Ka ʻĀina Wai, Cultivating wetland. In Ka Hoʻoilina: Puke Pai ʻōlelo Hawaiʻi. Kamehameha Schools Press (1): 4-7.
——2004. Ke ʻAno o ke Kālaiʻāina, Methods of managing the resources of the land. In *Ka Hoʻoilina: Puke Pai ʻōlelo Hawaiʻi.* Kamehameha Schools Press (3): 4-21.
Kirch, Patrick V., 1977. Valley agricultural systems in prehistoric Hawaii: An archaeological consideration. *Asian Perspectives* 20 (2): 246-80.
——1997. *Feathered Gods and Fishhooks: An Introduction to Hawaiian Archaeology and Prehistory*. Honolulu: University of Hawaii Press.
——2012. *A Shark Going Inland is My Chief: The Island Civilization of Ancient Hawaiʻi*. Oakland, CA: University of California Press.
Kubo, Dudley, Katin Henderson and Luciano Minerbi, 2006. Waipiʻo Valley Stream Management Plan. Unpublished report, Natural Resources Conservation Service, Honolulu, Hawaiʻi.
Ladefoged, T.N., M.D. McCoy, G.P. Asner and P.V. Kirch, 2011. Agricultural potential and actualized development in Hawaiʻi: An airborne LiDAR survey of the leeward Kohala field system (Hawaiʻi Island). *Journal of Archaeological Science* 38 (12): 3605-619.
Lebo, Susan, John Dockall and Deborah Olszewski, 1999. *Life in Waipiʻo Valley 1880 to 1949. Research Program.* Honolulu: Bishop Museum Press.
Linnekin, Jocelyn, 1983. The *hui* lands of Keanae: Hawaiian land tenure and the Great Mahele. *Journal of the Polynesian Society* 92 (2): 169-88.
——1987. Statistical analysis of the Great Māhele: Some preliminary findings. *The Journal of Pacific History* 22 (1): 15-33.
McGregor, Davianna, 1995. Waipiʻo Valley, a cultural *kipuka* in early 20th Century Hawaii. *The Journal of Pacific History* 30 (2): 194-209.
——2007. *Nā Kuaʻāina: Living Hawaiian Culture*. Honolulu: University of Hawaiʻi Press.
Melrose, Jeffrey and Donna Delparte, 2012. Hawaiʻi County Food Self-Sufficiency Baseline 2012. Unpublished report, Geography and Environmental Studies Department, University of Hawaiʻi at Hilo.
Olszewski, Deborah I. (ed.), 2000. The Māhele and Later in Waipiʻo Valley, Hawaiʻi. Unpublished report prepared for the Native Hawaiian Culture and Arts. Bernice P. Bishop Museum, Honolulu.
Palmer, Molly, Michael Graves, Thegn Ladefoged, Oliver Chadwick, T. Kaʻeo Duarte, Stephen Porder and Peter Vitousek, 2009. Sources of nutrients to windward agricultural systems in pre-contact Hawaiʻi. *Ecological Applications* 19 (6): 1444-453.
Petersen, G.T., 1970. Taro farming in Waipio Valley on the Island of Hawaii. In R.W. Armstrong and H.T. Lewis (eds), *Preliminary Research in Human Ecology. North Kohala Studies.* Department of Geography, University of Hawaiʻi, Honolulu, pp. 23-45.
Rainfall Atlas of Hawaiʻi, 2011. http://rainfall.geography.hawaii.edu/ accessed 1/12/2014.

Salmoiraghi, F. and Y. Yoshinaga, 1974. *Waipi'o: An Exhibition at the Wailoa Center.* Hilo, Hawai'i: University of Hawaii at Hilo Continuing Education and Community Service. Exhibition catalogue.

Spriggs, Matthew and Patrick Kirch, 1992. Auwai, Kanawai, and Wai: Irrigation in Kawailoa. In P.V. Kirch and M.D. Sahlins (eds), *Anahulu: The Anthropology of History in the Kingdom of Hawaii. Vol. 2.* Chicago: University of Chicago Press, pp. 118-64

United States Geological Survey, 1995. Kukuihaele, Quadrangle, Hawai'i, Waipi'o Valley. Map. U.S. Geological Survey.

Wright, G.F., 1914. Waipio Valley, Hamakua, Hawaii. Upper Portion. On file, Surveys Division, Department of Accounting & General Services, State of Hawaii, Honolulu.

ABSTRACT

The resilience and revitalisation of *taro/kalo* agriculture in the Hawaiian contact period is analysed in Waipi'o Valley, on the Big Island of Hawai'i. Historic work has demonstrated the effects of colonial contact on the people of Waipi'o. Documents from the Māhele period, census information and missionary records are combined to paint a picture of how life unfolded in Waipi'o Valley over time. What is alluded to, and yet unexplored, is the changing production system and an overall trend of decreasing and fluctuating wetland taro production, where traditional cultivation is transformed by the introduction of rice farming. Later in time this too fades out, when taro again becomes dominant. Interestingly, wetland taro cultivation in Waipi'o is still practiced today, with interest in revitalising the capacity of a once intensively cultivated valley. Here, the impact of rice, and other crop introductions, is explored in terms of revitalising these wetland traditions. This was done by generating "snapshots" of the landscape through time. Information detailing traditional owners, plot locations and pondfields metrics were derived from digitised historic survey maps, and modern remote sensing techniques such as high resolution LiDAR (Light detection and ranging) imagery. Combining this information not only catalogued the historic trend of declining wetland irrigation, but directly illustrates the influence of past agricultural choices on modern wetland revitalisation agendas.

Keywords: Waipi'o Valley, Hawaiian archaeology, LiDAR, irrigated agriculture, GIS analysis, resilience, revitalisation

CITATION AND AUTHOR CONTACT DETAILS

Jones,[1] Benjamin, Thegn Ladefoged and Gregory Asner. 2015. Tracing the resilience and revitalisation of historic taro production in Waipi'o Valley, Hawai'i. *Journal of the Polynesian Society* 124 (1): 83-109. DOI: http://dx.doi.org/10.15286/jps.124.1.83-109

[1] Corresponding author: Anthropology, University of Auckland, Private Bag 92019, Auckland 1142, New Zealand. E-mail: benjamin.jones@auckland.ac.nz