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Farming in Hawai'i from Colonisation to Contact:
Radiocarbon Chronology and Implications for Cultural Change

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ABSTRACT

Eighty-four radiocarbon samples from irrigated and non-irrigated agricultural fields on Kaua'i, O'ahu, Moloka'i, and Hawai'i Islands have produced dates as early as A.D. 500. The deposition of agricultural charcoal is discussed, and the Hawaiian radiocarbon dates are used to evaluate certain culture historical models: it appears likely that both irrigated and non-irrigated agriculture were established shortly after colonisation in both coastal and inland locations and that, as suggested by earlier researchers, windward areas were cultivated earlier, with leeward fields developing after A.D. 1200.

Keywords: AGRICULTURE, RADIOCARBON DATES, HAWAI'I, IRRIGATION, DRYLAND AGRICULTURE, CHARCOAL DEPOSITS.

INTRODUCTION

Archaeological research at agricultural sites in the Hawaiian Islands has now generated a substantial body of radiocarbon dates processed on samples collected directly from pondfield (irrigated) and permanent dryland (non-irrigated) fields. No longer is it necessary to date agricultural fields indirectly, through assumed association with dated sites of other types. It is time to reassess Hawaiian agricultural developments, using agricultural dates and, beyond that, to apply the agricultural data to Hawaiian economic and socio-political models.

The pre-Contact (pre-A.D. 1778) patterns discussed here are suggested by 84 dates, out of a total of 93 (Appendix 1) that could be provenanced with fair confidence to cultivated soils. The nine omitted dates produced 'modern' or 'less than' historic-era values. The 84 dates discussed were processed by Beta Analytic Inc. (74 dates), Teledyne Isotopes (7), U.S.G.S. (2), and Gakushuin Laboratory (1).

The sites that produced the dates (Fig. 1; Appendix 1) are located on Kaua'i (6 dates), Moloka'i (2), Hawai'i Island (14), and especially O'ahu (62) (Allen *et al.* 1987; Allen [ed.] in prep.; Allen-Wheeler 1981; Athens 1983; Clark and Kirch 1983; Davis 1988, 1989; Dicks *et al.* 1987; Kaschko 1982; Kelly and Clark 1980; Kirch 1975a, 1975b; Newman 1970; Schilt 1980, 1984; Walker and Haun 1988; Watanabe 1986; Weisler 1989; Williams 1989; Yen *et al.* 1972).

Ni'ihau, Lana'i, Kaho'olawe, and Maui are not yet represented. Dates that may represent agriculture on Kaho'olawe come from unclear contexts.

