Bet-hedging strategies, agricultural change, and unpredictable environments: historical development of dryland agriculture in Kona, Hawaii

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Abstract

It is argued that current models of agricultural change are overly focused on productive increases. Risk management strategies, practices that can be critical to the long-term survival of a given agronomic system, warrant a more prominent role. Neo-Darwinian theory, and the bet-hedging model in particular, offers a way to evaluate both kinds of agronomic change within a single theoretical paradigm, as well as a means of assessing the long-term outcomes of variant agronomic strategies. The bet-hedging model is used herein to assess agricultural change in an unpredictable Hawaiian environment, the Kona District of central West Hawaii. A fine-grained record of agronomic change from one of the region’s more productive areas is compared with patterns from the region at large. The analysis shows that variance minimizing (or risk management) strategies were initiated by 1450 AD, if not earlier, and occurred in even the most productive localities. Innovations in gardening architecture, novel cultivation practices and changes in the scale of agronomic integration, are argued to have been effective in reducing the impact of environmental variance. Later in time (after 1650 AD) there was a shift in emphasis to productive maximizing strategies, with implications for the region’s economic and socio-political stability.

Keywords: Agricultural intensification; Risk management; Bet-hedging; Neo-Darwinian theory; Hawaiian Islands; Kona field system

The concept of intensification has played a pivotal role in archaeological studies of agronomic change. Recent discussions have focused on both elaboration of the core concept and empirical recognition of the intensification process on the ground (e.g., Kirch, 1994; Leach, 1999; Morrison, 1994). Current models of intensification, however, are strongly focused on productive increases and often give insufficient attention to risk management, strategies that may be critical to the long-term survival of agricultural systems especially in unpredictable environments. Recent work in an extensive dryland field system on the central western slopes of Hawaii Island provides a new empirical context in which to discuss, in both substantive and theoretical terms, agricultural change. Particular attention is given to a case study from one of the most productive localities in the region, the historically important (see Beaglehole, 1967; Obeyesekere, 1992; Sahlin, 1995) land unit of Kealakekua Ahupua’a in the Kona District. Ethnohistoric and archaeological evidence from the region at large is also reviewed. In addressing the region’s agricultural history, issues of spatio-temporal variability in productive capacity, the degree and scale of agronomic integration, and the relative importance of productive maximizing versus risk minimizing strategies are explored.

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Background

By the time of western contact, Native Hawaiian farmers of central west Hawaii (Fig. 1) had developed a thriving agricultural economy on the lower slopes of the still active Hualalai and Mauna Loa volcanoes. Nearly 140 km² had been extensively modified by a variety of drystone masonry constructions, the most prominent of which were inland-seaward trending field walls known as kua′iwai (also iwi and iwi kuamo‘o; see Handy and Handy, 1972, p. 51; Major, 2001; Yen, 1978). Kua′iwai are often considered the hallmark of the Kona field system (Kirch, 1985; Soehren and Newman, 1968), being physically prominent and geographically widespread architectural features. Other common features included terraces, mounds, enclosures, and various other modifications aimed at creating microenvironments suitable for plant cultivation. Among the more novel constructions were water control devices for use with intermittent streams (Allen, 1984; Schilt, 1984) and flood water
drainages (Rosendahl, 1972b), rock mulching (Major and Allen, 2001), pit cultivation on barren lava flows, (Borthwick et al., 1994; Donham, 1990), and small-scale irradiation structures (Kawachi, 1989). Early historical and ethnographic observers speak of an intensively utilised landscape with permanent fields, short fallow cycles.
and high labour inputs in the form of soil manipulation, firing, mulching, weeding, etc. (e.g., Handy and Handy, 1972; Ledyard, 1963; Menzies, 1920).

Scholars have long noted the pivotal role of this and other Hawaii Island dryland field systems in supporting the development of chiefly hierarchies and facilitating sociopolitical integration (e.g., Hommon, 1986; Hunt, 1991; Kirch, 1985, 1994). From a power base in Kona, the Hawaii Island was the first of the Hawaiian archipelago to come under a single leader and, in time, this lineage went on to unite the whole of the chain. In his analysis of Hawaiian sociopolitical processes, Hommon (1986, p. 67) stressed the role of economic differences between the productive, long-standing windward economies and the youthful, “unstable” leeward ones in initiating rivalries and competition. Kirch (1985, p. 225) comments on both the “great productive capacity” of the dryland field systems in supporting the rise of the powerful Hawaii chiefdoms, particularly those of the Kona area, and the environmental constraints that ultimately led to territorial expansion (Kirch, 1994, pp. 266–267). Hunt (1991), in modelling the changing relationships between the relative costs of migration, agricultural intensification, and aggression, highlights the opportunities for emergent leadership. Despite the important role accorded to Kona’s agronomic resources, the empirical record of their development and information on the chronology of agronomic change vis-à-vis socio-political processes has been limited.

Lying in the rainshadow of the Hawaii island volcanoes, the relatively undissected district of Kona is best suited to dryland, rather than irrigated, agricultural technologies. However, the region is far from uniform in its agronomic potentials, a point which has not been fully considered in theoretical discussions of socio-political process. Kona’s heterogeneity is nowhere more apparent than on US Geological Survey maps that detail the extent and chronology of volcanic eruptive events over the last 4.0 ka years (Figs. 2 and 3, based on Lockwood et al., 1988 and Moore and Clague, 1991 respectively). There is considerable variation in local substrates, which range from deep well-weathered soils and fertile volcanic ash deposits to barren lava flows, some only a few hundred years old. Notably both volcanoes are still active, Mauna Loa volcano destroying a Hawaiian community as recently as the mid-1900s.

Further geographic variability is introduced by a strong coastal-inland rainfall gradient, with precipitation varying from as little as 500 mm (20 in.) at the coast to more than 2000 mm (80 in.) at 460 m (Fig. 4). Rainfall not only directly affected crop productivity, but also has played a key role in soil weathering. Inland areas typically have far more developed soils than coastal localities with similarly aged parent rock. Overlying this spatial mosaic is temporal variability in rainfall and unpredictable environmental perturbations. Droughts and dry spells were common events in the
past, alluded to in traditions and systematically demonstrated by Matsunaga (1983) with significant impact on Kona’s farmers, past and present. At the same time, flooding and erosion are constant hazards, particularly given the steep slopes found in many parts of Kona. Volcanic eruptions, while probably infrequent, are known to have taken place within the period of Hawaiian occupation (e.g., Ellis, 1963); they may have both enhanced and destroyed gardening opportunities, burning and burying some areas but fertilising others with rich volcanic ash deposits. These environmental characteristics as a whole combine to make Kona an unpredictable environment, particularly from an agro-nomic perspective.

Unpredictable environments like Kona are challenging places to make a living and many organisms develop specialised adaptations to cope with the risks and uncertainties that they present. In a stable and predictable environment, effective carrying capacity varies little and most of the variation is of small magnitude and infrequent occurrence (see Dunnell, 1989); perturbations that lower carrying capacity produce unpleasant but tolerable effects. Temporally variable environments, in contrast, are those where effective carrying capacity fluctuates considerably due to perturbations of significant magnitude, long duration, and/or relative frequency (Fig. 5). Populations in these kinds of environments risk catastrophic losses in bad years,
which may lead to extinction or emigration. Populations often deal with unpredictable environments by devising buffering strategies that serve to alleviate risks or stresses (e.g., exchange relationships, storage facilities, etc.).

One of the ways that environmental variability in Kona structured Native Hawaiian farming was in the development of a series of well-defined planting zones that extended across the district (Table 1). These named zones were defined on the basis of altitudinal variation in soil, rainfall, and temperature. Among the traditional Polynesian crops grown here were taro (*Colocasia esculenta*) which was considered the Hawaiian staple, and secondary starches such as sweet potato (*Ipomoea batatas*), banana (*Musa* sp.), yam (*Dioscorea* spp.), and breadfruit (*Artocarpus altilis*). The most intensively cultivated and productive zone was the well-watered, inland ‘Apa’a zone and it was here where the extensive field walls or *kuaiwi* were most common. A second important zone was the Kalu‘ulu where breadfruit was cultivated in formal plantations. This was unusual in the Hawaiian context, as elsewhere in the archipelago breadfruit was more commonly grown singly or in small numbers and, contrasting with some other central Polynesian islands, it was not a popular food crop. The coastal Kula and upland ‘Ama‘u zones were less productive but nonetheless still considered important food producing areas. These four zones were sufficiently well defined and obvious on the ground that numerous early

![Theoretical model of the effects of an unpredictable environment on productivity and population persistence (based on Dunnell, 1989, Fig. 2.2).](image)

Table 1

<table>
<thead>
<tr>
<th>Name of Zone</th>
<th>Description</th>
<th>Elevation</th>
<th>Primary Crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kula</td>
<td>Plain, open country, inland from the coast</td>
<td>Coast–500 ft (0–150 m)</td>
<td>Sweet potato, <em>wauke</em>&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Kalu or Kalu‘ulu</td>
<td>Luxuriant, cultivable zone</td>
<td>500–1000 ft (150–300 m)</td>
<td>Breadfruit with <em>wauke</em>&lt;sup&gt;b&lt;/sup&gt; understory and sweet potato</td>
</tr>
<tr>
<td>‘Apa’a</td>
<td>Dry zone</td>
<td>1000–2500 ft (300–750 m)</td>
<td>Taro, sweet potato with sugar cane, <em>kī</em> and banana</td>
</tr>
<tr>
<td>‘Ama‘u</td>
<td>Upland/fern zone</td>
<td>2000–3000 ft (600–900 m)</td>
<td>Banana and ‘ama‘u fern</td>
</tr>
</tbody>
</table>


<sup>b</sup> Paper mulberry or *Broussonetia papyrifera*.

