– ARTICLE –

The Geometry of Loko Kuapā Kīholo: the regional significance and cultural context of a Royal Hawaiian Fishpond

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ABSTRACT

Kīholo fishpond is located on the north-west coast of Hawai'i Island. In 1859, less than fifty years after its construction, the artificial pond was inundated by a voluminous Mauna Loa lava flow and only small remnants of the original bounding wall remain. Historical accounts of its original scale are ambiguous and incomplete. In this paper we describe newly-discovered, lava-surrounded remnants of the wall that allow an estimate the fishpond's original size. An analysis of the fishpond is presented in order to weight its potential function within the Hawaiian food economy against its place in elite status competition. We reconstruct the original pond's configuration using a combination of geomorphological evidence, flow surface features, archaeological analogy and inference. We then calculate the labor required to have constructed the fishpond and, with the help of historical fisheries data, provide an estimate of the potential production. This empirically grounded input – output relationship is then evaluated in terms of the political, economic and ecological variables relevant to the development of political complexity in Hawai'i. We conclude that the pond lacked an efficient short-term subsistence function. The results suggest that large royal fishponds should be considered in terms sometimes reserved for monumental architecture. We conclude that large fishponds, in contrast to complex but incrementally constructed dry land agricultural works, played significant symbolic roles in wealth-displays and in elite status competition.

Keywords: fishpond, Hawai'i, Kīholo Bay, lava flow, Kamehameha, wealth finance, energetic analysis, political-economy.

INTRODUCTION

Hawaiian archaeology has long emphasized historic and pre-historic social transformations which led to a complex indigenous political-economic system. Between initial colonization of the islands and European contact, Hawaiian polities evolved from structured, kin-based chiefdoms to what some argue are primary states (Kirch 2011, 2012, Hommon 2013; for an alternative to the state-based model see Bayman and Dye 2013). Here we focus on one mechanism through which these socio-political changes manifest themselves. These transformations toward higher orders of complexity began in earnest at least two centuries prior to the first Western influences (i.e., Capt. James Cook's arrival in 1778). Successive and increasingly intense interactions with foreigners after that time built on what were sophisticated political foundations (e.g., Mills 2002).

Political organization structures the behavior of entrepreneurial elites within society. A minority may encourage the intensification of agricultural production through the manipulation of peasant labor and the control of material and social capital. When an elite class depend overwhelmingly on centralizing and controlling the means of subsistence production, a classic 'staple finance' economy may emerge (Earle 1997, Johnson and Earle 2000).

A staple finance system was supported in Hawai'i by an extremely efficient geographic organization of the economy. The traditional land divisions in Hawai'i were called *ahupua'a.* These discrete island sections usually stretched from the uplands to the sea and their boundaries were marked by a stone cairn (*ahu*) with an image of a pig (*pua'a*) surmounting it. They were defined and governed as independent and self-sufficient units giving great latitude and flexibility to the aristocracy (*ali'i*) and their ranking land managers and specialist bureaucrats (*konohiki*). Within these competing intra-island units, autonomous chiefs maximized their followings and sought paramount status over others. These interactions played out at such a scale that they had landscape level ecological effects (e.g., Vitousek, *et al.* 2004).

Most of the high-value items used in status displays in Hawai'i were perishable materials and not often preserved in the archaeological record. Despite this general lack of visibility, 'wealth financed' economic strategies have been shown to operate in Hawai'i. Items such as elaborate red

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and yellow feather cloaks provided opportunities for some chiefs to display their status more prominently than others (Tomonari-Tuggle 1996, Kirch 2011, 2012 and Hommon 2013). A case has also been made for certain lithic resources – in particular fine-grained, flinty, basalt quarried from Mauna Kea – providing an avenue of wealth finance (Kirch *et al.*, 2012). These resources were effective as forms of wealth and used for status-display because they were differentially distributed and not available within every *ahupua'a*. Such circumstances predisposed certain resources to chiefly monopoly and regal control, they may have required different social means to mobilize labor toward their production. This would be especially true with 'value-added' commodities that require not only harvest but processing to attain value.

The Hawaiian economy was certainly dynamic and it would be interesting to know how fast these changes in political structure occurred. A new consensus is forming concerning the date of the initial colonization of the Hawaiian Islands by Polynesian seafarers, and thus time available for socio-political change. The previous 'orthodoxy' estimated Polynesian arrival in Hawaii'i between AD 350–750 (Kirch 1985, 2011b). Reevaluations of previous radiocarbon dates have produced competing 'short chronologies' for the occupation of the islands. On one extreme is Wilmhurst *et al.* (2011) whose meta-analysis of 1,434 dates from across Polynesia place the pulse of immigration to outlying Eastern Polynesia at *c.* AD 1190–1290. Others, based on the reevaluation of sites such as the O18 site on the Waimanalo Plain of O'ahu (Dye and Pantaleo 2010) and of the Pu'u Ali'i sand dune, South Point, Hawai'i, in addition to proxy paleozoological and botanical data (Athens et al. 2002) and with reference to chronologies of other Central Eastern Polynesian island groups (Allen and Kahn 2010), place the earliest settlement around AD 1000.

The revision of colonization dates has real implications for the rate of evolutionary change in the Hawaiian polity, as they shorten the interval within which these major sociopolitical changes occurred from 1,600 to as little as 800 years. The transition from a ranked, kin-based society to a stratified and exclusively classist society is seen to have begun within the two centuries before contact. This conclusion is largely based on evidence of agricultural intensification in wet and dry land field systems and by the initiation of major monumental construction in core areas (Hommon 2008, also esp. 2013, Kirch 2002). Understanding the operation of parallel wealth financing during these periods may thus broaden the inflection point of the major sociopolitical and economic transition to state level society in Hawai'i.

This paper suggests that the construction of fishponds is potentially one such marker in this sociopolitical dynamic. Specifically, the construction of Kīholo pond was a significant attempt by Kamehameha-the-Great to legitimize and solidify his sovereignty. We argue below that the Kīholo fishpond, and by extension many other major fishponds throughout Hawai'i, are examples of 'wealth finance' operations. In such cases, dispersed and high valued resources were intentionally concentrated and monopolized by elites for social and political ends. We argue that fishponds, large ones in particular, were primarily a means of securing luxury goods for the social legitimization and display of political authority.

Grand scale fishpond construction differs from terrestrial forms of landesque capital intensification. The arable land on Hawai'i, for example, experienced perhaps two centuries of technological innovation, growth and productive increases between the 15th and 17th Centuries (McCoy and Graves 2010). The dry land field systems in the Kohala District (Ladefoged *et al.* 1996) and within the Kona Field System (Allen 2001), for example, expanded over an even longer time span. Investments in the intensification of all these productive systems resulted in centuries of cumulative elaboration. The construction of walls, mounds, terraces, ditches, irrigation channels (*'auwai*) and other infrastructure incrementally increased production to unprecedented levels. The common people (and source of all surplus labor) depend on terrestrial infrastructure for their subsistence and were therefore vested individually and communally in it (Lepofsky and Kahn 2011). Fishponds have a special symbolic power and represent a product of commoner labor from which the common people saw no subsistence return.

In order to substantiate these generalizations we present data from a case study below. Before we lay out our reconstruction of Kīholo pond it is necessary to provide some cultural context and background.

BACKGROUND

Fishponds have long been recognized as being integral to Hawaiian culture. Their form and scale were raised to unique technological heights in eastern Polynesia and in particular in Hawai'i (Summers 1964, Kikuchi 1973, 1976). Small ponds and traps provided subsistence buffers during periods of settlement development and larger state-sponsored ponds ultimately played a role in political specialization.

