Archaeology in Oceania

Archaeology in Oceania, Vol. 52 (2017): 70–80
DOI: 10.1002/arco.5121

Evaluating agricultural bet-hedging strategies in the Kona Field System: New high-precision ^{230}Th/U and ^{14}C dates and plant microfossil data from Kealakekua, Hawai‘i Island

MARK D. McCOY, MARA A. MULROONEY, MARK HORROCKS, HAI CHENG and THEGN N. LADEFOGED

MDM: *Southern Methodist University;* MAM: *Bishop Museum;* MH: *Microfossil Research Ltd;* HC: *Xi'an Jiaotong University;* TNL: *University of Auckland*

ABSTRACT

The Kona Field System, located on the leeward side of Hawai'i Island, is comprised of a network of stone field walls, terraces, mounds and other agricultural, residential and religious features stretched over an estimated 163 km². Previous research indicates a construction history of the fields that could have begun as early as the Foundation Period (AD 1000–1200), followed by a shift in agricultural strategies from those that reduce variance in yield (AD 1450–1600) to a strategy of production maximisation (after AD 1600) attributed to the growing political economy. However, these propositions are based on radiocarbon dates, many of which do not meet minimal standards for acceptable sample selection. We report the results of new excavations at the Amy Greenwell Ethnobotanical Garden in Kealakekua that suggest (1) that agricultural infrastructural improvements were being made by AD 1400, and (2) that agronomic infrastructure continued to be added to optimal lands and elsewhere after AD 1700 as decisions regarding agricultural strategies became coopted by political elites. There remains a great deal about the Kona Field System that is still poorly documented through archaeology.

Keywords: agricultural strategies, risk management, bet-hedging, political economy, Hawaiian Islands, Kona Field System

RÉSUMÉ

Le système de champ Kona, situé sur le côté sous le vent de l'île de Hawaii, est composé d'un réseau de murs de terrain en pierre, des terrasses, des monticules et d'autres caractéristiques agricoles, résidentielles et religieuses tendues sur environ 163 km². Des recherches antérieures indiquent une histoire de la construction des champs qui auraient commencé dès la période de la Fondation (AD 1000–1200), suivie par un changement dans les stratégies agricoles de ceux qui réduisent la variance du rendement (AD 1450–1600) à une stratégie de production maximisation (après AD 1600) attribué à l'économie politique croissante. Cependant, ces propositions sont fondées sur des dates de radiocarbone, dont beaucoup ne répondent pas aux normes minimales pour la sélection de l'échantillon acceptable. Nous rapportons les résultats de nouvelles fouilles sur le jardin ethnobotanique Amy Greenwell à Kealakekua qui suggèrent (1) l'amélioration des infrastructures agricoles ont été réalisés par AD 1400, et (2) l'infrastructure agronomique continué à ajouter aux terres optimales et ailleurs après l'an 1700 que les décisions concernant l'agriculture stratégies se sont cooptées par les élites politiques. Il reste beaucoup de choses sur le système Kona champ qui est encore mal documentée par l'archéologie.

Mots Clés: stratégies agricoles, la gestion des risques, bet-couverture, l'économie politique, l'îles de Hawaii, le système Kona

Correspondence: Mark D. McCoy, Department of Anthropology, Southern Methodist University, Dallas, TX 75275, USA. Email: mdmccoy@smu.edu

INTRODUCTION

Concepts developed by evolutionary archaeology for explaining foraging have been brought to studies of food production through common concerns regarding strategic investment of time and effort in activities that were, ideally speaking, meant to buffer against future shortfalls, a behaviour commonly known as bet-hedging. Allen (2004) implemented bet-hedging to explain a major shift in the development of an agricultural field system in Hawai‘i

Disclosure statement: The authors have no conflicts of interest to report.

Island's Kona District. Using the best available chronological data, including her own excavations in Kealakekua (Allen 2001; see also Burtchard 1996), Allen outlined an explanation for why people invested in a network of stone field walls, terraces, mounds and other agricultural, residential and religious features stretched over an estimated 140 km^2. She suggested that natural variability in rainfall and soils created conditions that promoted an earlier strategy of investment in upland locations that were optimal for the types of root crops available and the establishment of a breadfruit tree zone. According to Allen (2004), the goal of these farmers was to minimise the risk of yield variance. Later, with the creation of royal centres along the coast, beginning with the legendary king of the island ʻUmi-a-Līloa, farmers abandoned further infrastructural investment in the optimal zone and farmed more risky, drier, areas downslope in an effort to maximise production.

In the years that have followed Allen's (2004) bet-hedging model of agricultural development in the Kona Field System (KFS), new research on other non-irrigated field systems in the Hawaiian Islands has revealed the dynamic relationship between people and their island environments (see Vitousek *et al.* 2014). Importantly for evaluating Allen's (2004) bet-hedging model, there have also been revisions in what is considered acceptable in terms of radiocarbon sample selection and methodology in Hawaiʻi (Rieth & Athens 2013). These new narrow requirements mean that the number of dates that are acceptable to build a picture of agricultural development shrinks from hundreds to less than ten (Rieth *et al.* 2011). With so few dates – and new evidence that would put the introduction of breadfruit closer to AD 1300, which is much earlier than previously estimated at AD 1500 (McCoy *et al.* 2010) – we felt it was time to revisit the underlying chronological evidence for the KFS and what it means for bet-hedging risk minimisation and production maximisation.

In the following, we report on new AMS radiocarbon dates on short-lived material excavated from the KFS and the first high-precision ^{230}Th/U dates on coral left as garden offerings in the Hawaiian Islands. With the aid of new palaeoethnobotanical evidence for a diverse set of economic plants – including sweet potato, taro, breadfruit, coconut, candlenut, paper mulberry and ti – we describe the chronology of agronomic infrastructure in an optimal zone for farming in Kealakekua. We suggest that the chronology of agricultural development in the KFS is in need of revision, with the onset of gardening in the ideal upland areas by calAD 1400, with a lag of 100–200 years between the onset of gardening in the optimal and riskier areas. Also counter to the previous chronology, we see evidence for continued intensification within the optimal gardening zone, and other areas, after AD 1700, postdating the establishment of royal centres. This is not to say that notions of bet-hedging risk minimisation and production maximisation are not valuable. In this revised chronology, we would suggest that early efforts to increase production beyond the household level were a type of a bet-hedging strategy, and that what we see in the later period is an extension of that trend, but with demands and decision-making reorientated from the household level to the political elite.

BET-HEDGING, AGRICULTURE AND ARCHAEOLOGY

One contribution of evolutionary theory to archaeological interpretation has been to formalise variables crucial to investigating human subsistence – such as risk and optimality – with much of the focus on the transition to food production and the development of social inequalities (see Mattison *et al.* 2016). In Hawaiʻi, there have been a number of attempts to expand these approaches to explain the historical trajectory of agricultural development (Allen 2004; Ladefoged & Graves 2000, 2008; McElroy 2007), often with a consideration of the political economy (Earle & Spriggs 2015). These studies suggest that it is impossible to divorce ancient farming from the creation of the broader political economy due to the overwhelming archaeological and ethnohistorical evidence linking the development of the subsistence and prestige economies in Hawaiʻi (Earle 1978, 1997, 2002; Kirch 1977, 1984; McCoy 2005, 2006; McCoy & Graves 2010, 2012).