<sup>c</sup> *Cordyline fruticosa.*
European visitors commented on them, noting in particular the walled fields of the 'Apa'a zone and the breadfruit plantations of the Kalu'ulu (Fig. 6).

Agricultural features within the 'Apa'a zone have been studied in some detail in Kealakekua Ahupua'a (Allen, 2001). This traditional land unit is centrally located within the Kona District (see Fig. 1) and is perhaps best known for Kealakekua Bay where Captain James Cook anchored in 1779 and later lost his life. Kealakekua translates literally as "path of the gods" and the well-sheltered bay was the locus of a major temple complex, several smaller religious structures, and a chiefly residential area. At western contact, the annual harvest rites (the Makahiki), a 4-month long period of ritual and tribute collection in honor of Lono, the Hawaiian deity of dryland agriculture and rain, was centered at the bay (Handy and Handy, 1972). Important from an agronomic perspective, some of the oldest volcanic surfaces in the region are found here, flows that long ago weathered into rich soils (see Fig. 2). The excavation site reported below is ca. 1.5 km inland from Kealakekua Bay at ca. 460 m elevation, within the Amy B.H. Greenwell Ethnobotanical Garden, a research and educational facility administered by the Bernice Pauahi Bishop Museum of Honolulu. Archaeological research here was initiated here by Patrick Kirch and Douglas Yen (Kirch, 2001) in the late 1970s and more recently continued by other Museum staff (Allen, 2001).

Mostly within a steeply sloping area, the Greenwell Garden property preserves nearly 300 traditional Hawaiian features (Fig. 7), including stone mounds, walls, agricultural terraces, small habitation features, and most prominently the mounded wall-like structures known as kua'wi. These wall-like features parallel the slope and often run for a kilometre or more (Fig. 8). As suggested above, they are widely distributed, occurring throughout the district, from Kailua to Kealakekua (see Fig. 1). One translation of the word kua'wi is "backbone" (Pukui and Elbert, 1986, pp. 98, 155–156), presumably a reference to their appearance, but possibly a metaphor for the importance of these walled fields to the prehistoric Hawaiian economy. Research at Greenwell Garden provided an opportunity to examine the historical development of dryland farming in what is potentially one of the region's most productive areas, one with deep, well-weathered soils and relatively high rainfall. Moreover, given the proximity of these gardens to the religious and political centre at Kealakekua Bay, they are important to understanding the inter-relationships of agronomic development and socio-political processes.

Fig. 6. Emic agricultural zones. Based on engraving by Kapohoni, which was based on a drawing by Persis Goodale Thurston in ca. 1840 (used with permission of Persis Corporation).
Fig. 7. Map of archaeological features at Greenwell Garden.
Fig. 8. Aerial photograph of Kealakekua Bay and inland region showing inland-seaward trending field walls (photo by R.M. Towill Corporation; used with permission).
Dimensions of agricultural change

Hommon (1976, 1986), Kirch (1985, p. 224, 1994), and others have argued that the dryland farming complexes of leeward Hawaii Island were highly intensified. Hommon (1986) further proposed that the increasing use of ever more marginal areas and attenuated fallow cycles, ultimately led to soil exhaustion, erosion, and crop failure; this in turn resulted in “irregular and unpredictable oscillations” in the amount of agricultural surplus that was available to the chiefs. More specific claims have been made by Tomanari and Tuggle (1980, see also Kirch, 1994, p. 265) working in the Kohala dryland field system of northwest Hawaii. They argue that agricultural growth in Kohala had reached its limits—the point where productive gains were no long possible. However, recent fine-grained investigations by Ladefoged, Graves, and colleagues (Ladefoged and Graves, 2000; Ladefoged et al., 1996; Ladefoged et al., 2003) are now calling into question some of these earlier ideas about the degree and process of intensification in the Kohala area. These debates, and recent discussions of the intensification concept generally (e.g., Leach, 1999 and comments therein), point to the need to further consider the character, timing, and magnitude of agricultural change in Kona as well.

In her classic work on agricultural growth, Boserup (1965) defined intensification as a progressive increase in the frequency of cropping, and the concomitant decrease in field fallowing. More specifically, Boserup saw intensification as a transition from long-fallow forest swiddening or shifting cultivation, to multi-cropping in permanent fields, a process she argued was driven by population pressure and aimed at increasing productivity. Brookfield (1972) subsequently suggested that intensification should be measured by “inputs only of capital, labour, and skills against constant land,” and recognised a causal role for social demands, as well as population increases, again emphasizing productive increases. Morrison (1994, 1996) attempts to shift our attention from the cause(s) to the process of agricultural change. She argues that the progressive, typological stages of Boserup mask variability that may be central to understanding how and why agricultural change occurred. Critical in this regard is the recognition that a given agricultural economy may involve a mix of technologies or strategies, each with variable productive capacities and limitations. Consideration of individual agronomic components, the ways in which they are organized and distributed, and the changing constellation of strategies over time, may lead to new insights on underlying causes of agricultural change (Morrison, 1994, 1996). Within her expanded view, specialization, diversification, and in some cases expansion, are potentially important strategies along with increased labour and/or capital (see also Kirch, 1994). Similarly, changes in the organization of labour and the structure of agronomic management may also have important effects on agronomic success (see Athens, 1999; Brookfield, 1999; Morrison, 1994). Brookfield (1972, 1999), for example, argues that changes in management strategies alone can be far more effective in increasing productivity than additions of field labour, while Boone (1992) notes that complex production systems which involve cooperative effort benefit from greater efficiency.

More recently, Leach (1999) has questioned our ability to archaeologically distinguish intensification (the process) from intensive land use (a state), a terminological distinction previously made by Morrison (1994). Leach challenges the necessity of an early stage of long-fallow shifting cultivation and the adequacy of current Pacific data (often palynological and sedimentological) for its demonstration. Moreover, she notes that simple swiddening technologies may co-exist with more sophisticated (and presumably more “evolved”) ones like irrigated pondfield agriculture, echoing Morrison’s (1994) call to recognize the individual components and strategies of an agronomic system. She emphasizes that capital investments, such as complex gardening architecture, do not necessarily evidence intensification, as they may be constructed during initial development of a garden parcel; intensification requires a demonstrable chronological sequence of increasing labour input (capital or otherwise) to a given area of land. Central to Leach’s argument is the idea that some aspects of agrarian change may not be intensification.

While these discussions represent important advances in our conceptualisation of the process of agriculture change, I suggest that they give insufficient attention to the role of strategies aimed at agronomic stability (i.e., risk aversion or risk management strategies) as opposed to short-term productive increases. Risk has been defined as unpredictable variations in the environment, natural or social, that will potentially result in adverse consequences, while uncertainty relates to the lack of information about those risks (Cashdan, 1992; Halstead and O’Shea, 1989). The timing, frequency, magnitude, duration, and predictability of such variation determine the nature of those risks and their consequences (Halstead and O’Shea, 1989). Risk management strategies mediate these dimensions of environmental variability, typically by redistributing people, produce, or risk itself, through settlement mobility, exchange relationships, crop diversification, technological innovation, storage, and the like (e.g., Halstead and O’Shea, 1989; Winterhalder, 1988). Risk management strategies may have negligible, or even reduced, effects on productivity. Morrison (1994, pp. 138–139) considers risk as a potential cause of intensification, and intensification as a means of reducing risk, but largely dismisses the concept because of the difficulties of measurement. Numerous examples from the literature, however, demonstrate
ways in which risk can be measured, along with the attendant human responses (e.g., Halstead and O’Shea, 1989; Kennett and Kennett, 2000; Ladefoged and Graves, 2000; Larson et al., 1996; Madsen et al., 1999; Rautman, 1993).

Summarizing to this point, the process of agricultural intensification may take a variety of forms (e.g., increased labour and capital inputs, specialisation, diversification, and in some contexts expansion), may be directed to different purposes (e.g., basic subsistence, generation of surplus, risk management), and may have varied outcomes (e.g., productive increases, enhanced stability, or even agronomic failure). Moreover, some intensive land-use practices may not be the product of an intensification sequence and intensification is not the only kind of agrarian change, as relatively cost-free changes may occur and investments of labour, capital, etc., may also be reduced, a process some refer to as “disintensification.” Following from the above, rather than focusing solely on increases in energetic inputs (intensification), it might be useful to examine the apportionment of various kinds of agronomic investments in general (i.e., both increases and decreases), variability in component strategies, and the long-term outcomes.

Biological models of bet-hedging (Frank and Slatkin, 1990; Seger and Brockmann, 1987; Slatkin, 1974; Stephen and Krebs, 1986) potentially provide a useful framework for structuring such an investigation. These models contrast strategies (reproductive or behavioural) that either maximize benefits or minimize variance, in varied selective contexts. The models predict, and empirical evidence supports, that maximizing strategies are more advantageous in stable and predictable environments where year-to-year variance is minimal, while variance minimizing strategies can enhance long-term fitness in temporally variable environments (e.g., Frank and Slatkin, 1990; Nilson et al., 1996). Given that reproduction is multiplicative, the best measure of fitness in these contexts is the geometric mean of a trait in each environmental state (see discussion in Madsen et al., 1999, pp. 258–259). As Madsen et al. (1999, p. 260) note, the mathematics of variance minimization explain not only ecologically based risk minimization behaviours but also phenomena as diverse as stock market strategies and life insurance policies.