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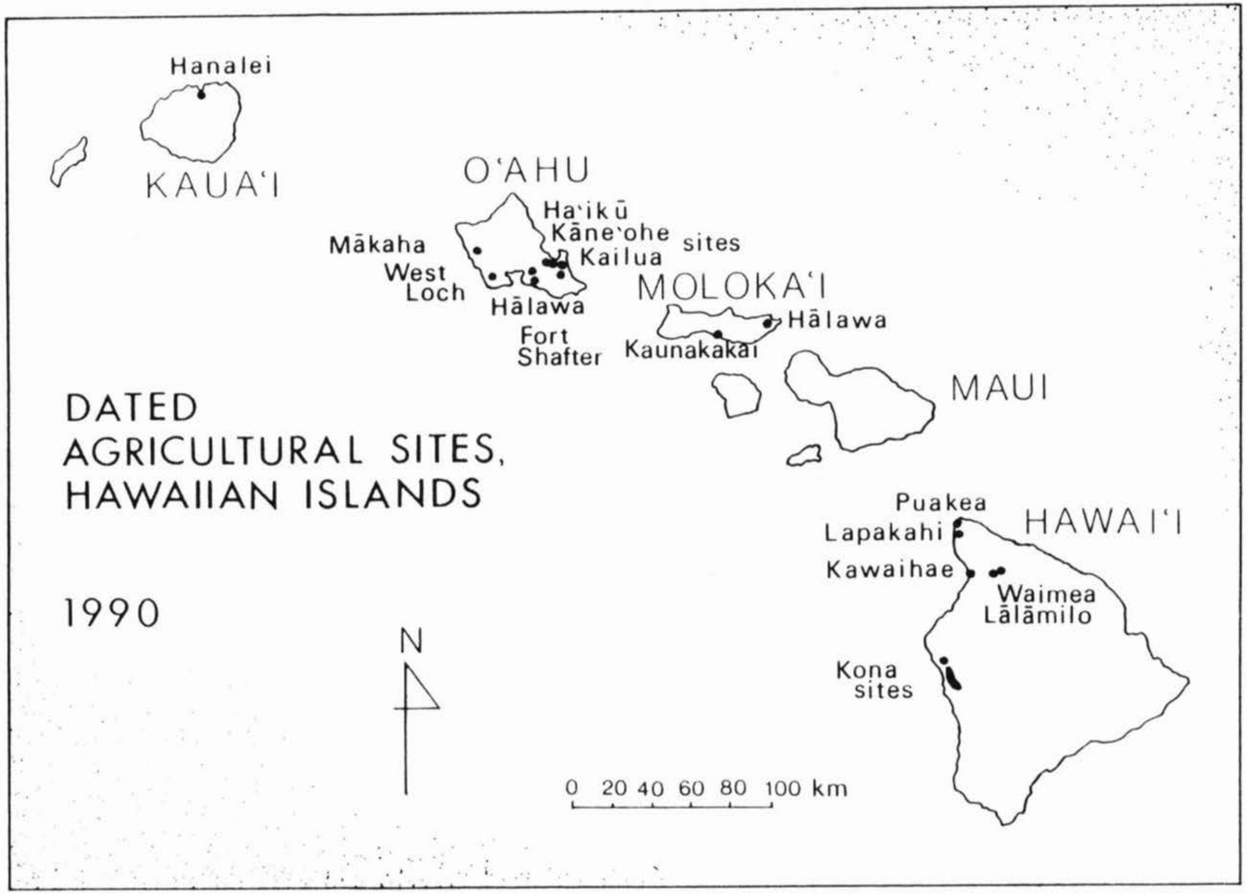

Figure 1: Hawaiian sites and localities mentioned in the text.

Most of the fields were used for the cultivation of taro (*Colocasia esculenta*), the dominant crop in Hawai'i until the mid-nineteenth century, when Chinese immigrants began to place large areas of former taro lands under rice cultivation. Pre-Contact dryland fields and gardens supported primarily taro and sweet potato (*Ipomoea batatas*) (e.g., Handy and Handy 1972; Yen 1974).

The 84 date ranges considered here were calibrated following Stuiver and Pearson (1986); the annual frequency distributions presented as Figures 2 to 5 were prepared by Eric Komori and Tom Dye, using the CALIB computer program (Dye, this issue; Stuiver and Reimer 1986). The dates and ranges reveal interesting patterns, not only in terms of pre-Contact agricultural and other cultural patterns, but also in terms of research biases over the years, and how those biases may affect our interpretations of Hawaiian prehistory.

RADIOCARBON-DATING AGRICULTURAL FIELDS: RATIONALE

Dating graphs are only as accurate as the data they incorporate. Biases and errors, although invisible in the printed distribution diagrams, influence our results: these may include methodological and theoretical biases; incorrect interpretation of site depositional processes; variable collection and processing practices; unpredicted, unrecognised sample contamination; and errors in analysis.

Certain changing research biases are discussed here. Although detailing collection and interpretive procedures and potential errors is beyond the scope of this article, certain points are mentioned briefly.

Serious problems can result from unresolved collection and/or laboratory processing errors. As an example, charcoal (HRC-895/896) from a deposit in a deeply-buried layer (VIII) in Luluku, Kāne'ohe, O'ahu (Fig. 1; Appendix 1) was split and sent to two different radiocarbon laboratories, Beta Analytic (Beta-16266) and Teledyne Isotopes (I-14520). The date range suggested by Beta Analytic is A.D. 410–1000); the Teledyne range is A.D. 1410–1955. A third sample, sent to Beta, was dated to A.D. 250–660, overlapping the other Beta range.