Fishponds were noted prominently in McAllister's 1933 survey of the archaeology of O'ahu. The O'ahu fishponds in and around Pearl Harbor were very large (Stokes 1909). Unfortunately, these ponds and traps were almost entirely destroyed by improvements to the naval facility. These types of pond/trap are described for other parts of central and western Polynesia. These *loko 'umeiki*, functioned as elaborate sets of stone weirs, used to corral and net fish as they were forced through the trap by the ebb and flow of the tides.

Indigenous Hawaiian fishponds show a variety and elaboration of types. Kikuchi's classified the aquacultural forms found in Hawai'i into eight different types (1973: 187) of two basic forms, the shore ponds and the inland ponds. Inland ponds were often integrated into the fresh water irrigation works of a taro field while shore ponds have specially configured sea-walls that extend out onto reef flats of the near shore or, sometimes that enclose entire shallow bays. *Loko Kuapā* refers to the pond, lake or pool (*loko*) and the wall (*kuapā*) of the fishpond that is built on a reef. While fish traps on large tidal flats like those of O'ahu's south shore are found throughout the Pacific, *Loko kuapā*, constructed along rocky shores, are a unique Hawaiian invention and are found nowhere else in Polynesia (Summers 1964: 2).

Compared with fish traps found in other parts of Oceania, Hawaiian ponds stand out in three respects. 1) They emphasize stocking and raising fish, rather than trapping wild individuals, 2) they are more technologically advanced as evidenced by the application and use of sluice gates (*mākāhā*), and 3) Hawaiian ponds were the exclusive property of a distinct class of people (Kikuchi 1973: 206). In Hawai'i's highly stratified society only the ali'i 'owned' ponds. Kikuchi draws a parallel between the plot of land set aside and reserved for the production of elite tribute/tax (the *ko'ele*, see Kirch 2012: 224) and the original fishponds. No commoner owned land. Kikuchi indicates the possibly of a growing political role that the ponds may have played in the flourishing of the royalty (Kikuchi 1973: 222).

Large fishponds were sometimes associated with particular gods. For example, Kane and Kanaloa, two major dieties central in origin mythology, are said to have wandered about O'ahu and constructed the fish traps referred to above (Kikuchi 1973: 135). Alekoko, a very large inland pond on Kaua'i, is referred to in histories as early as those dated by geneaological counts to the 13th century. reign of Chief Ola (Kikuchi 1973: 183). This pond is a good example of an inland type well integrated into a wetland valley taro field system. Early references to the construction of a *kuapā* type fishpond are found as early as the middle of the 15th century. Fornander, for example, places the construction of Keone'o'io on Maui at that time (1880: 71).

Suitable fishpond locations did not seem to drive settlement patterns. Kikuchi notes that the patterns of settlement emphasize the prominence of areas of agricultural potential over those of fishpond location in times of population expansion. In fact, there is a distinct lack of settlement around some ponds, for example Hommon and Barrera (1971) found no evidence of dense residential habitation in their survey of the Kahana Valley on O'ahu and its associated ponds. Where ponds were constructed was largely a function of geology. Apple and Kikuchi (1976: 58) note that some ponds may have been located away from populated centers and intentionally separate. This would serve the purpose of preventing any symbolic or real pollution as well as making it easier to monitor and protect from poaching.

It was the commoner's duty within the feudal-like Hawaiian system to offer their labor at the behest of the king. These vassals would be organized by local leaders and 'offered' to the paramount in a form of corvée labor. This type of labor is by definition in lieu of paid taxes, usually for public works projects, and usually intermittent. In one instance, an 18th century. chief named Koihala was rebelled against and killed by his subjects because he demanded too much of them in the construction of a pond at Honuapo, Ka'ū, Hawai'i (Malo 1951: 202). Ultimately, while smaller ponds were controlled and administered by a local family, only the elite controlled the larger ones (Kikuchi 1973: 99). These 'Royal Ponds' were reserved for their exclusive use.

Pond walls were constructed by dry-stacking rock. Shore ponds would have needed constant care in the face of seasonal storms. A method of core filling was sometimes employed and varying effort was put into the facing and finishing of walls. This would also include the design and construction of the *mākāhā*. The *mākāhā* were critical features in the design of the pond. These gates allowed water to circulate in the pond maintaining a health marine habitat while also allowing the small fry to enter but containing larger fish. The Hawaiians did not actively breed fish in the ponds; rather, wild young were caught either in the trap as above or with nets, and reared to size.

Differences between fishponds across the islands are instructive. Molokai is particularly noteworthy for an abundance of ponds, especially the *loko kuapā* type. The South shore of the island is so full of ponds that many, in fact, share walls. Hawai'i Island, with 21 times the population and 3 times the shoreline of Molokai, differs in interesting ways. Both islands have about 60 ponds (Hawai'i–59 ponds, Molokai – 62) but, they are distributed very differently with implications for their perceived value. On Hawai'i, only 10% of the *ahupua'a* have a pond, whereas on Molokai 60% of the *ahupua'a* do (Hommon 2013: 86).

Kikuchi's landmark 1973 dissertation and subsequent documentation and writings demonstrate how intimately integrated aquacultural systems were with wetland irrigation systems. Tied to subsistence farming traditions, ponds have often properly been lumped in with the infrastructure of the agricultural system in treatments of productivity, intensification and political economic development (Hommon's (2013) particular emphasis on terrestrial crop and swine production, for example). Kikuchi recognized the tertiary importance of ponds in overall subsistence. Kikuchi's own productivity models (1976: 298) suggest that all of the ponds in the archipelago (n=360) with an average production of 410kg/ha/yr could produce 1,053 metric tons of food. Considering the large population at the time, this was far too little to be of much influence when compared to the sum production of terrestrial crops like taro, sweet potato, banana, breadfruit, etc., on land

THE CASE STUDY

The present study concerns Kīholo fishpond, located on the northwest shore of Hawai'i island in the ahupua'a of Pu'uwa'awa'a (see Figure 1). It is now encompassed within Kīholo Bay State Park. The extant fishpond is classified as a type II – *Loko pu'u'one* or *haku'one,* terms that refer to the sand berm separating the pond from the sea (Kikuchi 1973, Apple and Kikuchi 1975). However, a previous far more massive pond, a 'Type I' or *Loko Kuapā* existed here until it was inundated by a lava flow in 1859. The original pond is the subject of our analysis below.

The destruction of the pond in 1859 by an eruption of Mauna Loa volcano was well reported in both the Hawaiian language and English newspapers of the time (e.g. Ka Hae Hawai'i, The Polynesian, and the Pacific Commercial Advertiser) as well as in early western scientific journals of volcanology (see Barnard 1990 for a compendium of these accounts) and ethnohistoric records (Westervelt 1999 (orig. 1916)). However, estimates of the fishponds scale are ambiguous and solid empirical evidence of its size is lacking. Ellis (1963 (orig. 1827)) writes of a mouth half-a-mile (805 m) wide and equally as deep, and Maguire (1966) translates historic oral accounts that boast of it being 600 acres (243 ha) or more in size.