Madsen et al. (1999) have recently applied bet-hedging principles to a consideration of cultural elaboration (e.g., monumental architecture, burial ceremonialism) and the question of why it proliferates in some contexts and not in others. Building on the ideas of Dunnell (1989), they suggest that when energy is directed to non-reproductive (or “wasteful”) activities, population sizes are reduced directly through lower fecundity. Cultural elaboration can also be advantageous in that it provides “a sink of ‘excess’ time and resources that can be devoted to subsistence/reproduction under stressful conditions” (Dunnell, 1999, p. 245). In the Madsen et al. (1999) model, “thrifty” individuals are those who maximize reproduction while “wasteful” individuals expend energy on cultural elaboration at the cost of fewer offspring; the relative benefits of the two kinds of behaviours vary in relation to environmental predictability. Exploring these relationships using an agent-based SWARM simulation, they demonstrate that individuals who maximize reproductive success have enhanced fitness in predictable environments and sometimes in unpredictable ones as well, over the short-term. However, in unpredictable environments, “wasteful” phenotypes experience a lower variance in fitness (relative to “thrifty” phenotypes) over the long run and increase in frequency within a given population (Madsen et al., 1999, pp. 270–271). The results suggest that cultural elaboration is most likely to appear and persist in unpredictable environments and that populations practicing elaboration under such conditions will experience enhanced fitness relative to those who do not (see also Dunnell and Greenlee, 1999 and other papers in this volume; also Hunt and Lipo, 2001). The cultural elaboration model developed by Dunnell (1989) and elaborated by Madsen et al. (1999) is only one example of how these kinds of contrastive behavioural strategies can differentially affect long and short-term reproductive success. As Madsen et al. (1999) note, mobility and storage can also be effective variance minimization strategies and may even decrease selection for “wasteful” traits. Biologists provide other examples of how unpredictable environments can favour the transmission and selective retention of variance minimization traits (e.g., Bulmer, 1994 and references therein; Nilson et al., 1996; see also Boone and Kessler, 1998).

Strategies associated food production can also differentially affect fecundity and fitness (after Madsen et al., 1999). In this regard it is useful to contrast productive maximizing agronomic strategies with variance minimizing (or risk management) ones. Fig. 5, based on Dunnell (1989) illustrates the theoretical relationship between temporal variation in productivity in unpredictable environments and the impact on three populations of different sizes. As Dunnell (1989) observes, all populations can tolerate minor short-term shortfalls in productivity (Fig. 5, Time A). Major shortfalls (Time B) or repetitive ones (Time C) can have more drastic implications. Populations fixed at smaller sizes (Fig. 5, Population 3) are more likely to cope with significant shortfalls, whereas larger populations (Fig. 5, Population 1) may experience significant losses or even extinction. In temporally unpredictable environments, effective risk management strategies enhance fitness in two ways. First, they reduce temporal variation in productivity by ameliorating environmental perturbations or stabilising the agronomic environment. For example, technologies that enhance moisture retention can offset water stress...
under conditions of drought. The impact of floods, slope wash, and erosion can be reduced through the construction of stabilising architecture such as slope terraces, water diversion devices, etc. Similarly, both crop diversification and changes in the scale of agronomic management can redistribute the impact of risk. Fitness is also enhanced when energy is directed away from the primary activities of food production. More specifically, populations heavily engaged in variance minimization strategies may produce less food, with the result that fecundity is lowered and populations are stabilised at smaller sizes. As Madsen et al. (1999) demonstrate, in unpredictable environments low fecundity reproductive strategies experience lower child mortality rates and higher geometric mean fitness, and thus increase in frequency over time relative to high fecundity strategies.

In contrast, populations practising productive maximizing strategies attempt to maximize their immediate productive returns through shortened fallows, more intensive tending, nutritional additives, etc. Over the short run these populations will benefit from comparatively larger food supplies, which support relatively larger populations and thereby enhance reproductive success (e.g., offspring survival). However, when environmental perturbations occur productivity may be drastically reduced, with a negative impact on offspring survival and population stability in general. Productive maximizing strategies run the risks of long-term declines in productivity through nutrient depletion, soil run-off, and increased susceptibility to disease in the case of crop specialisation. Importantly, any food surpluses generated by productive maximizing strategies can be funnelled into other practices that mediate temporal variability in productivity, including storage, exchange, and cultural elaboration; these various strategies do not necessarily preclude one another (see Dunnell, 1999, p. 247). Also of note, any given agronomic system will most likely include both kinds of strategies. It is the relative balance of these over time, and the nature of the selective environment, that has implications for fitness.

In light of the foregoing, the challenge is to differentiate the two contrastive sets of strategies, evaluate their impact on agricultural productivity and stability, and monitor their effect on population size and structure over time. Initially the function of a given strategy or technology can be modelled using an engineering or experimental approach. For example, dryland agricultural terraces have been demonstrated to be effective devices for stabilising slopes, increasing soil depth, and most importantly, for retaining moisture (Allen, 1991; Sandor, 1992; Sandor et al., 1990; Treacy and Denevan, 1994)—all functions that could be critical in certain environmental contexts. Similarly, Maxwell (1995) reviews a significant body of experimental data that demonstrates the positive effect of rock mulching on water retention, temperature control, and by extension crop success in arid environments. Maxwell’s (1995) work also illustrates the potentially useful role of distributional studies. Examining the occurrence of this technology across two arid environments he found that rock mulching was more common in the region that experienced greater variation in the amount, predictability, and timing of rainfall, supporting the idea that rock mulching functions as a variance minimization device. The functional impact of production maximizing strategies can also be modelled through experimental studies. Strategies that potentially provide significant increases in productivity (and may also be archaeologically visible) include shortening of field fallow times, technological innovations, crop specialisation, increases in labour to bring marginal fields into production, among others. Some strategies may effect both productive increases and management of risk. Changes in the scale of agronomic management in particular might be an example, wherein productivity is enhanced through greater efficiency and variance reduced through coordinated field preparation, planting, and harvesting.

Modelling the function of these traits alone is insufficient, as effectively these are hypotheses about their potential performance. The important second step is to evaluate their correlation with the relevant environmental parameters and track their relative success within specific agronomic contexts over time. Stabilising architecture, for example, would be expected to correlate with geomorphically unstable environments and its relative success could be evaluated through analyses of erosion rates before and after terrace emplacement (e.g., Allen, 1984). The impact of shortened field fallows on soil quality might be evaluated through soil chemistry studies (e.g., Sandor, 1992). Some technological changes might enhance productivity to the degree that selection for variance minimization strategies is significantly reduced. In the absence of environmental perturbations, production maximization strategies would be expected to result in population increases (assuming surplus is not directed to other variance minimizing strategies), while variance minimization ones should stabilise or lower population size. As the simulations of Madsen et al. (1999; see also Dun nell and Greenlee, 1999; Hunt and Lipo, 2001) illustrate, both production maximizing and variance minimizing strategies potentially have implications for population age structures as well, with juvenile mortality rates and adult-to-juvenile ratios varying in predictable ways. In unpredictable environments an emphasis on agronomic variance minimizing strategies would be expected to correlate with a higher geometric mean fitness and an equal ratio of adults to juveniles, while an emphasis on productive maximizing strategies would result in a comparatively lower geometric mean fitness, a higher birth rate, and a higher rate of juvenile mortality. These are features of demographic structure that can be empirically evaluated using skeletal
assemblages (but see Dunnell and Greenlee, 1999, pp. 386–387 for important taphonomic considerations).

The bet-hedging model described above allows us to make testable hypotheses about the spatial and temporal occurrence of two contrastive types of agronomic behaviour: productive maximizing and variance minimizing strategies. Some ways in which we might recognize the two contrastive strategies and evaluate their effectiveness have been proposed. The model further allows predictions about the impact of the relative balance of these strategies on population size and structure. With these ideas in mind, I examine agronomic developments at Greenwell Garden and in the Kona region at large.

Agronomic change at Greenwell Garden

Early land use

Current models of Hawaiian dryland gardening suggest that early efforts to cultivate leeward Hawaiian environments involved shifting cultivation practices, specifically sequences of vegetation clearance, burning, and planting, followed by periods of fallow and subsequent re-use (e.g., Kirch, 1984, pp. 188–189, 1994; Rosendahl, 1972a). This assumption is reasonable, as shifting cultivation is ethnographically well known from several areas of the Pacific (e.g., Kirch, 1994). However, it is difficult to demonstrate archaeologically as it is among the more intractable gardening technologies (e.g., Leach, 1999; Morrison, 1994; Yen et al., 1972, p. 91). Indicators used in Hawaiian contexts include sequential charcoal lenses or continuous low level background charcoal; wood charcoal and phytolith sequences suggestive of a shift from primary to secondary vegetation; and sedimentary changes indicative of recurrent soil exposure and instability. However, these kinds of finds are uncommon and more often than not slash-and-burn technologies have been assumed rather than demonstrated. Leach (1999) makes similar observations for the Pacific at large and questions common assumptions about the primacy of long-fallow, shifting cultivation practices. In Kona, evidence for an early swiddening phase has likewise been difficult to detect. Archaeological study along the lowland Kuakini highway corridor identified remnant A-horizons with abundant charcoal and indigenous forest land snails—remains which Schilt (1984) and Allen (1984) argued represented an early period of slash-and-burn gardening. Their findings further suggested that only with erosion and redeposition of soils from more inland areas did the arid lowlands of the highway corridor come under intensive cultivation. Elsewhere buried charcoal lenses have been interpreted as evidence of alternating cycles of field clearance and fallow (Hammatt and Clark, 1980, as found in Schilt, 1984, p. 285).