Consideration of the political economy complicates the notion of bet-hedging, which is defined as "a strategy that reduces the temporal variance in fitness at the expense of a lowered arithmetic mean fitness" (Ripa *et al.* 2009). Bet-hedging is often invoked when alternative strategies that either minimised variance or maximised benefits are considered in selective contexts (Allen 2004: 206). Allen (2004) and others (e.g. Madsen *et al.* 1999) note that bet-hedging and a reduction in temporal variance in subsistence returns can be achieved in some contexts by enhancing spatial diversity in resource production, a process that can enhance long-term fitness with short-term energetic costs. Spatial diversification of crops is but one means of reducing yield variance, with crop diversification through multi-cropping strategies and crop rotations, and temporal diversification through scheduling and food storage, being important in some contexts (Marston 2011). Reducing temporal variation in fitness can also be achieved via surplus production, again a strategy that might have long-term benefits but that incurs short-term costs for some in terms of energy expenditure. By boosting production beyond the starvation threshold, the chance of production falling below that threshold, even in the worst years, is reduced (Marston 2011). This overproduction and surplus generation can be achieved through intensification within fixed areas of land, or through expansion into new previously unused zones.

In the absence of strong top-down authority, food production was often organised and controlled at the family level within the domestic mode of production (Earle 2015; Field *et al.* 2010; Morehart & De Lucia 2015; Sahlins

1972). In this mode, surplus generation was generally low, with energy expenditure or costs to individuals also being relatively low. In contrast, when non-producer authorities gained effective top-down control, surplus generation would have increased at the expense of the labour of the farmers. During the shift from the domestic mode of production to a highly controlled political economy, surplus production shifts from low levels of overproduction to higher, and in some cases, even maximal levels. Surplus generation reduces the chances of production falling below minimal subsistence levels, thereby acting as a strategy that reduces the temporal variance in fitness. It is the recognition that spatial diversification of crops and surplus production have implications for long-term fitness that calls for a refinement of the application of bet-hedging in Kona.

THE KONA DISTRICT, HAWAIʻI ISLAND

The Kona District is a ~2000 km^2 ancient political unit on the leeward side of Hawaiʻi Island. The area lacks permanent streams due to porous soils. Rainfall is strongly orographic, based on diurnal temperature fluctuations with an inversion at higher elevations (increasing from ~750 mm per year along the coast to 2000 mm per year at an elevation of ~950 m, with decreases further upslope). There has been considerable volcanic activity in the area, with overlapping lava flows (Trusdell *et al.* 2006), some as recent as 65 years ago (Lockwood 1995).

ʻUmi-a-Līloa, the first king of Hawaiʻi Island, came to power around AD 1570–1590, when he broke with tradition and moved the island's political centre from the rich windward valley of Waipio to the leeward coast of Kona (Kamakau 1961: 34; Kirch 2010: 168). In the next two centuries, between AD 1600 and the arrival of Captain Cook in AD 1779, six royal centres were built along a 30 km stretch of the Kona coast (Kailua, Kahaluʻu, Keauhou, Hōlualoa, Kealakekua and Hōnaunau) (Cordy 2000). These centres were occupied by elites and typically included royal compounds (or palaces; e.g. Flannery 1998), temples (*heiau*), massive stone walls to delineate ritually important areas (*puʻuhonua*), sledding tracks (*holua*), compounds for priests, grounds for training and sports, fishponds and mausoleums, all surrounded by a dense population to support the court.

The royal centres of Kona were provisioned by a highly productive rainfed upland agricultural zone roughly 35 km long and up to 7 km wide (Kelly 1983; Schilt 1984; Soehren & Newman 1968). This upland zone, called by archaeologists the KFS (State Site Number 50-10-37-6601), probably began with shifting cultivation that was transformed to formal fixed fields marked by massive stone field walls called *kuaiwi*. More than clearing features, these walls were gardening infrastructure; infrastructure that probably originated within the domestic mode of production and was later coopted, developed and controlled by elites (Allen 2004; for a discussion of this process in the Leeward Kohala Field System, see Field *et al.* 2010).

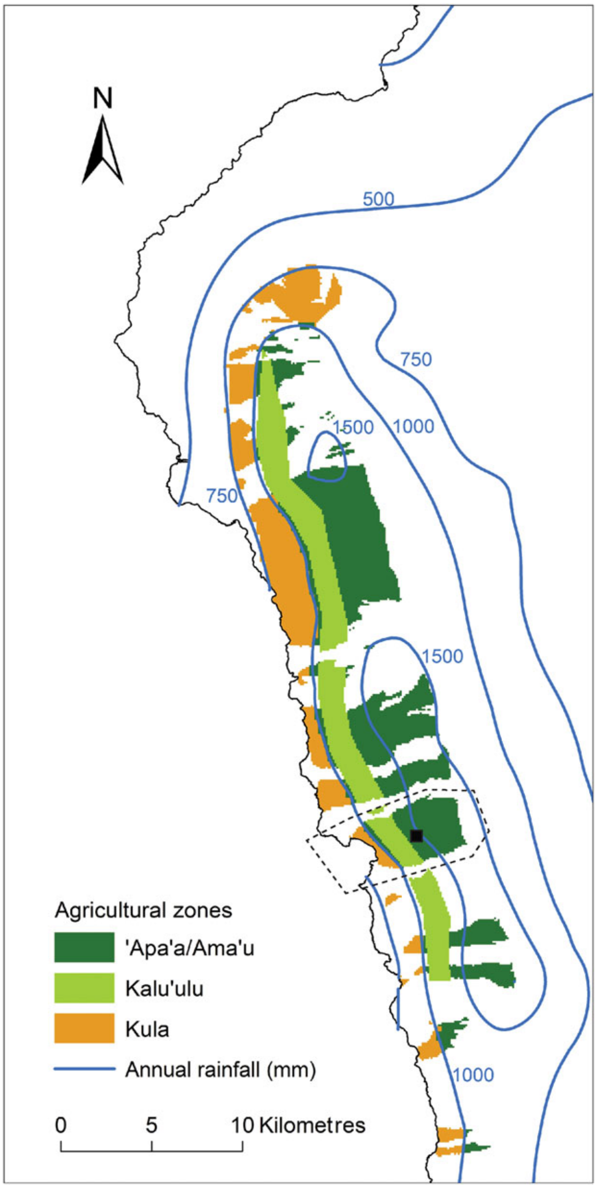
Estimates for the total area of the upland KFS vary, with Ladefoged *et al.* (2009) suggesting that discontinuous zones of non-irrigated fields had a total area of 147 km^2. In that study, the intersection of several environmental variables (rainfall, elevation, the age of the geological substrate and soil nutrient levels) were used to define the maximum likely extent of intensified farming. New rainfall data (Giambelluca *et al.* 2013) have been incorporated into the model (Figure S1), as have parameters for breadfruit production (Lincoln & Ladefoged 2014), and a revised estimate for the total extent of the discontinuous zones of non-irrigated fields and breadfruit production is 163 km^2 (Figure 1). The projected upper/eastern edge of the KFS bordered forest and was defined by high elevation, where low temperatures would have constrained production. The downslope western boundary reached the sea, or near the coast, in places, and was defined by the 750 mm rainfall isohyet, the minimum amount of rainfall necessary for intensified crop production. In the GIS model, areas within those boundaries on substrates older than 500 years could sustain breadfruit production, with substrates less than 4000 years deemed unsuitable for intensive agriculture due to inadequate soil development on these relatively young geological substrates.