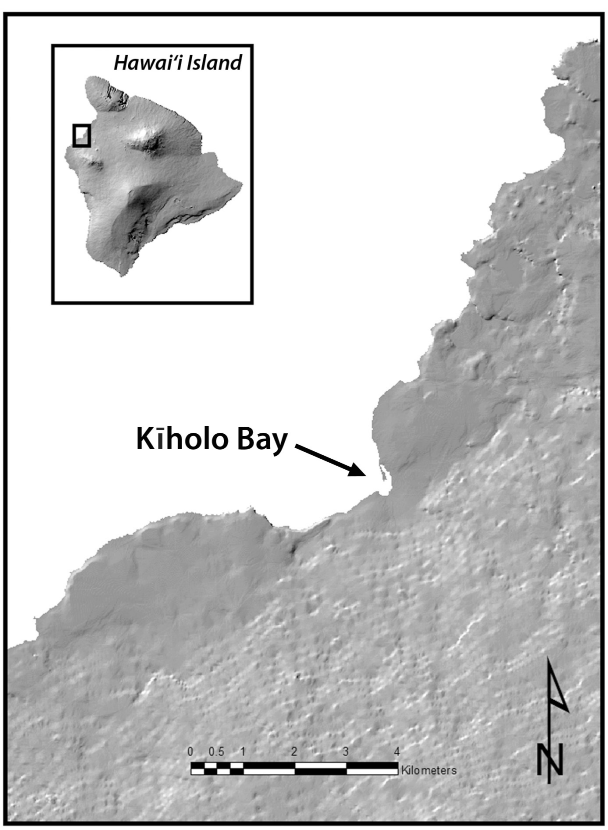

Figure 1. Map of Hawai'i Island showing location of Kīholo Bay.

The oral and written ethnohistoric record reinforces the royal nature and conspicuous ownership of Kīholo pond by Kamehameha-the-Great–the famed unifier of all the Hawaiian Islands and testifies to the cultural importance of the site. The *loko kuapā* at Kīholo is associated with his twin 'uncles', who were his allies and ardent supporters. These twins were brought up alongside Kamehameha as they all were chiefly youths in the court of the former paramount (Kalaniopu'u the reigning king of Hawai'i during the fateful encounter with Capt. Cook). One uncle, Kamanawa is said to have resided at Kīholo at the time of Kalaniopu'u's death and the other, Kame'eiamoku, lived one *ahupua'a* adjacent at Ka'ūpūlehu. Kīholo was the site of Kamehameha's blood uncle, Keouakuahuula's 'ōmu'o; where in ritual fashion he removed the glans of his penis before proceeding to his surrender and sacrifice at Pu'u Koholā (Kelley 1996). Keoua's defeat signaled Kamehameha's dominance.

After the 1801 loss of Pa'aeia pond during a Hualālai lava flow (Kauahikaua and Camarra 2000, Kauahikaua et al., 2002) Kamehameha ordered the *loko kuapā* at Kīholo built. The event would also commemorate the move of his capital to Kamakahonu (Kailua-Kona). The royal center of Kailua was well established at the time, that is, the 'salubrious core' of central Kona had become 'agglutinated' with many household, administrative and ritual sites (*sensu* Hommon 1976). This included an already established royal type I pond at Kaloko. Kīholo lies quite some distance to the north (~20 km). As mentioned above, this isolation from the royal center may have been desirable and may have reinforced the nature of its sacred prohibition (*kapu*).

The precise year of the *loko kuapā's* construction is hard to establish. Kaakua (1859) states that it was 1810, Cordy (2001:39) says it was 1805 and Barrera (1971) working from *Mahele*-era boundary commission award testimonies places the event in 1812. During this period Kamehameha undertook the construction of three large fishpond projects including two others on Maui: Loko Nui and Loko Iki at Haneo'o, Hana (Apple and Kikuchi 1975:102). For relative comparison, Table 1 provides summary statistics on these and other ponds mentioned in the text.

Faced with a declining population and in the context of his relatively recent consolidation of rival kingdoms and the enlargement of his court as well as with full knowledge of increasing foreign influences, it is our opinion that Kīholo fishpond represents a clear and conscious expression of Kamehameha's supreme status writ in the vernacular of old.

There are few direct observations of the size of Kīholo fishpond but William Ellis (1963:296, reprint of 1827 edition) made the following description when he saw it in 1823:

> This village [Kihoro] exhibits another monument to the genius of Tamehameha [sic]. A small bay, perhaps

Table 1. *Comparison of the size/area (in hectares) of type I ponds – Loko Kuapā – on Hawai'i and Maui (after Kikuchi 1973 and Apple and Kikuchi 1975).*

Name*	*Ahupua'a*	District	Island	Area (hectares)	Other/Note
Kanakea (H25)	Waiakea	Hilo	Hawai'i	0.81	
Lihikai (H12)	Keokea	Hilo	Hawai'i	0.65	
Lihikai (H13)	Keokea	Hilo	Hawai'i	0.49	
Waihonu (H65)	Maka'oku	Hilo	Hawai'i	1.21	
Honu'apo (H16)	Honu'apo	Ka'u	Hawai'i	1.62	
Makaha (H46)	Miloli'i	S. Kona	Hawai'i	0.40	
Kaloko (H24)	Kaloko	N. Kona	Hawai'i	4.45	229m long, 10.7m wide, 1.8m high.
Lahuipua'a (H41)	Kalahuipua'a	Kohala	Hawai'i	2.02	
Waipuhi (H70)	Kalahuipua'a	Kohala	Hawai'i	0.81	
Kaonoulu-kai (F6)	Kalepolepo	Kihei	Maui	2.43	334m long, 2,400 cubic meters Vol.
Haneo'o (Loko Nui) (F3)	Haneo'o	Hana	Maui	4.53	Destroyed by '46 tsunami
Kuamaka (Loko Iki) (F3a)	Hamoa	Hana	Maui	0.81	Destroyed by '46 tsunami
n=12			**Average:**	**1.69**	
			Std. Dev.:	**1.45**	

* (Kikuchi 1973, and Apple and Kikuchi 1975)

> half a mile across, runs inland a considerable distance. From one side to the other of this bay, Tamehameha built a strong wall, six feet high in some places, and twenty feet wide, by which he had an excellent fish-pond, not less than two miles in circumference.

The geological features we describe below have allowed us to reconstruct the original pond geometry. Based on our findings we also discuss the motivations and incentives for the construction of large-scale architecture of this sort, and we propose that large fishponds were an essential tactic in the elite's strategy to dominate politically. On the basis of our historically based quantitative estimate of costs and benefits of construction, we argue that symbolic and political motivations were paramount to any strictly economic or ecological ones when it came to building ponds of this size.

RECONSTRUCTION OF THE GEOMETRY OF LOKO KUAPĀ KĪHOLO

Physical Evidence

The seaward wall of the pond is not an impressive sight today. Portions are visible only at the extreme southern end and in several small islands of older substrate surrounded by younger lava flows to the north (*kīpuka*). The most well preserved southern terminal section is battered by storm surf and is losing integrity quickly. It is represented in part by a lava mold – a negative feature (see Figure 2). Its original shape is preserved where a tongue of *pāhoehoe* (a smooth, unbroken and fluid type of lava) overtopped the wall and solidified in the terminal phases of the eruption. The stacked rocks of the wall have subsequently been removed by wave erosion, leaving a sort of trace fossil of the original wall. The relatively steep angle of the batter-facing on the seaward side is still apparent. Here it is evident that the wall was 1.5 meters above mean tide and at least 6 meters across, confirming a portion of Ellis' account.

Geophysical Evidence

In an effort to refine historical descriptions of Kīholo and elsewhere in Hawai'i, Jim Kauahikaua conducted proton-procession magnetic surveys on both the 1859 flow field at Kīholo and of the 1801 flow from Hualālai that covers Loko Pa'aeia (Kauahikaua and Olmsted 1994, James *et al.*, 1997). Fishpond walls and other stacked boulder structures composed of randomly oriented basalt blocks should appear as significant magnetization anomalies against the surrounding homogenously oriented native basaltic lava. However, weak linear patterns of negative magnetic anomalies originally reported are now interpreted as insignificant in consideration of 'magnetic noise' that could not be controlled for and do not correlate with our placement of the wall location. Perhaps with future technical refinements of the magnetometer instruments or with other means of remote sensing this will become an efficacious method of reconstructing prehistoric features inundated by lava flows.