At Greenwell Garden we anticipated that initial clearance of native vegetation would have resulted in relatively abundant charcoal in the earliest cultural contexts. Additionally, we expected a continued and possibly increasing representation of charcoal in local sediment profiles, if fire had continued to play a significant role in gardening technologies. The first expectation was not met, as charcoal was poorly represented in most of our excavation units and especially so in basal cultural levels, as observed in stratigraphic sections (Major and Allen, 2001), macrobotanical samples (Lennstrom, 2001), and charcoal particle analyses (Ward, 2001). In contrast, continuing and intensified firing over the 400-year period represented here did seem apparent, particularly in the pollen column samples (Ward, 2001), consistent with what we might expect if the length of field fallows was decreasing. In retrospect, our initial ideas that early burning episodes would be preserved on this steeply sloping area were perhaps overly optimistic. The initial removal of vegetation would have created a quite unstable sedimentary environment, as discussed further below. The findings of Schilt (1984) further suggest that in such sloping areas, original surfaces are likely to be retained only in protected microenvironments. It is also possible that shifting cultivation practices never played an important role at this locality.

The earliest features identified thus far at Greenwell Garden are pits, hearths, and pavements, along with dispersed charcoal and artefacts. Their antiquity is indicated primarily by their stratigraphic positions, and to a lesser extent, the associated radiocarbon samples (Table 2, Fig. 9; see also discussion below). The recovered artefacts include a variety of tools that are consistent with, but not necessarily restricted to, gardening activities such as vegetation clearance, crop tending, and plant processing. Volcanic glass flakes and cores, basalt flakes, small adzes, and vesicular basalt abraders are the most common finds. The limited stone architecture, the low diversity of artefacts, and the absence of faunal remains all suggest that these remains represent short-term campsites or temporary field shelters. Radiocarbon dating places these activities in the period between ca. 1400 and 1650 AD (BETA-102024, 102026, 1028501 in Fig. 9, Table 2), while the stratigraphic position of at least three such activity areas beneath kuaiwi structures indicates that they precede kuaiwi construction. Given coastal settlements elsewhere in the region that date to between 600 and 1100 AD (Kirch, 1985), the Greenwell Garden radiocarbon ages seem rather late for first use of this particularly productive zone but as noted above, erosion may have removed evidence of the earliest periods of use. One earlier sample (BETA-128504), albeit in secondary context, suggests burning on the landscape at a much earlier point in time, ca. 1018–1277 AD, possibly in conjunction with gardening but maybe from natural fires.
The first significant structural modifications at Greenwell Garden take the form of large terraces. These terraces extend for several meters across the slope and are faced with sizable boulders. Their large size, combined with a poverty of associated artefacts, suggests an agricultural function. Their antiquity, relative to kuaiwi, is indicated in several cases by their stratigraphical position beneath kuaiwi. Further, several of these large terraces extend across more than one field as defined by the kuaiwi. A single radiocarbon sample (BETA-128503) returned an age range of 1472–1645 AD, leaving open the chronological relationship between these large terraces and the occupation features discussed above.

As large structures built on an unstable slope, the cross-slope terraces would have required a considerable expenditure of energy. They indicate the development of at least semi-permanent plots. It seems likely that they were built with the aim of stabilizing the relatively steep slopes of this area. Their construction may have been stimulated by earlier periods of uncontrolled erosion and poor crop returns, brought on by vegetation clearance, burning, and attempts to cultivate the unmodified slopes.

The cross-slope terraces were followed by construction of the inland-seaward trending structures known as kuaiwi (see Fig. 8). Although sometimes referred to as walls, they are more accurately, at least at Greenwell, elongate mounded ridges, sometimes 3–4 m in width (Fig. 10). Notable features of their construction include delineation of their edges with large cobbles and small boulders, stony mantles of smaller cobbles of relatively uniform size, and a lack of well defined wall faces. Excavation revealed that the stony caps overlie substantial mounds of soil (Fig. 11), a characteristic that probably relates to both purposeful construction and the soil-holding properties provided by the overlying rocks. The inclusion of artifacts within the kuaiwi mantles, such as volcanic glass flakes, adze performes, and abraders, indicates that they incorporate sediments from earlier cultural activities.

Field boundaries and facilities

The cross-slope terraces were followed by construction of the inland-seaward trending structures known as kuaiwi (see Fig. 8). Although sometimes referred to as walls, they are more accurately, at least at Greenwell, elongate mounded ridges, sometimes 3–4 m in width (Fig. 10). Notable features of their construction include delineation of their edges with large cobbles and small boulders, stony mantles of smaller cobbles of relatively uniform size, and a lack of well defined wall faces. Excavation revealed that the stony caps overlie substantial mounds of soil (Fig. 11), a characteristic that probably relates to both purposeful construction and the soil-holding properties provided by the overlying rocks. The inclusion of artifacts within the kuaiwi mantles, such as volcanic glass flakes, adze performs, and abraders, indicates that they incorporate sediments from earlier cultural activities.

Direct dating of kuaiwi construction is difficult. In the Greenwell Garden case, dates associated with underly-
These dates are associated with *in situ* features and thus they provide a maximal age for construction of the overlying *kuaiwi*. Elsewhere Kirch (2001) identified a U-shaped shelter that had been cut into a *kuaiwi*. Excavation revealed that use of the U-shape involved levelling of the *kuaiwi* fill to form a pavement. Dispersed charcoal from below the pavement dated to post-1403 AD (ANU-4784) and post-1474 AD (ANU 4785). Unfortunately it is not known whether the charcoal samples date *kuaiwi* construction or derive from earlier activities. Taking the available dates together with the stratigraphic relationships of terraces and *kuaiwi*, I suggest that the Greenwell *kuaiwi* date to ca. the 1500–1600s.

Various functions have been assigned to *kuaiwi*, although only at Greenwell Garden have they been studied in detail. They have been identified as boundary markers (King in Beaglehole, 1967, p. 521; Menzies, 1920, pp. 75–76; Yen, 1978), repositories for unwanted rocks (e.g. Crozier, 1971; Soehren and Newman, 1968), and planting structures (King in Beaglehole, 1967, p. 521; Menzies, 1920, pp. 75–76; Yen, 1978). Running parallel to the slope, they clearly did not serve as windbreaks or for erosion control, as may have been the case with prominent cross-slope walls in the Kohala and Waimea dryland field systems to the north (see Kirch, 1985; Ladefoged et al., 1996, 2003; Rosendahl, 1972a). To the contrary, the Greenwell radiocarbon evidence suggests that slope stabilization may have taken place at an earlier period, as noted above.

The earliest European accounts allude to *kuaiwi* as boundary markers, suggesting that they served to demarcate individual family plots (King in Beaglehole, 1967, p. 521; Menzies, 1920; Ledyard, 1963, p. 118). Their elongate coastal-inland orientation is conceptually and geographically consistent with the axes of larger traditional land units such as *ʻili* and *ahu*pu`a`. Moreover, the 19th century land court records reveal that individual claims were often made within elongate parcels (Kelly, 1983); these may correspond on the ground
to the fields delineated by *kuaiwi*. While a boundary function seems obvious, it is curious that field boundaries would be allowed to consume such large proportions of productive land. At many localities, *kuaiwi* are typically 2–3 m in width and may take up as much as 25% of a given individual field. If the sole objective was to demarcate boundaries then we would expect more efficient markers, as for example straight-sided walls that elsewhere are common features of the Hawaiian archaeological landscape. The correlation of *kuaiwi* with the best soil areas also hints at an agronomic function, as simple boundaries markers would be more likely to cross-cut a variety of soil and terrain types.

The first archaeologists to systematically study *kuaiwi* (Soehren and Newman, 1968) argued that they were rock repositories. In their view, *kuaiwi* grew slowly over a considerable period of time. Crozier (1971) further suggested that the low height of *kuaiwi* served to facilitate movement between fields. Excavation of the Greenwell *kuaiwi*, however, shows them to be far more formal in their construction (see below) and argues against a primary function as rock repositories. Moreover, aerial examination of the Greenwell features indicates that some *kuaiwi* were built to avoid, rather than incorporate, natural rock outcrops (see also Soehren and Newman, 1968, p. 6), which would have been ideal places to discard loose rocks from the fields.

Support for the idea that *kuaiwi* had an agronomic function comes from several sources. Early historic visitors observed plantings of sugar cane or *ki* (*Cordyline fruticosa*), paper mulberry (*wauke*, *Broussonetia papyrifera*), and/or banana along the margins of *kuaiwi* (King in Beaglehole, 1967, p. 521; Menzies, 1920, pp. 75–76). These crops were generally supplementary resources, food and otherwise, but importantly the leaves also were used for field mulch. Additionally, they were considered famine foods (bananas, *ki*, and sugar cane) and played a part in rituals and ceremonial feasts (bananas, *ki*, and paper mulberry) (Handy and Handy, 1972). The clear separation of rocks and soil seen in the Greenwell Garden *kuaiwi*, and their significant width (3–4 m) led Major and Allen (2001) to suggest that the stony *kuaiwi* caps functioned as “mulch,” acting to reduce evapotranspiration, hold soil, and maintain soil warmth. Stone mulches are widely reported in the literature (see Maxwell, 1995, and references therein) and detailed experimental work indicates their effectiveness in increasing crop yields. Particularly important in the Kona context, rock mulch can have a significant impact on the long-term water storage capacity of a soil. Alderfer and

Fig. 10. *Kuaiwi* in the project area, currently planted in *Ki* shrub (*Cordyline*) and banana.
Merkle (1943), for example, demonstrated that bare plots can lose up to 60% of incoming rainfall to runoff, while rock mulched plots lose only 3–10%. The ethnographic accounts point to their use as planting areas, while *kuaiwi* morphology suggests how they could be effective agronomic facilities, particularly during periods of low rainfall. In sum, while one important function of *kuaiwi* may have been as field boundary makers, several aspects of their construction and use suggest they were designed with additional concerns in mind, mostly likely moisture and soil retention. In this regard they could have served as important planting facilities for use in times of drought.