The discussion that follows addresses certain questions concerning the origin and nature of charcoal deposits in agricultural fields, in order to defend the dating of agricultural charcoal, and suggests parameters within which agricultural dates are reliable. I strongly encourage researchers working throughout the Indo-Pacific basin to date charcoal from well-defined and closely-controlled agricultural contexts, particularly when the sample is identifiable as a native plant. Few agricultural dates are yet available for areas outside Hawai'i; in fact, the earliest dates available for irrigated fields in the Pacific come from the Hawaiian Islands. Even in Hawai'i, the data base is really relatively robust only for O'ahu.

This discussion considers only *charcoal* dating. The dating of uncharred organics in an agricultural soil cannot yet be recommended, for the following reasons. Most agricultural soils in the humid tropics form on mixed sediments and soils transported from upslope localities by natural and/or cultural agents. These combined materials, which represent various ages and sources, are further mixed in the agricultural fields during cultivation. The datable organics in field soils are very finely fragmented and difficult to identify. At present, organics associated with actual site use are not differentiated from older organics for radiocarbon dating analysis. Bulk soil sample dates are therefore not yet considered reliable indicators of site age.

DEPOSITION OF CHARCOAL IN HAWAIIAN AGRICULTURAL FIELDS

Charcoal can arrive in agricultural fields in several ways. Lightning fires are rare in windward Hawaiian areas but must be considered in dry zones. The other documented depositional regimes, whether they result in primary or secondary deposits of charcoal, are all cultural.

Historical information

Charcoal was traditionally deposited in Hawaiian agricultural fields during clearing or refiring, and probably as fertiliser and mulch. Historical and ethnohistorical information suggests that most charcoal found in *kula* (hillslope) dryland taro and sweet potato fields resulted from the slash-and-burn clearing of forest or grassy vegetation in the field areas. Many dryland taro fields were reburned after four or five leaves had sprouted on each plant, to encourage luxuriant growth (Handy 1940; Kamakau 1976: 32).

The *ha'aheo*, 'aristocratic', dryland planting method included systematic mulching with *kūkaepua'a* (*Digitaria* spp.) grass in burned fields (Handy and Handy 1972: 105; Kamakau 1976: 32). Kamakau's statement that irrigated taro was also planted by the *ha'aheo* method in *'āpa'a* (dry) areas suggests that some pondfields, like dryland fields, were cleared by firing. Signs of initial firing of fields for pondfield—not dryland—cultivation are common on slopes in Maunawili and Luluku, both in windward O'ahu, and have been described for other areas including upper Mākaha Valley, leeward O'ahu (Green 1980: 75) and windward Kohala on Hawai'i Island (Tuggle and Tomonari-Tuggle 1980).

Bottomland fields (*pālāwai*) for sweet potato cultivation were cleared by burning. Although I have been unable to find a description of taro *pālāwai* clearing, bottomlands were certainly used for taro cultivation, and charcoal is common in thin bands that strongly suggest burning *in situ* throughout terraced bottomland taro fields in Luluku and Maunawili.

Mulching material in both dryland and irrigated fields probably included charcoal. Malo (1951: 205) indicates that many farmers added a mulch of "*kukui* [*Aleurites moluccana*] leaves, ashes, or dirt" to the taro planting holes. Other historical sources mention fertilisers and mulches including grasses (especially *kūkaepua'a*), bulrushes, ferns, *kukui* and *hau* (*Hibiscus tiliaceus*) leaves and branches, soil, and 'trash', which included weeds, probably soil, and possibly charcoal (Dunford 1980; 'I'i 1959; Kamakau 1976; Mitchell 1982; Wichman 1965). Burnt bone was applied to fields ploughed by *kerbau* during the nineteenth century (Handy 1940: 43). The only item in this list that is easily recognisable archaeologically is *kukui*, which is almost invariably present in pondfields, in the form of nutshells.