Geomorphology

Over 95% of the original *kuapā* was covered by *pāhoehoe* in 1859. What is left is a large linear geological feature on

Figure 2. *Kuapā* lava mold, beach is to the upper left, note rubble in foreground and raised *pāhoehoe* rampart behind feature.

the surface of the lava field, like a rampart or bench where cooled material and crust on the surface abutting the obstruction has inflated and rotated forming a distinctive escarpment (see Figure 3 and 4). This feature is contiguous and aligned with the small remaining section in the kīpuka mentioned above. It runs for 1,330m (4,363.5 ft.) over the current flow field as measured from aerial images. The linear feature is quite distinct on an oblique angle Google Earth image (see Figure 5).

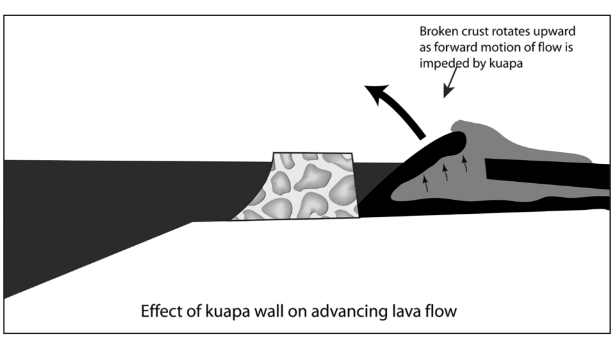

Figure 3. Cross-section illustration of the process by which the advancing 1859 *pāhoehoe* lava flow was blocked by the fishpond wall, overtopping an obstruction with the characteristic block rotation resulting at the front. Continuing internal injection of molten lava beneath crust raises flow surface and eventually may bury the original wall – but a linear inflection point remains to mark the buried *kuapā*.

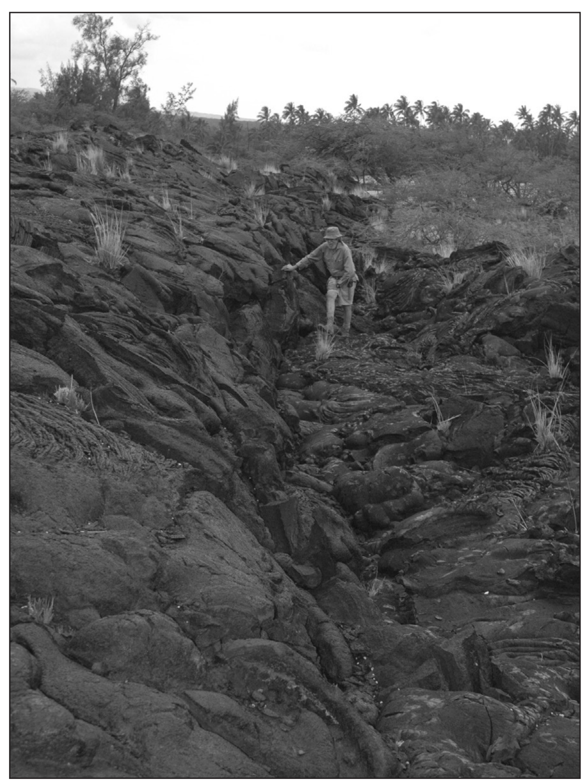

Figure 4. The *pāhoehoe* rampart along the line of the former kuapā. Although the wall (beneath the person) has been completely covered with lava, its original position is marked by the ridge of *pāhoehoe* crust that was rotated upward as lava ponded and inflated upslope of the wall.

Figure 5. An oblique aerial image from Google Earth Pro, with the linear rampart demarcated.

Field investigation and reconnaissance of the area of the lava flow surface also indicated an association of isolated, cobble-size 'floater' rocks resting above lava covered sections of the wall. These floaters match (in texture, color and mineralogy) the character of older, orange, Hualālaʻi rock that were used for wall construction. Some fragments of the native Hualālaʻi rock, quarried locally from sites further inland and stacked on the reef to construct the fishpond wall, were lifted by the fluid dynamics of the viscous flow and dislocated vertically as the lava inundated the wall.

The prehistoric shoreline is not as easily inferred. An estimate was made based on multiple lines of evidence. First, there are signs of lava having been emplaced on top of water. The steam produced in this interaction carries and precipitates minerals from the cooling lava, staining the surface of the flow field and leaving variously a white-yellow-orange patina (see Figure 6a). These areas of phreatic staining are especially dense in the southern portions of the flow field where the lavas' primary surfaces dominate (i.e., where successive phases of the eruption have not covered the surface with another layer of molten rock).

A second direct indication of lava having been emplaced on water is given by the presence of pipe vesicles in the basalt. Several outcrops were exposed as a result of the post-eruption, (historic) reconstruction of the Ala Kahakai Trail where the internal texture of the lava flow has been exposed (see Figure 6b).

Additional circumstantial evidence can be found in the placement of a *hōlua* – a traditional grass covered stone sled-way for chiefly competition and entertainment – found at Kīholo (Ching 1971). If we assume an analogous orientation and placement with other *hōlua* at Aimakapa'a pond at Kaloko *ahupuaʻa* to the south, for example, this can help us to infer the ponds back edge.

Topographic features of the current landscape also aid in placement of the *loko*. The estimated flow thickness and the elevation of the terminal flow contact along the southern periphery suggest a roughly parabolic shape for the pre-1859 coast. Etymologically, 'Kīholo' is defined literally as a fish hook (Pukui and Ebert 1986), suggestive of a smoothly curved arc of the previous bay shore. Figure 7 shows the current configuration of the 1859 flow our interpretation of the prior geometry based on the multiple lines of evidence outlined above.

From aerial photos we measured a length of 1,330 meters for the pond mouth, combined with our bay shore location estimate, we calculate (Area = $(\pi * \text{radius}^2)/2$) that the pond area was a maximum of 69.5 hectares or, 171.7 acres. This is smaller, by more than two-thirds, than the