After emplacement of the *kuaiwi*, evidence for further capital investments at Greenwell Garden is quite limited and may not occur until the historic period. Assuming the foregoing age estimates for *kuaiwi* construction are accurate (e.g., 1500–1600 AD), then there is a roughly 200–300 year period in which there are no further landscape modifications of consequence. From the Greenwell Garden evidence alone, it is unclear whether this represents a period of stability, or a redirection of efforts to archaeologically less visible investments (e.g., labour intensive ones).

**Final phase of physical modifications**

Rock mounds are another prominent feature on the Greenwell Garden landscape and throughout the Kona District. Of varied sizes, shapes, and construction techniques they too may have served multiple functions. Some appear to be clearing features, being large and un-patterned in their shape. A more interesting class consist of small stone-ringed mounds (ca. 1–1.5 m across) that were most likely planting features (see Major and Allen, 2001; Kirch, 2001). Like *kuaiwi*, the stone-ringed mounds have size-sorted rocky caps underlain by mounds of soil or in some cases a soil-filled pit. The boundaries between the rocky caps and the underlying sediments are often distinct, suggestive of formal construction. As with the *kuaiwi*, these characteristics are consistent with the use of rocks as mulch, aimed at reducing evapo-transpiration, holding soil, and maintaining soil temperature. The mounds also could have functioned as supports for traditional crops, such as gourds, or for post-contact crops like watermelon that were early introductions.

The mounds appear to be fairly late additions to the landscape, as indicated by their stratigraphic positions.
above the large terraces and the presence (albeit infrequent) of post-contact remains (Allen, 2001). At the same time, other features suggest that they are Native Hawaiian in origin. As described above, their construction is similar to that of the kuaiwi, albeit on a smaller scale. The associated artefact assemblages are also largely traditional, including volcanic glass and fine-grained basalt items. Further, small numbers of water-worn cobbles are consistently found in association with both kuaiwi and the stone-ringed mounds, either on the surface or in the stone fill. The function of these water-worn stones is not known but they could represent a symbolic link to Lono the god of dryland agriculture and the critical seasonal rains with which he is strongly associated. Kirch (2001) also proposed that they were ritual in nature. The ring mounds at Greenwell Garden appear to represent a continuation of traditional Hawaiian farming technologies into the earliest period of European contact.

Elsewhere in Kona, traditional gardening practices were on the decline as early as 1820 and by the 1840s many gardens had been converted to pasture (Schilt, 1984, pp. 280–284). Major’s (2001; see also Hammatt et al., 1995a) review of local documents, however, suggests that at Kealakekua traditional farming remained viable and flourishing through the early 1840s. The bay had a short-lived but intensive life as provisioning port in the early 19th century. Among the recorded exports were taro, yams, sweet potato, firewood, pigs, and salt (Major, 2001). Early western visitors also introduced a number of plants that they hoped Hawaiian farmers would cultivate and make available for ship provisioning; watermelons and pumpkins are two such examples (Ellis, 1963, p. 17). The Greenwell Garden stone mounds may date to this early provisioning period and could be an adaptation of native Hawaiian planting technologies to newly introduced plants; unfortunately pollen sampling in one such feature provided little additional information in this regard (Ward, 2001). In the early to mid-1800s Old World diseases led to significant population loss in the Kona region at large, as did out-migration to economic centers (Kelly, 1983; Major, 2001; Schilt, 1984). Especially devastating epidemics occurred in the mid-1840s and a severe drought around the same time had a heavy impact on gardening throughout Kona. These events may have been the final blow to traditional farming at Greenwell. In later years, however, the area was converted to coffee production.

Chronological issues

The data reviewed above suggests at least three and possibly four distinct periods of activity are superimposed on the Greenwell Garden landscape. The early activity areas were not necessarily related to agricultural use of the area, although the nature of the features and artefacts are consistent with short-term occupations such as might have accompanied early efforts at gardening. The cross-slope terraces and kuaiwi are less ambiguously agronomic in function and reflect growing investments in landscape capital and garden management. The final phase of land use here may relate to the early historic period and more speculatively, may represent attempts to modify traditional technologies to Euro-American crops.

One problem in evaluating the above model is the poor temporal resolution provided by the available radiocarbon dates. If we rely on the two sigma age ranges, there is considerable overlap between samples. Yet, the stratigraphic evidence indicates a historical sequence of agronomic change rather than an assemblage of contemporaneous features. In an effort to further analyse the available corpus of dates, a Bayesian model was applied (Jones and Nicholls, 2003; Nicholls and Jones, 2001). Three groups were defined based on temporally indicative but non-radiometric data:

Group 1: samples associated with features that are stratigraphically inferior to kuaiwi (BETA-102024, -128501, -102026);

Group 2: samples associated with kuaiwi fill (BETA-45644 and -45643; ANU-4785, and ANU-4784);

Group 3: a single sample (BETA-102027) associated with pollen from historically introduced species.

The early date from a probable mixed context (BETA-128504), another from a small terrace with an uncertain stratigraphic relationship (BETA-102025), and that from the large agricultural terrace (BETA-128503) were omitted from the Bayesian analysis. The constrained model (i.e., that based on the above groupings) was statistically compared with the unconstrained dataset. The results indicate that the constrained model is strongly supported, with a Bayes factor of 23.94 (e.g., is 24 times more likely). This suggests that despite the significant overlap in radiocarbon age ranges, there is a high statistical probability that definition of at least three periods of activity in the Greenwell Garden area is valid (a pattern that is also discernable in Fig. 9).

Regional developments

The Greenwell Garden findings demonstrate a succession of agronomic investments over time. These included capital improvements (terraces, kuaiwi, and rock mounds), new gardening technologies (rock mulching), possible reductions in the cropping cycle (suggested by increased charcoal production) and perhaps additions of new crops in the historic period. At least one class of features, the kuaiwi, link developments in this area with...
those occurring not only elsewhere in the ahupua’a, but across the Kona District at large. Other regional developments not observable at Greenwell Garden include the definition of planting zones (see Table 1), the rise of breadfruit as a supplementary crop, and increasing use of marginal environments. The development of Kona’s agricultural resources in general was undoubtedly a gradual and uneven process, with the timing of initial cultivation, the nature and direction of field expansion, and investments of labour varying by locality. The regional scale phenomena, however, are of particular interest as they potentially signal changes in the scale of energetic investments, the nature of agronomic oversight, and the emergence of regional coordination in agronomic activities. Drawing on a substantial body of unpublished cultural resource literature, summarized in Allen (2001), regional patterns of kuaiwi distribution, morphology, and chronology are considered below in an effort to assess their uniformity and by extension, the degree to which they reflect an integrated regional-scale development rather than local, independent processes.

Regional patterns of kuaiwi

*Kuaiwi* are found throughout the Kona District and have been a defining feature of the Kona field system, but they are discontinuous in their distribution. Elevationally, they are concentrated between ca. 300 and 600 m—the area of greatest rainfall and often the best soil development. This also is the ethnographically recorded ‘Apa’a zone where taro and to a lesser extent sweet potato were favored crops. While *kuaiwi* are most dense at these higher and better-watered elevations, they have been documented as low as 75 m (250 ft) with some well-preserved examples being recorded in soil-mantled terrain (Hammatt et al., 1995a, pp. 275, 280–281; see also Schilt, 1984); notably they are missing from adjacent pahoehoe lava flows. Possible remnants of *kuaiwi* have been seen as high as 760 m (2500 ft) in upper Kealakekua (Hammatt et al., 1995b), while in Kaloko to the north a concentration of *kuaiwi*-like walls were noted as high as 700 m (2300 ft) (Tainter, 1991). In general, these elevation limits are similar to those found in the Kohala field system where planting features become scarce at ca. 800 m (Ladefoged et al., 1996, p. 874); presumably they relate in large part to the upper limits of productive cultivation.

Latitudinally, *kuaiwi* are distributed across the whole of the region, but as noted above, have a patchy distribution. The aerial surveys of Soehren and Newman (1968) initially recorded them from Kealakekua to Kailua and recent archaeological ground surveys have confirmed and expanded on these early observations (e.g., Barrera, 1989, 1990a,b,c,d; Burtchard, ms; Crozier, 1971; Hammatt et al., 1995c; Henry and Rosendahl, ms; Kaschko and Rosendahl, 1987; Schilt, 1984; Tainter, 1991). Again the patterns indicate that the presence of *kuaiwi* is strongly tied to soil quality. For example, Burtchard (ms) recorded *kuaiwi* on prime soils in Keahou Ahupua’a but lacking in poorer soils at the same elevation. In Kalamawai’a’awa, lilioa, and Kalama-kumu Ahupua’a, Barrera (1991) noted a pattern of concentrated features (including *kuaiwi*) giving way to a remarkable lack of features as he moved from areas of relatively deep soils to those of little or no soils. Kaschko (1984; see also Hammatt et al., 1995a) reported *kuaiwi* in the deeper soil areas of Honuaino, Hokukano, Kanauuea, Haleki’, and Ke’ek’e’ Ahupua’a (e.g., Site 10,305). In Ka’awaloa, Walker et al. (1991) found “linear alignments” on the better Wai‘aha soils (see also Soehren and Newman, 1968, pp. 6–7), while farther north in Kahalu‘u, Walker and Rosendahl (1994) observed that the density of agricultural features was tied to soil quality, as well as rainfall and variations in surface topography.

*Kuaiwi* are especially plentiful in the Kealakekua area, as first reported by Soehren and Newman based on aerial surveys (1968) and subsequently observed by others (e.g., Barrera, 1989, 1990b,d, 1991; Kaschko and Rosendahl, 1987). Soehren and Newman (1968, p. 5) made note of the fairly regular spacing of the Kealakekua *kuaiwi*, which gave the “impression of a generally consistent distance.” They also observed cross walls running at right angles. In contrast to the *kuaiwi*, they commented that these features were distinctly unpatterned and almost random (Soehren and Newman, 1968, p. 5). The Greenwell Garden results suggest two potential explanations for this lack of patterning. First, if cross walls and terraces were erosion control devices, their placement was most likely dictated by slope conditions, something that may not have been apparent to Soehren and Newman during their aerial survey. Second, as structures that predate the *kuaiwi* we would not necessarily expect coherence in their spatial layout vis-à-vis *kuaiwi*.