Ethnohistorical sources record three zones of production within the modelled areas of intensive cultivation, with a fourth zone of forest resources above them (Figure 1) (Kelly 1983; Lincoln & Ladefoged 2014; Lincoln *et al.* 2014). The ethnohistorically defined zone closest to the shoreline was the *kula*, extending from the coast to approximately 150 masl elevation, and included an area where small household gardens and agricultural plots were maintained. Going upslope, the kaluʻ*ulu* was a 0.8–1.5 km wide agroforestry zone between ~150 and 300 m elevation, with breadfruit (*Artocarpus artilis* (*ʻulu*)) production and understorey sweet potato (*Ipomea batatas* ('*uala*)) and banana (*Musa spp* (*mai*ʻ*a*) cultivation associated with walls and cleared fields. The *apaʻa* is thought to have extended to an elevation of ~600 m (Lincoln & Ladefoged 2014: 195), although it seems likely to have extended even further upslope, and was probably the most intensively gardened zone of the KFS, planted in the full suite of dryland crops (sweet potato, taro (*Colocasia esculenta* (*kalo*), banana, *Cordyline fruticosa* (*kī*) and sugar cane (*Saccharum officinarum* (*kō*)). The ʻ*amau*, an agroforestry zone above the *apaʻa* fields extended to an elevation of ~900 m, and was based on understorey crops of banana and yam (*Dioscorea alata* (*uhi*)) under native canopy.

THE KEALAKEKUA SECTION OF THE KONA FIELD SYSTEM

There is no doubt that the KFS was in intensive production at the time of European contact (see sources in Kelly 1983). The question of its chronology, however, is a topic of debate. While the first written accounts of intensive gardening in Kealakekua go back to the 1779 visit of the

Figure 1. Gardening zones, KFS, Kealakekua. In this conservative model based on Ladefoged *et al.* (2009) and Lincoln and Ladefoged (2014), areas suitable for intensive agriculture are only on soils greater than or equal to 4 kya, with breadfruit production occurring on soils greater than 500 years. These production areas are classified by emic garden zones. The location of the Amy Greenwell Ethnobotanical Garden (AGEG) (square) is interpreted as being just above the *kalu'ulu* breadfruit zone and within the preferred '*apa'a* garden zone.



British Captain Cook (Kelly 1983), the KFS first came to the attention of archaeologists when rows of parallel coast-to-upland walls were noted in aerial surveys in the 1960s (Newman 1970). Archaeological excavations by Schilt (1984) in Kona yielded a broad date range for the KFS through the proxy evidence of dated habitation sites. In 1978, Kirch and Yen cleared and mapped the *kuaiwi* in the Amy Greenwell Ethnobotanical Gardens (AGEG), located in rich soils for farming (flow c.5 kya), after the land was bequeathed to the Bishop Museum (Kirch 2001). This was followed by a major excavation project directed by the Bishop Museum in 1996. The results of that project became the best single volume on the archaeology of the Kona Fields, entitled *Gardens of Lono* (Allen 2001). In that volume, and a later publication (Allen 2004), a new, more detailed, chronology of the field system was outlined.

Allen (2004) notes that two contrastive agricultural strategies were practiced in the KFS, one focused on variance minimisation associated with risk management, and the other focused on production maximisation. She proposed a temporal trend in these strategies, with a shift from variance minimisation to production maximisation. Agricultural activities focused on variance minimisation ameliorated environmental perturbations via the construction of infrastructural improvements and the diversification of crops. Allen (2004) suggested that agricultural terraces stabilised slopes, increased soil depth and retained moisture, whereas *kuaiwi* and mounds were planting features that facilitated rainfall penetration, reduced evapotranspiration and maintained soil warmth. Crop diversification was achieved through the establishment of the agroforestry *kalu'ulu* breadfruit zone. Allen (2004: 216) notes that this zone was probably established to utilise a niche unsuitable for other cultigens, and "… may have been a conscious attempt to diversify the local crop inventory … [and create] forage for pigs … a kind of 'storage device' … for protein". These variance minimisation strategies enhanced fitness in two ways (Allen 2004: 206-7): first, by reducing temporal variation associated with environmental perturbations; and, second, by directing energy away from "… primary activities of food production … with the result that fecundity is lowered and populations are stabilised at smaller sizes". The alternative agricultural strategy of production maximisation was achieved through shortened fallows and nutritional additives in the environmentally optimal *apa'a* zone, with expansion into and intensive cultivation of the more marginal lowland *kula* zone. Allen (2004: 207) acknowledged that production maximisation could generate surpluses that could be stored, exchanged and used to fund activities such as the construction of monumental architecture.

The distinction between variance minimisation and production maximisation was one of focus, with both strategies potentially being used at any one time, or sequentially. According to Allen (2004: 207), "It is the relative balance of these [strategies] over time, and the nature of the selective environment, that has implications for fitness." Having acknowledged the possible coexistence of both strategies, Allen did propose that there was a major shift in strategies within the KFS. She suggested that there was an early emphasis on variance minimisation via infrastructural improvements in the *apa'a* zone and the establishment of the *kalu'ulu* breadfruit zone, with a transition to production maximisation after AD 1600. Allen (2004: 219) noted:

> After 1600 AD, there are no further capital improvements indicated at Greenwell Garden [in the apa'a zone] and possibly an attenuation of the fallow cycle. At the same time, intensive use of the more marginal lowland areas (e.g., the Kula zone) becomes widespread in the district as a whole … Presumably it was sometime after this when systematic use of the most marginal agronomic environments, the barren lava flows, was initiated.

A detailed study of the KFS in Kealakekua undertaken by Tomonari-Tuggle (2003, 2006) challenges this chronology. Based on excavations in a portion of the KFS immediately downslope (*makai*) of the AGEG, Tomonari-Tuggle (2006: iii) suggests a "refined framework for understanding traditional Hawaiian occupation in the region". The chronological sequence of features excavated by Tomonari-Tuggle (2006) represents the first based on radiocarbon dates on charcoal identified as short-lived taxa. Since the study area is in what Tomonari-Tuggle argues was a prime location, and none of the radiocarbon evidence predates AD 1470, the excavation report suggests that much of the KFS developed later than previously thought. Tomonari-Tuggle further suggests some key developments dated to after AD 1750; only a few decades before Cook's arrival. In two recent syntheses of Hawai'i Island archaeology (Bayman & Dye 2013; Rieth *et al.* 2011), these new dates have been taken as the only reliable radiocarbon-based chronology for the KFS. In contrast to Tomonari-Tuggle's (2006) findings, recent work at Hōnaunau indicates that the accumulation of deposits associated with earliest occupation dates to AD 1288–1405 (2σ; Athens *et al.* 2007), with other cultural deposits bracketed to the period after AD 1650 (Rieth 2010, 2011).