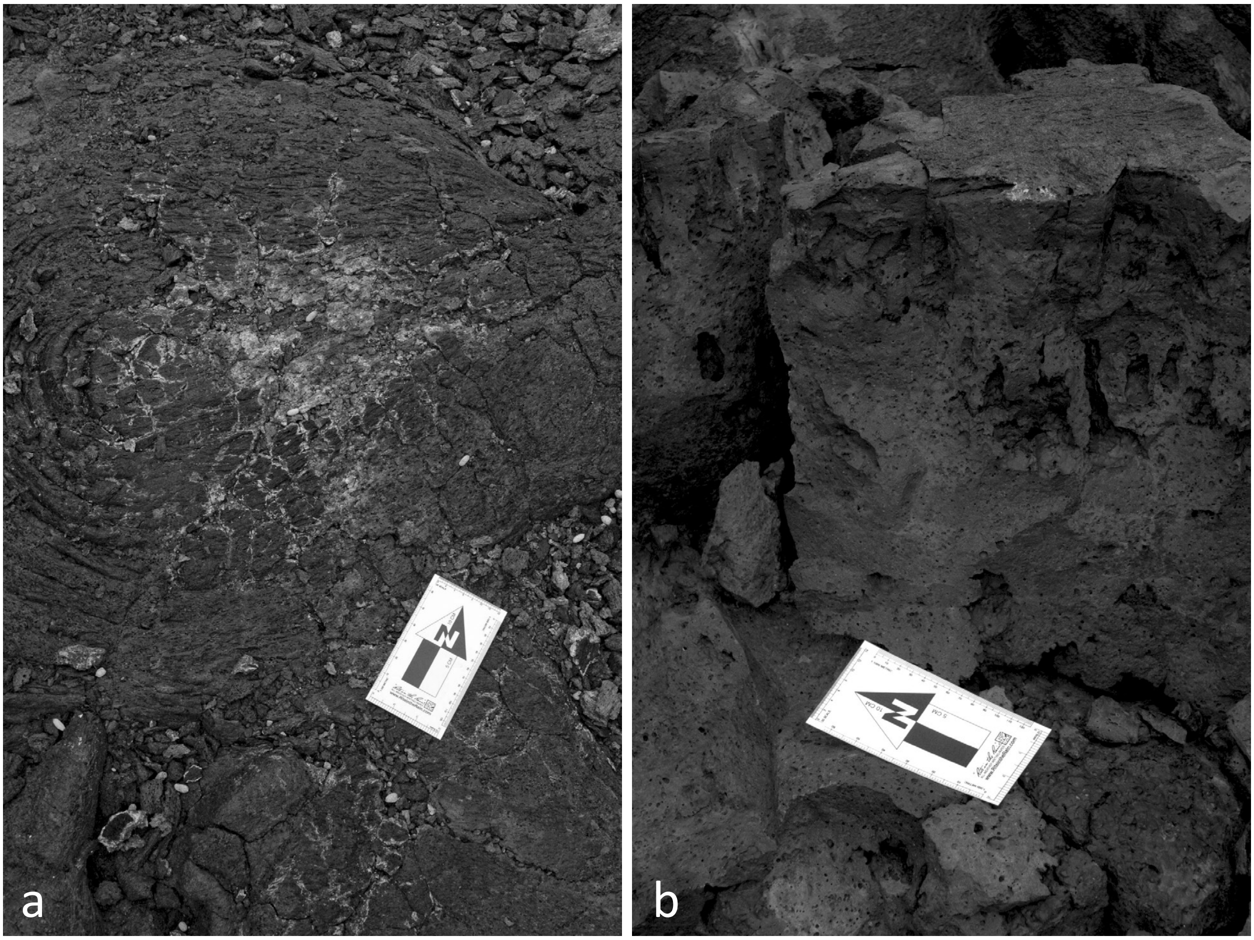

Figure 6. a) Photo of a typical phreatic stain on the flow field surface indicating the flow poured into water (which formed steam) during lave emplacement and cooling. b) Photo of pipe vesicles found exposed in an outcrop of the 1859 flow along the reconstructed Alakahakai trail. These indicate that the flow overran water which flashed to steam and migrated upward through molten rock.

description of Maguire (1966) in the late 19th century (600 acres) but, far larger than William Ellis, describes it in his 1827 journal (805 meters wide). These discrepancies are enough to give serious pause whenever ethnohistoric data are relied upon for quantitative estimates of site features.

The following summary statistics were generated for the approximate size of Loko Kuapā Kīholo:

Length of wall: 1,330 meters (4,364 feet)
Volume of wall: 14,827 cubic meters (523,620 cubic feet)
Area of pond: 69.5 hectares (171.7 acres)

ENERGETIC ANALYSIS

Input:

What did it cost to build such an impressive pond? Labor estimates for pond construction are problematic for several reasons. First, only 23 in the entire Hawaiian islands are documented as having been made by man. In many cases oral histories document the assistance of *menehune* (mythical dwarf-men). It is clear that these were large scale construction projects, in all those cases, a line of men is used to move rocks sometimes distances of up to 2 miles. Furthermore, a work force of 10,000 is said by Kamakau to have been 'employed' in the construction of Haneo'o, Kalepolepo, and Keokea-kai on Maui during the reign of King 'Umi (Kamakau 1869). Kamakau reports that simply repairing Kalepolepo, with a 500 ft. long (152 m) *kuapā*, took several months of work (*ibid.*).

Michael Kolb (1991) presents a model of labor investment in the construction of Hawaiian heiau that includes a detailed consideration of both the general and locally specific variables involved in masonry construction on the islands. Kolb's model sums the costs of a project on the basis of six variables. These are the volume of rock in question, its specific gravity, excavation and transport (quarrying) costs, and the total masonry labor in addition to miscellaneous, yet critical construction of wooden components. Kolb (1991:137) fills in a remaining piece of the model by

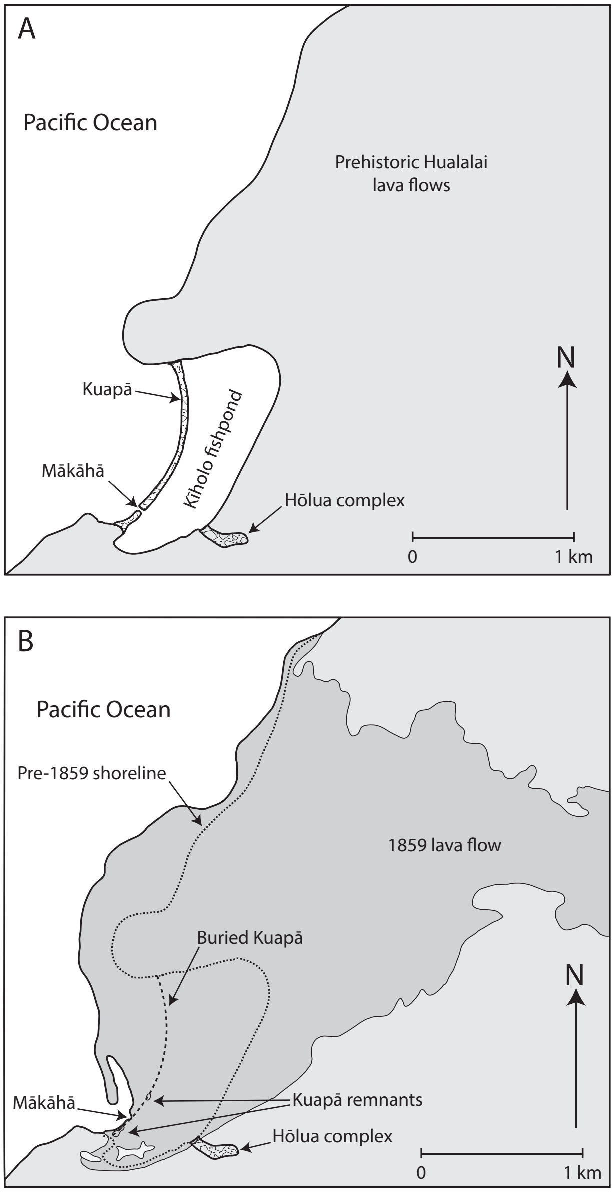

Figure 7. Geologic sketches of Kīholo Bay as inferred (a) before the 1859 eruption and (b) present, *kuapā*, *hōlua*, and reconstruction of indicated (from Lockwood 2000).

extrapolating based on observations and interviews of modern working stone masons in Hawaiʻi. He calculates that these men can fit rocks at a rate of about two cubic meters per day or, 5,260 kilograms per mason per day. The following calculations are based on Kolb's model.