The mound-like morphology seen at Greenwell Garden appears to be a common *kuaiwi* form. Elsewhere *kuaiwi* have been reported as averaging 2–3 m in width but ranging up to 5 m (Barrera, 1989; Kaschko, 1984; Schilt, 1984, p. 225; Soehren and Newman, 1968, p. 6). *Kuaiwi* heights in these localities ranged from 30 to 100 cm (Barrera, 1989; Kaschko, 1984; Schilt, 1984, p. 225). At Holualoa-4, Hammatt et al. (1995c) recorded wide linear features, including both straight-sided walls and less formal linear mounds but the authors suggest that the straight-sided features are historic coffee farming constructions (see also Soehren and Newman, 1968, p. 6). The available data indicates that these inland-seaward oriented constructions of significant extent often take the form of wide linear mounds. This pattern occurs across multiple localities and conditions, and suggests that we are looking at a purposeful
construction technique rather than straight-sided walls in a state of deterioration. Ethnohistoric observations support this view, as for example, the account of Archibald Menzies in 1793 (Menzies, 1920, p. 75):

In clearing the ground, the stones are heaped up in ridges between little fields and planted on each side, either with a row of sugar cane or the sweet root of these islands... so that even these stony uncultivated banks are by this means made useful to the proprietors...

Kuaiwi are perhaps most distinguished from other garden architecture by their extraordinary length. Although few have been followed in their entirety, as they tend to cross-cut numerous modern land-holdings, aerial photos and ground surveys indicate that in many cases they extend for several kilometers across the landscape (e.g., Soehren and Newman, 1968; Schilt, 1984, p. 225; Allen, 2001; see also Fig. 8). Their length is also strong evidence that kuaiwi were not the products of individual farmers, but related to larger social groups (e.g., at least extended families and probably larger land-holding groups).

Outside of the Greenwell Garden examples, the internal construction details of kuaiwi are poorly documented and few have been excavated. Trenches through two in the Kuakini Highway corridor revealed that they rested on the present ground surface and were underlain by thick soil deposits (Schilt, 1984, p. 227). As at Greenwell Gardens, there was a fairly clear boundary between the stony caps and the underlying soil. Other excavated examples are reported in less detailed, limiting effective comparisons (e.g., Barrera, 1990c; Hammatt et al., 1995c). The universality of the construction patterns seen at Greenwell Garden, namely: (1) the definition of kuaiwi borders by larger cobbles and boulders; (2) the presence of relatively uniform-size stony caps, (3) the apparent mounding of soil under the rocky caps; and (4) clear separation of soil and rock, consistent with effective use of rocks as mulch, remains to be fully demonstrated.

Similarly, there is little regional evidence on the timing of kuaiwi appearance but what is available generally supports the Greenwell Garden sequence. The dating of these features is problematic on a number of counts. Charcoal is often not abundant and locating samples that unambiguously relate to kuaiwi construction (rather than earlier activities or subsequent use) is difficult. At Greenwell Garden, our confidence in assigning lower age limits to the kuaiwi was enhanced by broadly consistent results from multiple samples both within particular features and across the property. To the north in Holualoa, matrix materials from a kuaiwi returned a date of cal 1020–1240 (two sigma) (Hammatt et al., 1995c). This single sample is unexpectedly early in light of both general archaeological models of the dryland farming developments (e.g., Hommon, 1986; Kirch, 1984) and the Greenwell Garden radiocarbon series. The sample should probably be viewed with some skepticism as an age for the kuaiwi structure itself, although it may be dating gardening activity of some kind. At Ka‘awaloa, an AMS sample from a cross-slope wall dated to the ca. the mid-15th century AD (Barrera, 1990c), consistent with the Greenwell Garden chronology. The only other locality where a sequence of gardening architecture has been documented in detail is in the Kuakini highway corridor. In one case Schilt (1984, pp. 225–228) argues that stratigraphic evidence indicates an early phase of slope modifications to take advantage of runoff, followed by kuaiwi construction in the late prehistoric period. More generally she suggests that kuaiwi were in place by AD 1600 based on their spatial association with other dated structures. At present the most secure chronological information on kuaiwi structures comes from the Greenwell Garden. Arguments about the contemporaneity of kuaiwi construction across the region and their relationship to other features of community integration can be modelled at present but not fully demonstrated.

Development of Kona’s breadfruit groves

While kuaiwi partitioned the landscape along inland-seaward axes, further structure was imparted by the well-defined emic resource zones which paralleled the coast (Table 1). Known from early ethnohistoric accounts and mid-19th century land court records (e.g., Kelly, 1983), these zones were spread across the whole of Kona District, from Kealakekua to Kailua, like the kuaiwi. They were not only conceptual but also formally expressed on the ground (see Fig. 6). Of particular interest here is the Kalu‘ulu zone described in the early historic accounts of Menzies (1920), Ellis (1963) and others as the breadfruit (Artocarpus altillis) “plantations.” Menzies (1920, pp. 74–76) in particular comments on the well-spaced character of Kona’s trees and the “luxuriancy of their crop and foliage,” in contrast to the more crowded groves he observed in Tahiti. The concentration of breadfruit found here is unusual for Hawaii, differing from their more typical solitary cultivation elsewhere (Handy and Handy, 1972).

Exactly when Kona’s breadfruit plantations were established remains obscure. There are indications that breadfruit was a relatively late introduction to Hawaii. Oral traditions place its arrival after the 14th century (Handy and Handy, 1972, pp. 149–155). A review of several wood charcoal assemblages (Allen and Murakami, 1999) was broadly supportive, with no records of breadfruit before 1500 AD. Contrasting with the many named varieties found in central Polynesia (e.g., 200 in the case of the Marquesas Islands), there is only a single variety in the Hawaiian Islands (Handy and Handy, 1972, p. 1509; Ragone, 1991); the lack of local varieties...
of breadfruit, contrasting with other Hawaiian staple crops, is probably also a reflection of a late introduction.

Interestingly, growing conditions in the Kalu'ulu zone were less than ideal for breadfruit. Pursglove (1968, p. 380) suggests that annual temperatures between 70 and 90 F and rainfall of ca. 60–100 in (1524–2540 mm) is preferable. The Kalu'ulu zone, with an average rainfall of ca. 40–70 in., was adequate but suboptimal. Breadfruit would have been more productive in the higher 'Apa'a zone, where rainfall is both greater and more consistent, but this area was apparently reserved for taro, the preferred Hawaiian staple; these distributions are not consistent with efforts to maximize productivity. Given that breadfruit was neither a highly desired food (Handy and Handy, 1972), nor grown in its optimal habitat, breadfruit cultivation in the Kalu'ulu zone may have been aimed at utilizing a niche where few other crops could grow (see also Kelly, 1983). Development of these groves may have been a conscious attempt to diversify the local crop inventory and importantly, breadfruit would have been useful as fodder for one of the few Hawaiian domesticates, the pig. Pigs have often been considered a kind of "storage device" for surplus food resources and in Hawaii played a critical role in late prehistoric political and religious rituals (e.g., Kirch, 1984). In purely functional terms, during periods of decreased productivity, the slaughter of pigs would have provided extra protein and freed up other food resources for human consumption.

Expansion into marginal habitats

The late prehistoric expansion of gardening activities into the most marginal lands of the district in late prehistory is also a notable regional trend. Importantly, these marginal areas are not necessarily the peripheries of the district, contra the more general model of Hommon (1986), but are often interspersed between more productive areas. Although such expansion falls outside of Brookfield's (1972) conventional definition of intensification, as Morrison (1994, 1996; see also Athens, 1999 and Leach, 1999, p. 318) observes, when viewed at the scale of a given sociopolitical territory, the process of bringing areas previously used for alternative purposes (as for example harvesting of wild plant resources) into agronomic production might be usefully recognized as a form of intensification. These marginal areas included the most arid regions and those with very poor soil development; areas near the upper limits of productivity may also have been brought into systematic production at this time (see also Cordy, 2000).

Schilt's (1984; see also Allen, 1984) Kuakini Highway study in the Kula Zone provides the most detailed view of land use patterns in Kona's drier lowland localities where soil development was often minimal. Occasional instances of small-scale, seasonal gardening are evidenced by ca. 1400 AD but house sites are routinely located elsewhere. After 1600 AD, the situation changes dramatically and garden features appear throughout the highway corridor in great abundance. Moreover, a limited number of habitation sites are also constructed in the lowland region, regularly dispersed amongst the dryland gardens. Local geomorphic records document the appearance of eroded soils from inland areas at this time, suggesting that the productive potential of the Kula Zone may have been enhanced relative to earlier times.

Elsewhere extremely marginal lands, the barren lava fields, were brought into cultivation. Archaeological survey has identified planting features on both un-vegetated pahoehoe (smooth) and 'a'a (crumbly) lavas. In the former case, lava blisters were modified by the addition of small windbreaks, soil filling, and perhaps purposeful collapse of the blisters. On 'a'a flows, simple pits are more common. In both cases, survey has identified substantial tracts with modifications of these kinds, in essence agricultural "fields" on barren lava flows. The Reverend William Ellis in 1825 describes traditional planting practices in these kinds of environments:

Small gardens were seen among the barren rocks on which the houses are built, wherever soil could be found sufficient to nourish the sweet potato, the water melon, or even a few plants of tobacco, which in many places seemed to be growing literally in the fragments of lava, collected in small heaps around their roots (in Handy and Handy, 1972, p. 526).