Today, we have three competing estimates for the earliest gardening in Kealakekua: (1) between AD 1000 and 1300 (e.g. Allen 2001, 2004); (2) between AD 1300 and 1470 (e.g. Athens *et al.* 2007); and (3) after AD 1470 (e.g. Tomonari-Tuggle 2006) (Figure S2). The first scenario is within current best estimates for the colonisation of the Hawaiian Islands (Kirch 2011), but is only supported by a single radiocarbon date on unidentified charcoal. The second is based on proxy evidence for upland gardening in Kealakekua in neighbouring Kaloko Pond (postdating AD 1288, rounded to AD 1300) and nine dates on unidentified charcoal in Kealakekua with early age ranges that predate AD 1470, and later age ranges that predate AD 1650. The third scenario puts the onset of gardening no earlier than the earliest time range in the current small pool of dates on short-lived taxa in Kealakekua.

EXCAVATIONS IN THE AMY GREENWELL ETHNOBOTANICAL GARDENS, KEALAKEKUA, KONA

We conducted limited excavations within the AGEG to determine the timing of agricultural development in the area and the significance of these for bet-hedging strategies. The AGEG is home to a series of upland-to-coast orientated field walls, or *kuaiwi*, that are the defining characteristic of the KFS (for a fuller formal description of *kuaiwi*, see the Online Supplemental Material). Allen's (2001; 2004) previous investigations in the AGEG yielded a remarkably early radiocarbon date (AD 1000–1200), but this date has been regarded as unreliable in recent evaluations of the chronology of Hawai'i Island (Rieth *et al.* 2011). One goal of our fieldwork was to recover two types of material useful for good-quality radiometric dates relevant for archaeology: short-lived charcoal for radiocarbon dating and branch coral for ^{230}Th/U dating. Branch coral is a relatively common material found as ritual offerings at sites across the Hawaiian Islands, but has been rarely been documented in the context of gardens (see Schilt 1984).

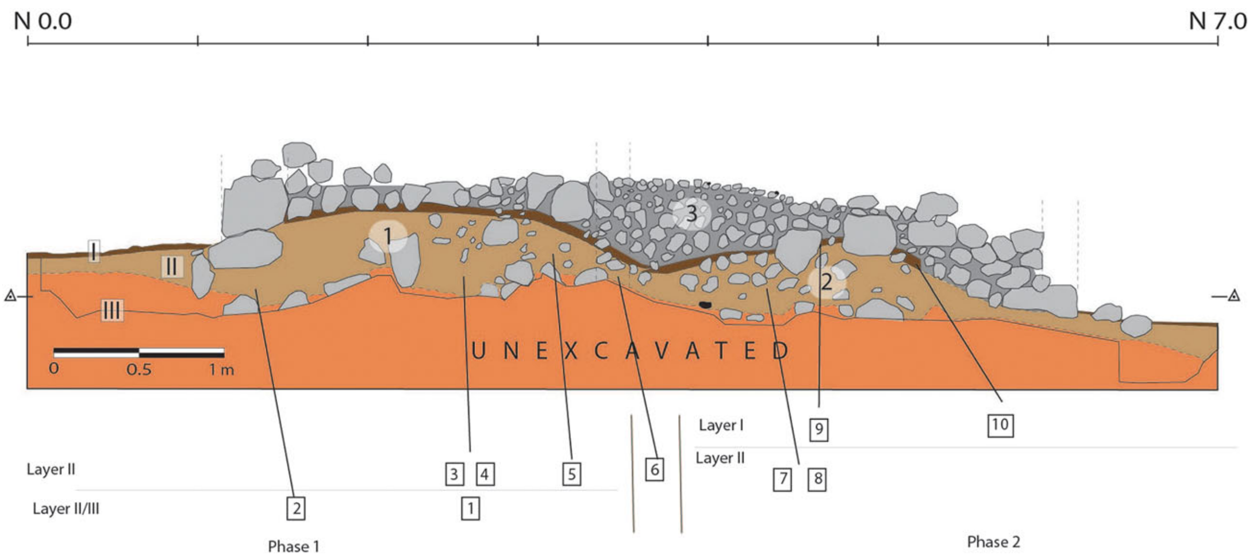
We excavated a 7 × 1 m trench (referred to as Trench #1 in the field notes) across a well-preserved section of Kuaiwi I (also known as Feature 41; Allen 2001). This section is located near the location of the earliest date reported from previous excavations (Kuaiwi I, TU 18; Allen 2001), and at roughly the same elevation where the full stratigraphic sequence of a *kuaiwi* had been previously exposed and described in excavations in 1996 (ST 8; Allen 2001). This *kuaiwi* is notable for its thickness and the presence of small irregular terracing on its surface (Figure S3).

The relative position of deposits and stone allowed us to define three phases of *kuaiwi* construction (Figure 2). Specifically, the relative difference in elevation between the two sides of a buried alignment (Figure S6) suggests that the southern half belongs to the earliest phase of gardening, called Phase 1. During this first phase, the feature was a low, linear mound orientated upland-to-downslope. The northern half of the trench shows a repetition of this same pattern later in time, and slightly lower, abutting the middle alignment. If stones found within sediments were worked in over time (Figure S5), then there is reason to believe that there would have been some stone mulching throughout the use of the *kuaiwi*. The cap of stone that is visible today was interpreted as the final construction phase, called Phase 3.

PALAEOETHNOBOTANICAL RESULTS: PLANT MICROFOSSIL AND CHARCOAL ANALYSES

A total of 16 sediment samples from the excavations at the AGEG were analysed for pollen, phytoliths and starch to provide a record of past vegetation, environments and human activity (Table S4). Unburned examples of candlenut and coconut shells were also recovered that we presume represent relatively recent, and possibly post-garden abandonment, material that has accumulated in Layer I. Charcoal was collected *in situ*, through screening, flotation (~75 litres of sediment), and micro-charcoal noted during specialised plant microfossil analyses. Short-lived taxa and/or parts of plants were selected for radiocarbon dating, including one example of an introduced economic plant, the paper mulberry (cf. *Broussonetia*). For a full

Figure 2. A cross-section of Kuaiwi I, showing construction Phases 1–3 superimposed on the west profile of Trench #1. Phase 1 of the feature probably resembled the soil-and-stone field walls found throughout the Kohala Field System, but orientated in an upslope–downslope direction. Phase 2 is a second linear mound of soil-and-stone constructed parallel to Phase 1. While the incorporation of stone throughout gardened soils suggests that there was always some amount of lithic mulching over these features, the final stone fill on top of Phases 1 and 2 is given its own designation (Phase 3). Locations of individual samples (1–10, outlined in squares) are shown on the profile and below on a schematic representation of the relationship between Layers I, II and III and Phases 1 and 2. Layer III is interpreted as ungardened natural soil, Layer II as gardened soils and Layer I as post-abandonment deposition.



description of laboratory methods and detailed results, see the Online Supplemental Material.