The average specific gravity of basalt in Hawaiʻi is 2.93 grams per cubic centimeter (Dana 1878). The density of highly vesicular rocks such as the material in question may be closer to 2.4 grams per cubic centimeter, however, we use the higher figure for comparability. The most difficult variable to estimate for the Kīholo case is the costs of quarrying, which increase exponentially with distance from the site. At a transport distance of 100 meters, three to five metric tons of material can be transported by a man in a five-hour workday; at 200 meters that total falls to about one ton, and at 300 meters the estimate is well below a single metric ton (Erasmus 1965: 286). On Hawaiʻi, fractured outcrops of usable rock are common on the surface where young lava flows dominate the landscape. We identified and characterized likely quarry sites, finding that some sources of appropriate slabs of *pāhoehoe* were at least 500 meters distant.

With additional adjustments for the more-time consuming finishing of the facing (batter) of the fishpond's outer wall, and with some conservative accounting of what was probably significant and detailed woodwork to construct the *mākāhā* (sluice gates) for the pond, an empirically based estimate for the total cost of constructing the Kīholo *loko kuapā* can be made. Using the above estimates for both volume and weight of material, stacking the rock for the fishpond would take 8,300 raw person-days (83 days for a crew of a hundred, or just over a week if the labor force were one thousand). Adding the cost of quarrying and transporting the raw material to the site reveals an interesting and significant dynamic to the enterprise. That is, if we assume that material is locally available at an average distance of only half a kilometer, and as Erasmus' model estimates, a rate of half a metric ton (500 kg) per day per worker, supplying the material would take the same crew of 100 people an additional 869 days. Thus, of the *c.* 95,150 person-days required, the quarry and transport of material represents 91% of the overall cost by itself.

Output:

What did such a large pond produce in the way of fish? A 1901 report to Congress on Hawaiian fisheries (Jordan and Everman 1901) provides quantitative data used to place a range on potential Kīholo production. Data from six Hilo area (Hawaiʻi Island) ponds and 18 Molokaʻi island ponds were selected to give a range of production potential. Not unexpectedly, the harvest in lbs/acre varied considerably, from around 50 in Hilo to almost 300 on Molokaʻi. In both cases the main species collected were the striped mullet or, *ʻamaʻama* (*Mugil cephalus*).

Using these yield figures as proxies, we propose that Kīholo pond could have produced somewhere between 8,585 -51,510 lbs of fish per year. At 520 calories per lbs. of fish (www.nutritiondata.self.com) this total represents an annual production range of 4,464,200–26,785,200 calories (a mean of 15,624,700 calories). This would be enough fish, if harvested and eaten on a single day, to feed 5,208 people on a 3000 calorie-per-day diet. However, the sum of the construction effort (with man-days converted to calorie requirements) is estimated to have been on the order of 285,441,600 calories. Therefore, providing enough fish calories to feed the workforce during the construction period could require 18.26 years of average fishpond harvests. Building a large pond was a very long-term investment, approximately equal to the time often attributed to an entire generation in genealogical reckoning. As social capital, on the other hand, the pond would bring an immediate return.

DISCUSSION/CONCLUSIONS

Mean statistics for phenomenon so dependent on specific local conditions are useful only for general comparisons. Note, for example, that there need not be any necessary relationship between wall length and pond area, as the shape of the original bay will be the more critical variable. Given this however, Kikuchi found that for the *kuapā* there were some consistent averages. For example, wall height and widths of 32 *kuapā* he measured were 'fairly uniform' resulting in an average of 6.66 feet (2 m) width and 3.84 feet (1.17 m) height. As a ponds length is mainly a factor of location, his measurement of 90 pond wall lengths showed more variability, ranging from 150 – 6,300 feet with a mode value between 1,200 – 2,000 feet, and an average of 1,600 feet (488 m). The average volume of 25 representative *kuapā* calculated by Kikuchi was 49,132 cubic feet (1,391 cubic meters) (Kikuchi 1973: 54–55). On a statistical basis, the ancient Kiholo pond's wall was ten-and-two-thirds-times as large (volumetrically) as the average comparable pond. This significant difference in volume can be attributed in large part to its massive width, as its length is not as remarkable in comparison to some other large ponds (*ibid.*). Kikuchi found that out of a total 125 Type I ponds the size, or area 'ranged continuously' between 0.5 to over 500 acres. However, the distribution shows very few reach sizes above 30 – 40 acres (or around 12 to 16 hectares) (*ibid.*: 80 and fig. 33). This reinforces our point that the pond built c. 1812 was a massive if not unprecedented endeavor.

The quantitative approach to the evaluation of the input and output of energy in this particular Hawaiian fishpond has allowed for estimations of the potential sources of labor and fisheries yield. In this way, we are in a better position to weigh alternative expenditures of specifically valued costs within a specific historical context. This formal energetic approach gives us better sense of substantive relationships involved in the process of economic intensification and political aggrandizement. *Prima facie*, the amount of labor required to build the pond and the potential yield of fish are significantly imbalanced. Symbolic elements and social values must have been strong factors in this decision to allocate such tremendous amounts of material capital and human labor.

Johnson and Earle (2000: 283) argue that Polynesian chiefdoms, political economies generally, and for Hawai'i in particular, were financed through a form of redistribution characterized as tributary taxation. The form of the commoner payment in traditional Hawai'i was generally staple goods through the institutions of the annual *Makahiki*. In some instances, specific items such as feathers, cordage or, koa (*Acacia koa*) logs may have been demanded. These commoner surpluses were then used to support craft specialists and other bureaucrats. This redistribution was the *ali'i's* obligation, but also it was meant to maintain their 'dominating position and imposing lifestyle' (*ibid.*).

It is important in this context to note also that fishponds did not produce staple foods but fish reserved for the *ali'i*. The topmost classes of Hawaiian royalty monopolized the husbandry of pigs in much the same way as they controlled the production of 'ama'ama, sometimes referred to as *pua'a kai* (sea-pig), which were considered elite luxury food items. Fishpond production was not oriented toward foodstuff manufacture for the masses. Instead they produced a specific commodity for the rulers when they demanded it.

In Johnson and Earle's classic formulation, the ali'i fulfilled their most important role in the cosmological sense, by bridging the sacred and mundane and channeling the *mana* (supernatural or divine power) of earth and sea through themselves and thereby maintaining stability. The agricultural economy was a grand metaphor and manifestation of this worldview. According to this view, the intensification that fueled the sociopolitical growth of Hawaiian polities was accommodated at the family or local level of agricultural organization (Johnson and Earle 2000: 287). However, fishpond production stands outside and removed from the commoner (*maka'āinana,* lit. the people who attend the land).

Kamehameha wasn't paying people–from the senior mason to the brute physical labor–in fish, or in any sort of wages, for that matter. Instead, a corvée force is most likely to have been set to work on the project. Supplying the corvée force would have been the responsibility of regional chiefs and a signal of their allegiance. The fishpond project was also likely a matter of solidifying alliances with a growing number of leaders on all the islands, each of whom had to be convinced to supply dozens of workers from their own 'capital/labor funds'. These subordinates could be rewarded with far fewer fish, literally speaking. In addition the fish these regional leaders did eat conveyed upon them special status. This tactic of incorporating non-kin allies may have been a key strategy for expanding political integration. It would also have had the potential to rally very large labor forces.

As we have argued, fishpond production represents a system of non-staple finance where capital-labor valuations are balanced differently than in relatively low-cost agricultural intensification projects. As such, the construction of royal fishponds on this scale should be viewed more appropriately in terms of strategies of social integration rooted in symbolic not economic realities. Over the long term, and perhaps in specific historically contingent instances (e.g., failed crop production) we grant that the ponds may have had limited roles in attempts to buffer subsistence shortfall by both elite and the common people. This may be particularly true of the lower order ponds managed by families and clans of the local village and directly integrated in to the *ahupuaʻa* subsistence economy. Innovation in the scale and frequency of regional prehistoric pond-construction sequences may reflect political adjustment as much as any response to population pressure or demographically induced intensification of production in the context of limited land (e.g. Hommon 2008).