Further detail is provided by a 1922 Hawaiian newspaper account:

Another way of doing this [planting sweet potatoes] was to rot weeds where the soil was good and then carry them to fill the hollows made on the pahoehoe and then plant whatever he chose. . . the sweet potato tubers borne on the pahoehoe lava beds were both large and sweet (in Handy and Handy, 1972, pp. 131–132).

As suggested by these accounts, cultivation of the barren lava fields was quite labour-intensive.

Changes in the scale of agronomic management

At western contact, Hawaiian society was characterised by a hierarchical system of land management, wherein high chiefs apportioned land to lower chiefs, including land managers or konohiki who organised certain aspects of production within sub-district land units, the ahupu'a. The Hawaiian chiefs routinely extracted tribute from local farmers in the form of food and other agricultural goods (e.g., Kirch, 1994, p. 265). Significant productive resources were required to support public works, temple construction, and defence forces; this was partly secured through systematic
taxation (see Boone, 1992; Kirch, 1984, 1985; Kirch, 1984, pp. 259–263; 1985, p. 235). Historic paramount Kam-ehameha I maintained a personal garden as well, a large plantation known as “Kuahewa” (Handy and Handy, 1972, p. 524; Malo, 1951). But more important were chiefly controlled plots known as ko’ele, a term often applied to a set of irrigated fields worked by corvée labour groups (Kirch, 1984, p. 288). Chiefly management of agronomic production is generally accepted, or even considered necessary, for development of large complex irrigation systems where control of water is critical (e.g., Allen, 1991; Wittfogel, 1957). Less clear is the degree of regional-level oversight that was operative in Hawaiian dryland farming contexts (but see Ladefoged and Graves, 2000). Further, how and why did gardens under the control of family units become part of a larger agronomic system? Chiefs may have coercively secured control of the productive economy for their own benefits but were there advantages to individual farmers as well?

In Kona, there are several indicators of increasing integration and coordination of the district’s agronomic resources over time. The foregoing review highlights kua’iwi features that suggest regional coordination. They are relatively uniform in their external morphology, fairly regularly spaced, and extend over considerable distances. They occur across the breadth of the Kona region, albeit discontinuously, having been described for several traditional sub-district land units or akupua’a. They are routinely associated with the region’s best soils, areas most likely to attract the attention of elites and consistent with ideas about where capital investments would provide the best returns. While their construction was technologically simple, the Greenwell Garden evidence suggests it was purposeful and not casual, involving planning, coordination, and a sizable labour force to implement. The Greenwell Garden kua’iwi are currently the best dated in the district and their construction is securely placed at sometime after the 15th century AD, and most likely in the 16th or 17th century AD, when there are other signs of Kona’s development as a socio-political and ritual centre for Hawaii Island (see Schilt, 1984; Kirch, 1985). As a whole, these characteristics indicate a high level of oversight in kua’iwi emplacement and on-going usage.

Regional integration is also reflected in the emic resource zones (e.g., Table 1) described at contact, which are found across the whole of the district. Most important in this regard are the breadfruit plantations. Their extent, their placement at a relatively uniform elevation, and their concentrated but well-spaced plantings are all features that suggest that they were established under the direction of a regional-level authority.

Oral traditions further suggest changing patterns of agronomic management. Sometime between 1400 and 1600 AD, the island was united under a single paramount chief, ‘Umi-a-Liloa (Kamakau, 1992; Kelly, 1983; Kirch, 1984, pp. 253–254; Schilt, 1984). Cordy (2000, p. 205), in his recent analysis of Hawaii Island oral histories, places the reign of ‘Umi, son of High Chief Liloa and a low ranking chiefess, in the period 1600–1620 AD. Following his father’s death, ‘Umi took political control from the hereditary paramount (his half brother) and shifted the royal court to Kona, moving it from its traditional windward location in Waipi‘o Valley (Cordy, 2000, pp. 206–207; Barrere, 1986, p. 117; Kame‘eleihiwa, 1992, p. 53; see also Kelly, 1983, pp. 1, 99; Schilt, 1984, p. 290). Traditions maintain that among ‘Umi’s major achievements was the designation of specialists, including farmers and land managers, and the setting out of a new administrative order (Kamakau, 1992, pp. 19–20). Dates from the Greenwell Garden kua’iwi are consistent with the later period proposed for ‘Umi’s reign. Although not empirically demonstrable, it is not unreasonable to suppose that the emplacement of kua’iwi and development of Kona’s breadfruit groves was a manifestation of ‘Umi’s new system of management or more broadly, sociopolitical structures that emerged during this general period.

The idea that dryland agricultural production in Kona might have come under some form of centralized management around the 17th century is consistent with, but does not necessarily follow from, more general accounts of Hawaiian socio-political development (e.g., Hommon, 1976, 1986; Kirch, 1985). Hommon (1986, pp. 63–64) proposed that the akupua’a land units emerged as a self-sufficient socio-economic units sometime after the 1400s, following population expansion into inland regions. By the 16th century, these developments are theorised to have led to disintegration of the archaic maka’a‘inana or ancestral kin-based socio-economic units and the beginnings of inter-district boundaries (Hommon, 1986, p. 67). Chiefly ascent, traditionally defined along hereditary lines, had given way to rulers whose position was legitimised by military force (Earle, 1978; Hommon, 1986; Kirch, 1984). Perhaps equally important, following Boone (1992), were demonstrations of managerial and administrative abilities. By the 17th century, a state-like socio-political system was in place and population levels had peaked (Hommon, 1986; Kirch, 1984; Schilt, 1984).

The process of agronomic integration described above potentially would have offered advantages to both chiefly elites and individual farmers. In emic terms, the chiefs required agronomic surplus to finance defence and territorial expansion, build temples, provide religious ceremonies, and generally enhance their prestige. The development of large-scale agronomic facilities and chiefly management of at least the more productive agricultural areas would have aided the creation of agricultural surpluses. The development of fixed agricultural plots of relatively uniform size, like those defined by the kua’iwi, would have provided a better means of
monitoring production and the flow of agronomic goods. Individual farmers would have benefited from the ability of chiefs to provide defence in an increasingly competitive environment, as well as public works, and in times of crisis, the redistribution of food (see Kirch, 1984, p. 260). Perhaps most importantly, shifts in the scale of management may have carried increases in efficiency of the kind suggested by Brookfield (1999, see below), leading to both increases in productivity and enhanced stability. In an unpredictable environment like Kona, managerial investments may have had far greater impact on productivity than inputs of field labour. Coordination of firing regimes, production of field mulches, and areal organisation of planting regimes are just a few of the practices that might have benefited from managerial oversight. Halstead and O’Shea (1989, p. 6); (see also Ladefoged and Graves, 2000, p. 444) also point to the potential advantages provided by hierarchical social institutions in buffering risk, while highlighting the instability that often accompanies implementation of such mechanisms:

One likely outcome of this process is the radical transformation of society, as perhaps in the appropriation of risk-related surplus for the maintenance of an elite. In this case associated changes in other aspects of social or economic behaviour are likely to unleash new sources of risk, leading either to the development of new coping mechanisms, and potentially the start of another cycle of cultural change, or to the undermining of existing coping mechanisms, resulting in catastrophic rather than transformational change.

Discussion and conclusions

The temporal sequence seen at Greenwell Garden, in the Kuakini Highway corridor, and in other areas of Kona speak to a complex multifaceted process of agricultural change over a relatively short period of time, perhaps no more than 400 years. The Greenwell Garden study in particular provides strong evidence for on-going investments in the area’s agronomic infrastructure, as well as changes in the intensity of site use over time. In this final section I summarise the Greenwell Garden sequence and regional trends, and consider these findings in light of the bet-hedging model outlined earlier.

I have intimated above that there is probably an earlier period of gardening at Greenwell that is not currently represented. This is based in part on much earlier settlement dates for the district at large combined with the high quality soils found here that make it a likely area for early cultivation efforts. Moreover, the development of Kealekekua Bay as ritual province, and epicentre of the annual island-wide harvest festival, suggests that the inland region was probably in production before 1400 AD. Other less sloping areas within Kealekekua Ahupua’a, and protected microenvironments at Greenwell Garden, are both areas that might preserve old land surfaces and warrant examination in future field studies. The initial phase of gardening within Greenwell would not necessarily have involved shifting cultivation but apparently it did not include formal demarcation of plots using stone architecture.

The large cross-slope terraces provide the first definitive evidence of gardening at Greenwell and they acted to create at least semi-permanent plots. The latter is consistent with traditional intensification models in that it signals increasing agronomic “sedentariness” and by extension a probable shortening of the fallow cycle. The creation of these flat surfaces would have only marginally increased the amount of arable land. A more important function was to stabilize the markedly sloping ground surface. Flooding and erosion plague farmers in Kona today (Lee, 1989) while the archaeological studies of Schilt (1984) and colleagues speak to the dramatic effect of these processes in the past. Terraces like those found at Greenwell Garden are effective in reducing slope erosion and crop damage because they decrease slope angle and length. Studies elsewhere (Allen, 1991; Kirch, 1980, p. 264; Sandor et al., 1990, p. 74; Treacy and Denevan, 1994) indicate that their most important function lies in trapping run-off and retaining soil moisture.

Examination of the post-terrace stratigraphic record at Greenwell Garden indicates their effectiveness in deterring erosion in later times. Prior to their emplacement, soil build-up was minimal but for the centuries that follow, an apparently continuous soil record is found (Major and Allen, 2001). In a good year (i.e., moderate and evenly distributed rainfall), differences in the productivity of un-terraced versus terraced slopes were probably negligible. Over the long run, however, the role of terraces in erosion control during periods of high rainfall and flooding, or in moisture retention during droughts, would have been critical in stabilising productivity, as well as ensuring the long-term viability of individual garden plots.