Compared with a previous study of fossil pollen, phytoliths and starch from south of the study area (Horrocks & Rechtman 2009) and a previous study within the AGEG (Ward 2001), the diversity of economic plants recovered during our analysis was much higher. In addition to the paper mulberry charcoal, microfossil evidence of five other economic plants (sweet potato, taro, breadfruit, coconut and ti) was identified in sediment samples. In contrast, Horrocks and Rechtman (2009) reported only three economic plants (sweet potato, banana and *Pandanus tectorius*) in 12 sediment samples that spanned the expected elevation range of the *kula* ($n = 6$ samples) and *kalu'ulu* zones, although we note that the fields in their study area were outside Lincoln and Ladefoged's (2014) GIS model for the geographical extent of the breadfruit zone. They report a remarkably high recovery rate: a 100% recovery rate for sweet potato in both zones and a 50–66% recovery rate for banana. In our 2015 AGEG samples, the recovery rates for some taxa were also high, especially for sweet potato, which ranged from 75% to 80% for sediment samples from fields between *kuaiwi* and sediments within the first phase of *kuaiwi* construction (Phase 1), thus underlining the ubiquity of the crop across the KFS. Preserved examples of economic plants were less common for sediments from the second phase of *kuaiwi* construction (Phase 2); this is consistent with these deposits having been farmed for a relatively shorter total duration than either the fields or previously constructed *kuaiwi* deposits.

CHRONOMETRIC RESULTS: ^{230}TH/U AND ^{14}C DATES

Charcoal from short-lived plants recovered in our excavations was submitted for ^{14}C radiocarbon dating (Table 1 and Table S1). The earliest of the nine new AMS radiocarbon dates is remarkably early – calAD 780–1024 (2σ, Beta-420388, RC-07) – and predates the previous earliest reported dates from the AGEG. We cannot say for certain that this is from anthropogenic burning; a natural source from local volcanic activity seems more likely.

The beginning of continuous evidence for burning is the earliest dated sample in Phase 1 deposits, calAD 1421–1499 (2σ, Beta-420384, RC-02); a result that has its highest probably range around calAD 1450 (90.5% of probability in calAD 1430–1485). This immediately predates the first unambiguous material signals of gardening here, a direct radiocarbon date of calAD 1485–1650 (2σ) on the human-introduced crop plant, paper mulberry (cf. *Broussonetia* sp.) (Beta-420387, RC-06); its highest probability is in calAD 1500–1600. Two branch coral fragments dated by ^{230}Th/U produced dates of AD 1517–1547 (2σ) and AD 1537–1559 (2σ). For a full description of the laboratory methods and detailed results, see the Online Supplemental Material. If these corals were deposited as offerings in gardens, they are strong independent confirmation that the fields were in active use from calAD 1550.

The most recent date from Phase 1 deposits (AD 1646–1950, Beta-420385, RC-04) and the earliest date

Table 1. New ^{14}C dates from AGEG excavations, Kuaiwi I, Trench #1. The earliest date (RC-07) is probably from natural fires before farming. The next series of dates from Phase 1 deposits include wood charcoal accumulated from no earlier than AD 1400 (RC-02), including the earliest direct date from a crop plan no earlier than AD 1500 (RC-06). Phase 1 gardens continued to be used through contact in AD 1779 (RC-03, -04, -05). The last set of dates on material found within and above the Phase 2 deposit suggest that the accumulation of charcoal from human activity began after AD 1700. The locations of short-lived taxa (RC-1 to -10) and Phases 1–3 are shown in Figure 2.

Sample	**Depositional context**	**Beta-**	**CRA**	**2σ calibration**	**Taxa**
RC-07	Probable pre-agriculture volcanic activity; found in Phase 2 deposits	420388	1090 ± 40 BP	CalAD 885–1020 (1065–930 calBP)	Small prickle
RC-02	First of continuous radiocarbon dates on short-lived taxa; found in Phase 1 deposits	420384	430 ± 30 BP	CalAD 1430–1485 (520–465 calBP)	Very small twig
RC-06	First directly dated Polynesian imported crop plant; found in deposit between Phases 1 and 2	420387	310 ± 30 BP	CalAD 1485–1650 (465–300 calBP)	Cf. *Broussonetia* (paper mulberry)
RC-03	Found within Phase 1 deposits	420163	240 ± 30 BP	CalAD 1640–1670 (310–280 calBP), calAD 1780–1800 (170–150 calBP) and calAD 1940 to post-1950 (10 to post 0 calBP)	\A *kukui* nutshell
RC-04	Found within Phase 1 deposits	420385	210 ± 30 BP	CalAD 1645–1685 (305–265 calBP), calAD 1735–1805 (215–145 calBP) and calAD 1930 to post-1950 (20 to post 0 calBP)	A *kukui* nutshell
RC-05	Found within Phase 1 deposits	420386	110 ± 30 BP	CalAD 1680–1765 (270–185 calBP), calAD 1800–1940 (150–10 calBP) and post AD 1950 (post 0 BP)	*Coprosma* (shrub/small tree)
RC-08	Found within Phase 2 deposits	420389	40 ± 30 BP	CalAD 1710–1720 (240–230 calBP), calAD 1825–1830 (125–120 calBP), calAD 1890–1910 (60–40 calBP) and post AD 1950 (post 0 BP)	Small-diameter twig
RC-09	Probable post-abandonment activity; found in deposits overlaying Phase 2	420390	107.5 ± 0.3 pMC	–	Coconut shell
RC-10	Probable post-abandonment activity; found in deposits overlaying Phase 2	420391	104.1 ± 0.3 pMC	–	Coconut shell

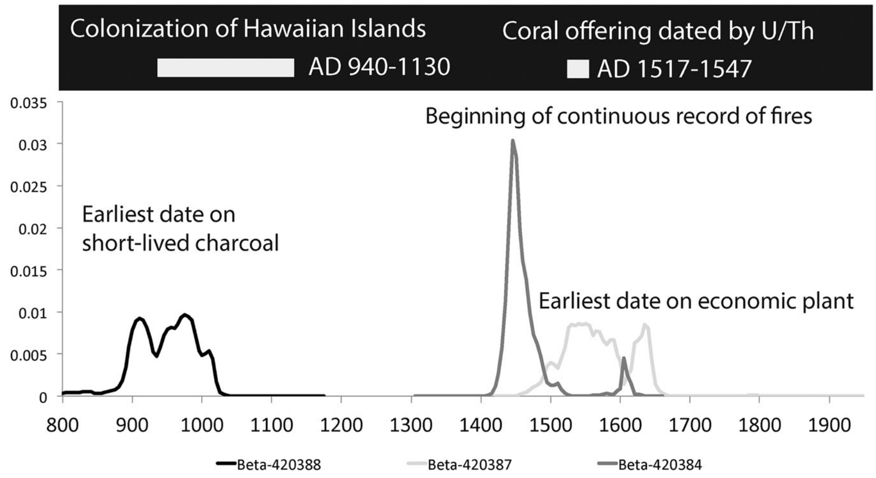
from Phase 2 deposits (AD 1695–1950, Beta-420389, RC-08) indicate that the full width of the *kuaiwi* was in use as a garden after calAD 1700. The other samples from Phase 2 deposits returned % modern (RC-09, RC-10) or were discovered by the laboratory to have been unburned (RC-01). Based on this evidence, we place the construction of the second phase after AD 1700.