Archaeologists should be aware of the special place that Royal type fishponds occupy and seek to integrate them meaningfully into settlement models. The relationship between capital and labor is different in the context of terrestrial agriculture, where improvements are regionally generated by the household or extended family level within the *koʻele* plots.

The early contact period when Kamehameha, a powerful regional sovereign, built Kīholo *loko kuapā* was an era in which 'the political economy of grandeur' (Sahlins 1992) was still practiced. Opulent displays of wealth and lavish consumerism by the *aliʻi* were necessary strategies in the maintenance and consolidation of power, particularly in the face of imposing 19th century European institutional competition.

Considered within this historical context and framed against the more general view that staple finance dominated Hawaiian political evolution, fishponds are slightly anomalous. They should not be assumed to occupy the same economic position or function as the construction and elaboration of intensive field systems (*cf.* McCoy and Graves 2010, Field *et al.* 2011). The decisions made by aliʻi were motivated by what Karl Polanyi (1944) called substantive economic rationale as opposed to the products of 'rational' or formal self-interested calculation. As Kikuchi recognized long ago, fishponds are inefficient devices in this sense (Kikuchi 1976: 295). When asking questions about pre-contact intensification of production, fishponds must be considered somewhat independently from larger scale staple financed infrastructure and landesque capital.

Kirch *et al.* (2012) propose that wealth finance institutions had a significant role in the expansion of political economies to the level of the state. As such, a political rather than an ecologically driven economy could be seen as co-dominant during periods of florescence. Our raw energetic analysis has shown that building a fishpond the size of Kīholo was a 20 year gamble. However, considering the considerable symbolic value and stakes (one's sovereignty) the scale and effort devoted to Kīholo can be well understood as 'rational'. The sociopolitical benefit was immediate and reinforced the *aliʻi's* role in the cosmos as a divine king.

The tradition of royal fishpond construction is testimony to the synergy of socio-political and eco-economic motivations in the successful intensification of economic and political production. There is no simple dichotomy between economic and ritual spaces within culture. The successful chief, anxious over administrative authority and eager to reinforce the class status of the *aliʻi* (Kirch 2011) would be skilled at balancing investments on both sides of this equation.

Intensification occurs on different levels, both fueling and being fueled by increasing social complexity. The changes in Hawaiian polity from complex chiefdom to archaic state can be increasingly viewed as originating from both the bottom-up, as in the case for intensive terrestrial and pond-field agriculture (*cf.* Dye 2010 and Lepofsky and Kahn 2011), but also with significant impetus from the top-down in the case of fishpond elaboration and other manipulations of wealth. Though often generalized as having been structured around a staple finance economy, complementary means of capital manipulation and redistribution must be appreciated for their significant socially integrative force.

It remains for future researchers to evaluate the place of other fishponds' construction in local and regional chronologies. Further systematic study in spirit of Kikuchi's holistic approach should include careful dating of pond constructions, where possible. This is a somewhat urgent cause given the rate at which ponds have been lost to shore line development. Preservation of these traditional cultural properties is crucial. The restoration of fishponds by non-profit groups and the National Park Service have become the locus of cultural revitalization efforts which could serve as models for both scientific research and community development.

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References

Allen, M.S. (ed.) 2001. *Gardens of Lono: Archaeological investigations at the Amy B.H. Greenwell Ethnobotanical Garden, Kealakekua, Hawaiʻi*. Bishop Museum, Honolulu.

Allen, M.S. and Kahn, J., 2010. Central East Polynesia: an introduction. *Archaeology in Oceania*, Vol. 45, no. 2, pp. 49–53.

Apple, R.A., Kikuchi, W.K., 1975. *Ancient Shore Zone Fishponds: an evaluation of survivors for historic preservation*, Office of the State Director of the U.S. Department of the Interior, National Park Service, Honolulu.

Athens, S.J., Tuggle D.H., Ward, J.V., Welch, D.J. 2002. Avifaunal extinctions, vegetation change, and Polynesian impacts in prehistoric Hawaiʻi. *Archaeology of Oceania* Vol. 37, pp. 57–78.

Barnard, W.M., 1990. Mauna Loa – A source book: historical eruptions and exploration, Vol. 1: 1778–1907, pp. 137–151.

Barrere, D.B., 1971. Anaehoomalu–A Hawaiian Oasis, Preliminary Report of Salvage Research in South Kohala, Hawaiʻi. Pacific Anthropological Records #15, B.P. Bishop Museum, Honolulu.

Bayman, J.M. and Dye, T., 2013. *Hawaii's Past in a World of Pacific Islands*. Society for American Archaeology Press, Washington, D.C.

Ching, F.K.W., 1971. Archaeology of South Kohala and North Kona From the Ahuapua'a of Lalamilo to the Ahuapua'a of Hamanamana; Surface Survey Kailua-Kawaihae Road Corridor. Hawaiʻi Dept. of Land and Natural Resources, Division of State Parks, Outdoor Recreation and Historic Sites. (Vol. 71, Issue 1 of Hawaiʻi State Archaeological Journal).

Cordy, R., 2000. *Exalted Sits the Chief, The Ancient History of Hawaiʻi Island.* Mutual Publishing, Honolulu.

Dana, E.S., 1878. *Manual of Mineralogy and Lithology,* 3rd ed. New Haven.

Dye, T. 2010. Social Transformation in Old Hawaiʻi: A bottom-up approach. *American Antiquity*, Vol. 75, no. 4, pp. 727–741.

Dye, T., Pantaleo, J., 2010. Age of the O18 site, Hawaiʻi, *Archaeology of Oceania*, Vol. 45, 113–119.

Earle, T.K., 1997. *How Chiefs Come to Power: The political economy in prehistory*, Stanford University Press, CA.

Ellis, W., 1963. *Journal of William Ellis–narrative tour of Hawaiʻi, or Owyhee; with remarks on the history traditions, manners, customs, and language of the inhabitants of the Sandwich Islands (1827)*, Advertiser Publishing Company, Ltd., Honolulu.

Erasmus, C.J., 1965. Monument Building: Some Field Experiments. *Southwestern Journal of Anthropology*, 21: 277–301.

Field, J.S., Ladefoged, T.N., Kirch, P.V., 2011. Household expansion linked to agricultural intensification during emergence of Hawaiian archaic states, *Proceedings of the National Academy of Sciences (PNAS)* 108, 7327–7332.

Fornander, A., 1880. *An Account of the Polynesian Race. Vol. 2*, London. Trubner.

Google Maps (2012) http://www.google.com/enterprise/earthmaps/earthpro.html.

Hommon, R.J., 1976. *The formation of primitive states in pre-contact Hawaiʻi*, Ph.D. Thesis, University of Arizona.

Hommon, R.J., 2008. Watershed, Testing the Limited Land Hypothesis, in: Dye, T. (Ed.), *Research Designs for Hawaiian Archaeology, Agriculture, Astronomy, and Architecture*, Society for Hawaiian Archaeology, Honolulu.

Hommon, R.J., 2013. *The Ancient Hawaiian State, Origins of a Political Society*. Oxford University Press.

Hommon, R.J and Barrera W.M., 1971. Archaeological Survey of Kahana Valley, Koolauloa District, island of Oʻahu. Report 71–3. Honolulu, Department of Anthropology B.P. Bishop Museum.