To evaluate these ideas further it would be useful to examine the sedimentological and agronomic histories of the adjacent lowland areas. To what extent did upland terrace construction provide significant control over local edaphic and geomorphic conditions? Schilt (1984) and colleagues working in the marginal Kuakini lowlands to the north found that over the centuries upland erosion was so severe that it resulted in considerable soil deposition to low-lying areas. Unfortunately, the agricultural landscape of upland Kuakini has not yet been systematically analysed, so it is not known if cross-slope terraces were also built there. Similarly, the impact of the Greenwell Garden terraces on farming at lower elevations has yet to be studied.
The second phase of capital investment at Greenwell Garden involved kuaiwi construction. Transferral of stones from adjacent open areas to these features may have had a marginal impact on plot productivity. More importantly, Major and Allen (2001) have argued, based on their construction features, that kuaiwi features were important planting facilities. Although ethnohistoric accounts mainly refer to their use in conjunction with minor crops, there is no reason that they could not have been used for staple crops as well. Kuaiwi would have been useful for maintaining soil moisture and warmth, with special utility under conditions of drought or cooler temperatures.

The primary function of kuaiwi, however, was most likely as formal land divisions. In this regard, I have argued that their appearance signals a shift in the scale of agronomic oversight, from individual families or extended families to a regional level of authority. Kuaiwi would have provided agrarian managers with a more effective means of monitoring production and reducing localised competition, therein stabilising or possibly improving productive capacity at the regional level. While the immediate goal of such a management system was probably to control resource production and distribution for the chiefs, other benefits may have included the redistribution of risk for the population at large through more efficient system maintenance including organisation of field fallows cycles, planting regimes, direction of labor and redistribution of goods. Kuaiwi could thus be argued to have functioned in a dual capacity, both reducing risk and increasing productivity through coordinated and more efficient management practices, as well as through their use as moisture-conserving planting features. Interestingly, the available radiocarbon dates suggest that kuaiwi construction (1500–1600 AD) preceded the period of intense regional competition that is apparent in other archaeological records (post-1600 AD) (e.g., Cordy, 2000; Schilt, 1984). This is an indication that their construction was driven by agronomic concerns rather than defensive/competitive ones. In other words, kuaiwi were not constructed as territorial markers under conditions of intense competition and conflict.

The 16th century may also have seen formal definition of Kona’s emic resource zones. In particular, there is some evidence that Kona’s breadfruit resources were developed around this time. While breadfruit was not highly regarded as a human food in Hawaii, it would have been useful forage for pigs, which played a significant role in Hawaiian religious rituals and could have acted as a kind of storage device for surplus food during good years. In times of famine or other food scarcity, supplies of this nutritious starch could have profitably been redirected to human populations (see Purseglove, 1968).

At Greenwell Garden, following terrace emplacement and kuaiwi construction, there is no archaeological evidence for further capital investments or variance minimization devices generally until the historic period. One interpretation is that this period reflects a redirection of gardening efforts to productive increases. Some support for this is found in Ward’s (2001) palynological analysis of samples from late garden features which indicates that charcoal production increased over time. The evidence is suggestive of increased burning on the landscape and presumably shorter periods of fallow, a pattern consistent with productive maximizing strategies.

Conclusions

The evidence detailed herein indicates that variance minimization strategies were in place in Kona by 1400–1450 AD and importantly, practiced in even the most productive localities like Greenwell Garden where the soils are comparatively deep and mature. These strategies diverted energy away from primary production and towards development of facilities and technologies that had stabilizing effects in the Kona context. Several of these devices have clear functional links with environmental variables that would have critically affected inter-annual agricultural production, namely variable precipitation and sedimentological instability. Shortly thereafter, by ca. 1500 AD, crop diversification, large-scale application of stone mulching technologies, and implementation of a regional system of agronomic management were also effected. Regional integration in particular may have been an essential precursor to the construction of large-scale agronomic facilities like kuaiwi, and would have aided co-ordination of productive activities and redistribution of labour and goods in response to changing conditions. These developments as a whole provided a more secure productive base and buffered against environmental perturbations.

After 1600 AD, there are no further capital improvements indicated at Greenwell Garden 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, as best demonstrated in the Kuakini Highway corridor (Schilt, 1984). Presumably it was sometime after this when systematic use of the most marginal agronomic environments, the barren lava flows, was initiated. Development of these marginal areas was quite costly, requiring large inputs of labour to make them productive. While they might be productive initially, the inherent vulnerability of these environments made them particularly susceptible to variation in precipitation, flooding, and soil degradation, especially as fallow cycles were shortened. Moreover, populations that came rely on the produce from these marginal fields would themselves be vulnerable to demographic loss. The patterns as a whole suggest a shift in the balance of variance minimizing and productive maximizing strategies, with the latter coming...
to dominate Kona’s agricultural practices in late prehistory. As Halstead and O’Shea (1989) observe, the development of an expanded social elite, which initially allowed for improvements in gardening efficiency, may have created new demands and stresses on what was always a delicately balanced agronomic system.

There both parallels and differences between the scenario I have outlined above and arguments made by Ladefoged and Graves (2000) for the Kohala dryland field system to the north. They too see a shift in the scale of agronomic management over time, from individuals to chiefs, and suggest that such changes could have functioned to alleviate risk. In Kona, I have argued that the processes of agronomic integration and shifts in the level of managerial oversight initially reduced risk through development of the district’s breadfruit resources, construction of multi-purpose facilities (kuaiwi) and probably through improved efficiency in routine agronomic tasks. However, over time, the needs and initiatives of a growing elite made increasing demands on producers and ultimately led to an emphasis on productive maximizing strategies; I suggest that the development of marginal areas was one such strategy. Ladefoged and Graves (2000) also argue that the chiefs played an important role in initiating the development of the marginal lands in Kohala. They further suggest, however, that because produce from these fields was “probably reserved for ceremonies, and as such would not have been available to support the dietary requirements of the local population” development of marginal lands would have had a dampening effect on population densities and the produce from them would have been available for distribution to the general populace in lean years (Ladefoged and Graves, 2000, p. 443). While these are possibilities, I argue that development of marginal areas could only be an effective buffer against environmental variability if a benign elite was in place (i.e., redistribution occurred), a secession/reduction of ritual ceremonies during bad years could be tolerated, and importantly in terms of the model presented earlier, if they enhanced/stabilized productivity over the long-term. If populations came to rely on these marginal fields for basic subsistence, the risk of demographic loss would be high.

The differences in perspectives outlined above underscore the difficulties of defining risk management (or variance minimization) behaviours and the importance of empirically evaluating the impact of different agronomic strategies. If Ladefoged and Graves (2000) are correct about the ways in which marginal field development lowered agronomic risk in Kohala, then the bet-hedging model predicts that we should see a corresponding stabilization of population size, shifts in population structure (as outlined previously) and reduced competition and nutritional stress.

I suggest that the demographic and social changes seen after ca. 1650 AD in Kona are consistent with predictions of the bet-hedging model, vis-à-vis an emphasis on productive maximizing strategies in unpredictable environments. Schilt (1984) documents increasing indicators of warfare and strife, as for example elaboration of refuge caves as defensive structures and temporary living areas. Cordy’s (2000) recent synthesize of Hawaii Island oral traditions points to the 1700s as a time of increasing warfare, with numerous large battles and invasions, both inter-district and inter-island. Some have also argued for a population decline around 1700 AD, possibly associated with famine, but there is no consensus on this issue (see Clark, 1988; Cordy, 1981, 2000, pp. 313–316; Kirch, 1984, 2000, pp. 293–296; Hommon, 1976; Schilt, 1984). Schilt (1984, p. 291) suggested this population decline represented a crisis in a system that had come to revolve around a “growth economy.” Like Hommon (1976, pp. 292–295), she argues that droughts and ensuing famines may have been a catalyst for political integration and territorial amalgamation in the post-1650 period. I have proposed, however, that regional integration had already taken place at an earlier period, represented agronomically by emplacement of the kuaiwi field system and development of the breadfruit plantations. What may be apparent at 1650 AD is the impact of the combination of an increasing emphasis on productive maximizing strategies, a large population, a growing costly elite, and the onset of environmental perturbations. The advantages provided early in time by political integration, territorial cohesion, and an emergent political hierarchy may have been lost as these same political forces attempted to maximize productive outputs, in an effort to generate surplus, in a risky and unpredictable environment.

While scenario outlined above is consistent with predictions of the bet-hedging model as applied to agricultural practices, the model cannot be fully evaluated with the data at hand. Considerably more detail on Kona’s agricultural history is needed, particularly excavation data that can inform on the construction, use, effectiveness, and chronology of gardening structures and variability therein. With regards to climatic information, I have necessarily relied on modern records of precipitation and flood patterns, along with geo-archaeological indicators of the effects of erosion. High-resolution prehistoric climatic data is required to more fully evaluate variability in precipitation over time and the onset and duration of significant climatic perturbations, particularly during the late prehistoric period. As outlined above, the bet-hedging model also makes predictions about the impact of different agronomic strategies on population size and structure. Unfortunately, we currently lack skeletal data from Kona that will allow for such assessment. Collins (1986) has analysed the relatively large Keōpū, Kona skeletal assemblage of 355 individuals from a 450-year period in some detail (see also a further analysis by Hunt and Lipo, 2001).
However, the lack of chronological control for specific individuals, means that potential changes in population structure cannot be discerned. Finally, the possibility that Kona’s population underwent a significant decline in the 1700s is an intriguing but under-studied possibility; a systematic in-depth re-analysis is clearly warranted, particularly given the volume of recent survey work in the Kona region.

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