The documentation of two phases of stone-and-sediment deposits below the stone fill that we see on the modern-day surface of *kuaiwi* is similar to previous excavations aimed at exposing the stratigraphy of *kuaiwi* in the AGEG (Kuaiwi IV, Allen 2001). Stratigraphic Trench 8 (ST 8) – a trench across Kuaiwi IV – looks similar to the west profile of Trench #1 (Kuaiwi I). Both have middle stone alignments that rest on ungardened soils. Major and Allen (2001: 24) note that deposition of sediment and stone above grade occurred at different times on either side of the central alignment:

> … the northern edge of the kuaiwi (ca 1–2 m from the north end of ST-8) has a greater proportion of large rocks than the rest of the feature. Although differentiation of construction episodes in piled stone architecture such as this cannot be accomplished with certainty, the absence of size sorting in the stones on the northern part could indicate an event that is distinct from the sequence evident in the southern 3 m of the trench.

Taken together, it appears that this section of the KFS went through an initial stage of raised field (above grade) sediment-and-stone field wall construction followed by expansion of raised gardens in parallel with the original field wall. A final stone capping of small terraces and other

Figure 3. A simplified chronology for evidence for early farming in the AGEG. The three ^{14}C dates are all reported for the first time in this study. The earliest is probably local volcanic activity. The second marks the beginning of continuous evidence of burning and is a good proxy for intensive gardening in the AGEG. The third date is currently the earliest direct date on charcoal from an economic plant. Also shown is the earlier of two ^{230}Th/U dates on coral left as an offering in the gardens.



planting features was then built over the top of the first two stages to create the wall's current form.

DISCUSSION

Our results suggest that a revision to the chronology of agricultural development in Kona is necessary; but not the one envisioned by recent syntheses (e.g. Bayman & Dye 2013; Hommon 2014; Rieth *et al.* 2011). In the absence of other independent evidence indicating otherwise, we view the radiocarbon dates in the AGEG that fall between the colonisation of the Hawaiian Islands around AD 1000 and signs of farming after AD 1400 as resulting from volcanic activity (Figure 3). It would be easier to attribute these dates to natural rather than human-induced fires if the charcoal recovered from AGEG sediments had yielded dates from across thousands of years of volcanic activity in the local area. This, however, is not the case. Charcoal from the AGEG has only returned dates from after the period of human colonisation. The association between the early dates from the AGEG and specific volcanic activity is problematic, as the published dates for individual volcanic flows are reported as single summary dates of averaged BP with an averaged error, and this makes them impossible to calibrate to calAD (Lockwood 1995; contra Athens *et al.* 2014b). Deposits associated with the earliest coastal occupation at Hōnaunau in the late calAD 1300s or early calAD 1400s probably coincide with the beginning of farming in upland Kona (Athens *et al.* 2007: iii; see also Athens *et al.* 2014b: 11). It is worth noting that even if these early dates from the AGEG represent occasional clearing and not just natural volcanic activity, the material record indicates that farmers avoided extensive non-irrigated farming in Kealakekua for between 200 and 400 years; that is, until sometime after AD 1400.

In Allen's (2004) publication, she proposed that early agricultural development in the KFS was associated with a variance minimisation strategy. She suggested that this was achieved by constructing infrastructural improvements (terraces, *kuaiwi* and mounds) in the optimal *apa'a* agricultural zone to ameliorate environmental perturbations, and by establishing the *kalu'ulu* breadfruit zone for crop diversification. Radiocarbon dates from recent research (see Table S2) and our excavations on short-lived taxa, and the high-precision uranium series dates on coral offerings, force us to question this restricted use of the landscape. These data suggest that early farmers were not restricting their activities to these two zones; rather, they were also utilising the *kula* zone before AD 1600. Table S2 shows all radiocarbon dates from Kealakekua. Focusing only on short-lived taxa, the samples represent the earliest signals of activity in Kealakekua's three emic zones (*apa'a*, $n = 6$ dates; *kalu'ulu*, $n = 8$ dates, and *kula*, $n = 2$ dates). The dates indicate a slightly earlier use of the *apa'a* zone in AD 1400–1500, closely followed by the use of the lower zones in AD 1500–1650. We note that the only identified charcoal comes from fire pits in Kealakekua's *kula* zone – a weak correlate for agricultural activity – so it may be possible to further tease apart this absolute chronology of expansion into the lower and drier portions of the area.

The window of time during which people restricted their activities to the optimal *apa'a* zone, if that was indeed the case, appears to have been limited, and by calAD 1500–1650 agricultural activities were taking place throughout the *apa'a*, *kahu'ula* and *kula* zones. According to Allen (2004) this spatial dispersion into more marginal environmental zones was a form of production maximisation, a strategy that she suggested only took place after AD 1600. We suggest that this expansion may well have increased production, but at the same time was a form of minimising variation. The lower diversity of crops necessary when farming outside the optimal *apa'a* zone – a fact well attested to in ethnohistory, and underlined in the palaeoethnobotanical evidence – included mainly low-labour input tree crops. Thus, while increasing-production-as-bet-hedging was under way before the first of the royal centres were built along Kona's coast, production was still short of the type of push for surplus that occurred when farmers worked the land beyond the domestic mode of production. Clearly, this is proposition that needs a great deal more attention to resolve, especially since Kona's royal centres have been held as a case study of how state formation can occur in the absence of urbanisation (Jennings & Earle 2016).

On the basis of Allen's (2004) earlier excavations in the AGEG, she also suggested that there were no further infrastructural improvements in the *apa'a* zone after AD 1600, with maximisation of production taking place via the development of the *kula* zone. Our recent excavations in the AGEG do not support this proposition. We documented infrastructural modifications during the second phase of development at Kuaiwi I in the AGEG dated to after AD 1700. While this excavation at a single *kuaiwi* in the vast KFS provides only a limited sample of agricultural development, we would suggest that it does represent further intensification after royal centres were being established along the coast (Kamakau 1961: 34; Kirch 2010: 168). Undoubtedly, the surpluses generated by enhancing, if not maximising, production in the *apa'a* and other zones of the KFS were important means of funding the construction of those centres. We suggest that the late developments documented in the *apa'a*, *kalu'ulu* and *kula* sections of Kealakekua represent the power of the political elite to dictate coordinated changes across the fields. We agree with Tomonari-Tuggle's (2006) suggestion that there were a great deal of later additions to the KFS, and interpret these changes as evidence of a change in the level of decision making and the geographical scale of decisions, in an effort to intensify production. This production of agricultural surpluses funded elite associated activities, but also helped reduce the impact of yield variance by boosting production well beyond starvation thresholds.

CONCLUSIONS

We have reviewed the current body of evidence for the chronology of the KFS and report the results of new excavations at the AGEG in Kealakekua in the heart of the KFS on Hawai'i Island. We suggest that infrastructural improvements were made within the KFS by calAD 1400 with evidence for use of all environmental zones by calAD 1500–1600; possibly immediately prior to when the first royal centres were established. Investment in infrastructure and spatial diversification would have been one means to enhance and ensure production within the patchy and temporally variable Kona environment. Agronomic infrastructure continued to be added to the optimal *apa'a* zone after calAD 1700, and to other sections of the fields, well after the establishment of coastal royal centres, as management and decisions regarding agricultural strategies became coopted by political elites. There remains a great deal that is still poorly documented through archaeology, including the period before AD 1400, the history of the region's extensive breadfruit orchards and farming in the post-European contact period.