James, D., Kauahikaua, J., *et al.*, 1997. Using geophysical magnetic surveying methods in locating a buried Hawaiian fishpond wall, Geological Society of America Abstracts with Programs v. 29, no. 1: p. 54.

Johnson, A.W., Earle, T., 2000. *The Evolution of Human Societies: From foraging group to agrarian state, 2nd ed.*, Stanford University Press, Stanford.

Jordan, D.S., Everman, B.W., 1901. Preliminary Report on an Investigation of the Fishes and Fisheries of the Hawaiian Islands, U.S. House of Representatives, 57th Congress, Washington, D.C.

Kaakua, J.H., 1859. Concerning the Lava Flow, *Ka Hae Hawaiʻi* (newspaper) Nov. 9, 1859

Kamakau, S.M., 1961. *Ruling Chiefs of Hawaiʻi*, Revised Edition, Kamehameha Schools Press, Honolulu.

Kamakau, S.M., 1869. 'Moʻolelo o Hawaiʻi.' Trans. from newspaper *Ke Au ʻOkoʻa*, Dec. 2.

Kauahikaua, J., Camara B., 2000. Most recent eruptions of Hualalai volcano, Hawaiʻi: Geological evidence from the historical record, *Geological Society of America Special Paper #345*, 25–32.

Kauahikaua, J., Cashman, K.V., Clague, D.A., Champion, D., Hagstrom, J.T., 2002. Emplacement of the most recent lava flows on Hualalai Volcano, Hawaiʻi, *Bulletin of Volcanology #64*, 229–253.

Kauahikaua, J., Olmstead, V., et al., 1994. Mapping rock walls buried by lava: physical evidence for large, Hawaiian fishponds inundated by 19th century lava flows, Geological Society of America Abstracts with Programs, v. 26 no. 7, p. A-262.

Kelly, M., 1996. A Brief History of the *Ahupuaʻa* of Puʻuwaʻawaʻa and its Neighbors in North Kona, Earle Bakken, publ., Kailua-Kona.

Kikuchi, W.K., 1973. Hawaiian Aquacultural System, Dept. of Anthropology, University of Arizona, Tucson.

Kikuchi, W.K., 1976. Prehistoric Hawaiian Fishponds. *Science,* Vol. 193 no. 4250 pp. 295–299.

Kirch, P.V., 1985. *Feathered Gods and Fishhooks: An Introduction to Hawaiian Archaeology and Prehistory*. University of Hawaii Press, Honolulu.

Kirch, P.V., 2002. *On the Road of the Winds, an Archaeological History of the Pacific Islands before European Contact*. University of California Press, Berkeley.

Kirch, P.V., 2011. *How Chiefs Became Kings: Divine kingship and the rise of archaic states in ancient Hawaiʻi*, University of California Press, Berkeley.

Kirch, P.V., 2011b. When Did the Polynesians Settle Hawaiʻi? A Review of 150 Years of Scholarly Inquiry and a Tentative Answer. *Hawaiian Archaeology*, Vol. 12 pp. 3–26.

Kirch, P.V., 2012. *A Shark Going Inland is my Chief*. University of California Press, Berkeley.

Kirch, P.V. and Jones O'Day, S., 2003. New Archaeological Insights into food and status: a case study from pre-contact Hawaii. *World Archaeology*, Vol. 34(3): 484–497.

Kirch, P.V., Mills, P.R., Lundblad, S.P., Sinton, J., Kahn, J.G., 2012. Interpolity exchange of basalt tools facilitated via elite control in Hawaiian archaic states, *Proceedings of the National Academy of Sciences (PNAS)* vol. 109 no. 4: 1056–1061.

Kolb, M., 1991. *Social Power, Chiefly Authority and Ceremonial*

Architecture in and Island Polity, Dept. of Anthropology, University of California at Los Angeles, Los Angeles.
Ladefoged, T., Graves, M.W., and Jennings, R.P. 1996. Dryland Agricultural Expansion and Intensification in Kohala Hawaiʻi Island. *Antiquity*. Vol. 70, pp. 861–880.
Lepofsky, D. and Kahn, J. 2011. Cultivating an Ecological and Social Balance: Elite Demands and Commoner Knowledge in Ancient Maʻohi Agriculture, Society Islands. *American Anthropologist*, Vol. 113, No. 2, pp. 319–335.
Lockwood, J.P., 2000. 'Cultural Geology' of the Napuʻu Area, North Kona, Hawaiʻi, Geohazards Consultants International, Inc. for The Nature Conservancy and Hui Ohana Mai Puʻu Anahulu a me Puʻu Waʻawaʻa, Volcano.
Maguire, E., 1966 (1999). *Kona Legends*, Petroglyph Press, Ltd., Hilo.
Malo, D., 1903. *Hawaiian Antiquities (Moʻolelo Hawaiʻi), 1898*, B.P. Bishop Museum Press, Honolulu.
McAllister, J. G. 1933. *Archaeology of Oahu*. Bernice P. Bishop Museum–Bulletin 104, Honolulu.
McCoy, M.D., Graves, M.W., 2010. The role of agricultural innovation on Pacific islands: a case study from Hawaiʻi, *World Archaeology* 42, 90–107.
Mills, P.R., 2002. *Hawaiʻi's Russian Adventure, A new look at old history*. University of Hawaiʻi Press, Honolulu.
Nutrition data (2012) Mullet. http://www.nutritiondata.self.com/facts/finfish-and-shellfish-products/4081/2
Polanyi, K., 1944. *The Great Transformation: the political and economic origins of our time*, Farrar and Reinhardt, New York.
Pukui, M.K., Elbert, S., 1986. *Hawaiian Dictionary, revised and enlarged ed.*, University of Hawaiʻi, Honolulu.
Sahlins, M., 1990. 'The Political Ecology of Grandeur in Hawaiʻi from 1810–1830.' In E. Ohnuki-Tierney (Ed.), *Culture through time: Anthropological Approaches* (pp. 26–56). Stanford University Press, CA.
Stokes, J.F.G., 1909. *Walled Fish Traps of Pearl Harbor*. B.P. Bishop Museum Occasional Papers Vol. 4, No. 3, Honolulu.
Stokes, J.F.G., and Dye, T., 1991. *Heiau of the Island of Hawaiʻi a historic survey of Native Hawaiian Temple Sites*, Bishop Museum Press, Honolulu.
Summers, C.C., 1964. *Hawaiian Fishponds*, B.P. Bishop Museum Special Publication 52, Honolulu.
Tomonari-Tuggle, M.J., 1996. *Bird Catchers and Bullock Hunters in the Upland Mauna Kea Forest: A Cultural Resource Overview of the Hakalau Forest National Wildlife Refuge, Island of Hawaiʻi*. International Archaeological Research Institute, inc., prepared for U.S. Fish and Wildlife Service.
Vitousek, P.M., Ladefoged, T.N., Kirch, P.V., Hartshorn, A.S., Graves, M.W., Hotchkiss, S.C., Tuljapurkar, S., and Chadwick, O.A. (2004) Soils Agriculture and Society in Precontact Hawaiʻi. *Science* v. 304 pp. 1665–1 669.
Westervelt, W.D., 1999. *Hawaiian Legends of Volcanos Collected and Translated from Hawaiian (1916)*, Mutual Publishing, Honolulu.
Wilmshurst, J.M., Hunt, T.L., Lipo, C.P., Anderson, A.J., 2011. High-precision radiocarbon dating shows recent and rapid initial human colonization of East Polynesia, *Proceedings of the National Academy of Sciences (PNAS)* 108, 1815–1820.