ACKNOWLEDGEMENTS

This research was carried out with permission and support from the Bernice P. Bishop Museum and funded in part by the Dean's Research Fund, Southern Methodist University and the Faculty Research Development Fund at the University of Auckland. Melinda Allen has been extremely generous, gracious and insightful in helping us interpret our data, and we are most thankful. We offer special thanks to the dedicated staff of the Amy Greenwell Ethnobotanical Garden, and the following individuals: Bobby Camara, Christina Carolus, Oliver Chadwick, Rob Hommon, Ann Horsburgh, Jen Huebert, Patrick Kirch, Natalie Kurashima, Noa Lincoln, Owen O'Leary, Sarina Pearson, Damion Sailors, Hannah Springer, Kelli Soileau, Ryan Terry, Peter Van Dyke, Peter Vitousek and Charmaine Wong.

REFERENCES

Allen, M.S. (ed.) 2001. *Gardens of Lono: Archaeological Investigations at the Amy B.H. Greenwell Ethnobotanical Garden, Kealakekua, Hawai'i*. Bishop Museum Press, Honolulu, HI.

Allen, M.S. 2004. Bet-hedging strategies, agricultural change, and unpredictable environments: Historical development of dryland agriculture in Kona, Hawaii. *Journal of Anthropological Archaeology* 23 (2): 196–224.

Athens, J.S., Ward, J.V. and Blinn, D.W. 2007. *Paleoenvironment of Pu'uhonua o Hōnaunau National Historical Park, South Kona, Hawai'i Island*. Report prepared for the National Park Service by International Archaeological Research Institute, Inc., Honolulu. Report on file with Hawaii State Historic Preservation Office, Department of Land and Natural Resources, Kapolei.

Athens, J.S., Rieth, T.M. and Dye, T.S. 2014a. A paleoenvironmental and archaeological model-based age estimate for the colonization of Hawai'i. *American Antiquity* 79: 144–155.

Athens, J.S., Ward, J.V. and Blinn, D.W. 2014b. *Fishpond Cores of Pu'uhonua o Hōnaunau National Historical Park, South Kona, Hawai'i Island*. Report prepared for the National Park Service by International Archaeological Research Institute, Inc., Honolulu. Report on file with Hawaii State Historic Preservation Office, Department of Land and Natural Resources, Kapolei.

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

Burtchard, G.C. 1996. *Population and Land-Use on the Keauhou Coast, the Mauka Land Inventory Survey, Keauhou, North Kona, Hawaii Island. Part I: Narrative*. Report prepared for Kamehameha Investment Corporation, Kailua-Kona by International Archaeological Research Institute, Inc.,

Honolulu. Report on file with Hawaii State Historic Preservation Office, Department of Land and Natural Resources, Kapolei.
Cordy, R.H. 2000. *Exalted Sits the Chief: The Ancient History of Hawai'i Island*. Mutual Publishing, Honolulu, HI.
Earle, T. 1978. *Economic and Social Organization of a Complex Chiefdom: The Halelea District, Kaua'i, Hawaii*. Museum of Anthropology, University of Michigan, Ann Arbor, MI.
Earle, T. 1997. *How Chiefs Come to Power*. Stanford University Press, Stanford, CA.
Earle, T. 2002. *Bronze Age Economics: The Beginning of Political Economies*. Westview Press, Boulder, CO.
Earle, T. 2015. Conclusions: Surplus and the political economy in prehistory. In C.T. Morehart and K. De Lucia (eds), *Surplus: The Politics of Production and the Strategies of Everyday Life*, pp. 307–325. University Press of Colorado, Boulder, CO.
Earle, T. and Spriggs, M. 2015. Political economy in prehistory: A Marxist approach to Pacific sequences. *Current Anthropology* 56 (4): 515–544.
Field, J.S., Kirch, P.V., Kawelu, K. and Ladefoged, T.N. 2010. Households and hierarchy: Domestic modes of production in leeward Kohala, Hawai'i Island. *Journal of Island and Coastal Archaeology* 5: 52–85.
Flannery, K.V. 1998. The ground plans of Archaic States. In G.M. Feinman and J. Marcus (eds), *Archaic States*, pp. 15–57. School of American Research, Santa Fe, NM.
Giambelluca, T.W., Chen, Q., Frazier, A.G., Price, J.P., Chen, Y.-L., Chu, P.-S., Eischeid, J.K. and Delparte, D.M. 2013. Online rainfall atlas of Hawai'i. *Bulletin of the American Meteorological Society* 94: 313–316.
Jennings, J. and Earle, T. 2016. Urbanization, state formation, and cooperation: a reappraisal. *Current Anthropology* 57 (4): 474–493.
Hommon, R. 2014. The Kealakekua Region: Salubrious core, political centre. *Journal of Pacific Archaeology* 5 (2): 40–50.
Horrocks, M. and Rechtman, R.B. 2009. Sweet potato (*Ipomoea batatas*) and banana (*Musa* sp.) microfossils in deposits from the Kona Field System, Island of Hawaii. *Journal of Archaeological Science* 36: 1115–1126.
Kamakau, S.M. 1961. *Ruling Chiefs of Hawaii*. Kamehameha Schools Press, Honolulu, HI.
Kelly, M. 1983. *Na Mala O Kona: Gardens of Kona. A History of Land Use in Kona, Hawai'i*. Departmental Report Series 83-2. Report prepared for the Department of Transportation, State of Hawaii by Bishop Museum Department of Anthropology, Honolulu. On file with Hawaii State Historic Preservation Office, Department of Land and Natural Resources, Kapolei.
Kirch, P.V. 1977. Valley agricultural systems in prehistoric Hawaii: An archaeological consideration. *Asian Perspectives* 20: 246–280.
Kirch, P.V. 1984. *The Evolution of the Polynesian Chiefdoms*, Cambridge University Press, Cambridge, UK.
Kirch, P.V. 2011. When did the Polynesians settle Hawai'i? A review of 150 years of scholarly inquiry and a tentative answer. *Hawaiian Archaeology* 12: 3–26.
Kirch, P.V. 2010. *How Chiefs Became Kings: Divine Kingship and the Rise of Archaic States in Ancient Hawai'i*. University of California Press, Berkeley, CA.
Kirch, P.V. 2001. Early archaeological investigations, 1978–1982. In M.S. Allen (ed.), *Gardens of Lono: Archaeological Investigations at the Amy B.H. Greenwell Ethnobotanical Garden, Kealakekua, Hawai'i*, pp. 47–66. Bishop Museum Press, Honolulu, HI.
Ladefoged, T.N. and Graves, M.W. 2000. Evolutionary theory and the historical development of dry-land agriculture in North Kohala, Hawai'i. *American Antiquity* 65 (3): 423–448.
Ladefoged, T.N. and Graves, M.W. 2008. Variable development of dryland agriculture in Hawai'i. *Current Anthropology* 49 (5): 771–802.
Ladefoged, T.N., Kirch, P.V., Gon, S.M., Chadwick, O.A., Hartshorn, A.S. and Vitousek, P.M. 2009. Opportunities and constraints for intensive agriculture in the Hawaiian archipelago prior to European contact. *Journal of Archaeological Science* 36: 2374–2383.
Lincoln, N.K. and Ladefoged, T.N. 2014. Agroecology of pre-contact Hawaiian dryland farming: The spatial extent, yield and social impact of Hawaiian breadfruit groves in Kona, Hawai'i. *Journal of Archaeological Science* 49: 192–202.
Lincoln, N., Chadwick, O. and Vitousek, P. 2014. Indicators of soil fertility and opportunities for precontact agriculture in Kona, Hawai'i. *Ecosphere* 5 (4): 1–20.
Lockwood, J.P. 1995. Mauna loa eruptive history – The preliminary radiocarbon record. In J.M. Rhodes and J.P. Lockwood (eds), *Mauna Loa Revealed: Structure, Composition, History, and Hazards*, pp. 81–94. American Geophysical Union, Washington, DC.
Madsen, M.E., Lipo, C.P. and Cannon, M. 1999. Fitness and reproductive trade-offs in uncertain environments: Explaining the evolution of cultural elaboration. *Journal of Anthropological Archaeology* 18: 251–281.
Major, M. and Allen, M.S. 2001. Archaeological excavations, 1996. In M.S. Allen (ed.), *Gardens of Lono: Archaeological Investigations at the Amy B.H. Greenwell Ethnobotanical Garden, Kealakekua, Hawai'i*, pp. 75–98. Bishop Museum Press, Honolulu, HI.
Marston, J.M. 2011. Archaeological markers of agricultural risk management. *Journal of Anthropological Archaeology* 30: 190–205.
Mattison, S.M., Smith, E.A., Shenk, M.K. and Cochrane, E.E. 2016. The evolution of inequality. *Evolutionary Anthropology: Issues, News, and Reviews* 25 (4): 184–199.
McCoy, M.D. 2005. The development of the Kalaupapa field system, Moloka'i Island, Hawai'i. *The Journal of the Polynesian Society* 116 (4): 339–358.
McCoy, M.D. 2006. Landscape, Social Memory, and Society: An Ethnohistoric–Archaeological Study of Three Hawaiian Communities. Unpublished PhD dissertation, University of California, Berkeley, CA.
McCoy, M.D. and Graves, M.W. 2010. The role of agricultural innovation on Pacific Islands: A case study from Hawai'i Island. *World Archaeology* 42 (1): 90–107.
McCoy, M.D. and Graves, M.W. 2012. Small valley irrigated taro agriculture in the Hawaiian Islands: An extension of the "wet and dry" hypothesis. In M. Spriggs, D. Addison and P. J. Matthews (eds), *Irrigated Taro (Colocasia esculenta) in the Indo-Pacific: Biological, Social and Historical Perspectives*, pp. 115–130. Senri Ethnological Studies 78. National Museum of Ethnology, Osaka.
McCoy, M.D., Graves, M.W. and Murakami, G. 2010. Introduction of breadfruit (*Artocarpus altilis*) to the Hawaiian Islands. *Economic Botany* 64 (4): 374–381.
McElroy, W. K. 2007. The Development of Irrigated Agriculture in Wailau Valley, Moloka'I Island. Unpublished PhD dissertation, University of Hawai'i, Manoa.
Morehart, C.T. and De Lucia, K. 2015. Surplus: The politics of production and the strategies of everyday and life – an introduction. In C.T. Morehart and K. De Lucia (eds), *Surplus: The Politics of Production and the Strategies of Everyday Life*, pp. 3–43. University Press of Colorado, Boulder, CO.
Newman, T. 1970. Hawaiian Fishing and Farming on the Island of Hawaii in A.D. 1778. Report prepared for the Department of Land and Natural Resources, Division of State Parks. Report

on file with Hawaii State Historic Preservation Office, Department of Land and Natural Resources, Kapolei.
Rieth, T. 2010. Archeological Data Recovery at Keone'ele Cove (PUHO-008), Pu'uhonua o Hōnaunau National Historical Park, Hōnaunau Ahupua'a, South Kona District, Island of Hawai'i. Report prepared for the National Park Service, Pacific West Region, Pacific Islands Support Office, Haleakalā National Park, Makawao, Maui, Hawai'i by International Archaeological Research Institute, Inc., Honolulu. Report on file with Hawaii State Historic Preservation Office, Department of Land and Natural Resources, Kapolei.
Rieth, T. 2011. Archeological Inventory Survey of the Paumoa Coastal Archeological Sites (PUHO-006 and PUHO-028), Pu'uhonua o Hōnaunau National Historical Park, Kēōkea Ahupua'a, South Kona District, Island of Hawai'i. Report prepared for the National Park Service, Pacific West Region, Pacific Islands Support Office, Haleakalā National Park, Makawao, Maui, Hawai'i by International Archaeological Research Institute, Inc., Honolulu. Report on file with Hawaii State Historic Preservation Office, Department of Land and Natural Resources, Kapolei.
Rieth, T. and Athens, J.S. 2013. Suggested best practices for the application of radiocarbon dating to Hawaiian archaeology. *Hawaiian Archaeology* 13: 3–4.
Rieth, T.M., Hunt, T.L., Lipo, C. and Wilmshurst, J.M. 2011. The 13th century Polynesian colonization of Hawai'i Island. *Journal of Archaeological Science* 38: 2740–2749.
Ripa, J., Olofsson, H., Jonzén, N. 2009. What is bet-hedging, really? *Proceedings of the Royal Society B* 277: 1153–1154.
Sahlins, M. D. 1972. *Stone Age Economics*. Aldine, Chicago.
Schilt, R. 1984. Subsistence and Conflict in Kona, Hawaii: An Archaeological Study of the Kuakini Highway Realignment Corridor. Departmental Report Series 84-1. Report prepared for the Department of Transportation, State of Hawaii by Bishop Museum Department of Anthropology, Honolulu. Report on file with Hawaii State Historic Preservation Office, Department of Land and Natural Resources, Kapolei.
Soehren, L.J. and Newman, T.S. 1968. The Archaeology of Kealakekua Bay. Report on file, Anthropology Department, Bernice P. Bishop Museum, Honolulu, HI.
Tomonari-Tuggle, M.J. 2003. Archaeological Inventory Survey at Captain Cook Ranch LLC, Ahupua'a of Kealakekua, Kona District, Island of Hawai'i. Report by International Archaeological Research Institute, Inc., Honolulu. Report on file with Hawaii State Historic Preservation Office, Department of Land and Natural Resources, Kapolei.
Tomonari-Tuggle, M.J. 2006. Archaeological Data Recovery Investigations of the Northern Portion of Captain Cook Ranch. Report by International Archaeological Research Institute, Inc., Honolulu. Report on file with Hawaii State Historic Preservation Office, Department of Land and Natural Resources, Kapolei.
Trusdell, F.A., Wolfe, E.W. and Morris, J. 2006. *Digital Database of the Geologic Map of the Island of Hawai'i* (ver. 1.0). U.S. Geological Survey Data Series 144 (supplement to I-2524A). Available at http://pubs.usgs.gov/ds/2005/144/.
Vitousek, P.M., Chadwick, O.A., Hotchkiss, S.C., Ladefoged, T.N. and Stevenson, C.M. 2014. Farming the rock: A biogeochemical perspective on intensive agriculture in Polynesia. *Journal of Pacific Archaeology* 5: 51–61.
Ward, J.V. 2001. Pollen analysis. In M.S. Allen (ed.), *Gardens of Lono: Archaeological Investigations at the Amy B.H. Greenwell Ethnobotanical Garden, Kealakekua, Hawai'i*, pp. 127–135. Bishop Museum Press, Honolulu, HI.

SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this paper at the publisher's website:

Online Supplemental Material