Historical information regarding ceremonial *imu* (earth ovens) that were excavated and used within pondfield terrace complexes, presumably resulting in the deposition of charcoal, is discussed in the following section.

Depositional processes: secondary and primary charcoal

Secondary charcoal generally reaches Hawaiian sites in sediments transported from upslope or upstream. Certain research questions asked today can benefit from the dating of even secondary charcoal, provided that sample and site integrity are interpreted accurately in the field, where associations between materials and matrix are amenable to examination. Dates based on secondary charcoal can suggest, for example, minimum sedimentation rates at a site—'minimum' because in-field analyses of sediments and soils are needed before it can be determined whether additional sediments have been lost, leaving no traces except erosional boundary characteristics. Dates based on secondary charcoal also inform about the period of occupation in a general area and may have important implications for even a primary site, as in the case of two dates (HRC-332, HRC-333) from lower slope localities beside Kawai Nui Marsh, O'ahu (Kelly and Clark 1980). These dates were the first evidence to suggest occupation around the Marsh border *ca.* A.D. 500–600, long before pondfield cultivation was established on the Marsh floor (Allen-Wheeler 1981; Cordy 1977, 1978, 1981).

It was at one time generally assumed that all charcoal in Hawaiian pondfields was secondary, transported there from dryland fields further upslope (e.g., Allen-Wheeler 1981; Athens 1983: 46; Kirch 1977: 255; Riley 1975a: 95, 1975b: 192). In the course of geoarchaeological investigations at a number of agricultural sites, both irrigated and non-irrigated, I have collected a large body of data that suggests otherwise.

Secondary charcoal is common in unterraced dryland fields in Hawai'i, where downslope transport is facilitated by overland floods and colluvial processes. Secondary charcoal transported from areas beyond site boundaries is much less common in even minimally-terraced dryland fields and is rarely recognised in well terraced pondfield soils. Field evidence cited by Allen *et al.* (1987: 177–179), Allen ([ed.] in prep.), Morgenstein and Burnett (1972: 96), Riley (1975b: 192–193) and Yen *et al.* (1972: 70, 89) suggests strongly that most charcoal recovered from terraced pondfields in Hawai'i represents primary deposition rather than secondary deposition from a source upslope beyond the boundaries of the complex. As is discussed below, a minor component may represent secondary deposition of charcoal originating in a primary deposit on another terrace in the same set, produced during the same period of use.

The even distribution of pondfield charcoal found archaeologically throughout both upper and lower terraces in sets in Luluku and Maunawili, in locations of varying distances from *'auwai* (ditches) and/or spillways, suggests that the charcoal was not transported into these complexes from further upstream by irrigation waters. Charcoal behaves like other lightweight solids during transport. Silts, clays, and the finest sands (and organics) float in slightly turbulent water and are transported primarily as suspended load, settling out as water velocity and turbulence decrease (Allen 1970; Fairbridge 1968). Charcoal carried by irrigation water would be expected to decrease dramatically in a terrace set as water depth and turbulence diminish; as distance from *'auwai*, stream, or posited upslope source increases; and as rock-walled terraces effectively trap water, soil, and all materials transported in either.

Pondfield terraces rely on carefully-engineered, near-level surfaces, as well as on rock retaining walls or earth berms, to slow both sedimentation and water flow efficiently. Although minor amounts of charcoal do travel short distances on a single terrace, sometimes collecting behind the berm or facing, and small amounts could conceivably pass from a higher terrace to the next terrace downslope through a gap spillway, it appears very unlikely that charcoal transported from terrace to terrace through channelled spillways could achieve the homogeneous dispersal that characterises fields from the uppermost to the lowermost terraces in complexes including those in Luluku and Maunawili.

Another type of evidence also suggests that most of the charcoal found in terraced pondfields originated in the terraced fields, rather than further upslope. While most or all of the pondfield layers in the sequences examined contain charcoal, the intervening colluvial deposits do not. Colluvial soils and sediments, invading from upslope, would be expected to produce the majority of the charcoal in each sequence if the charcoal recovered were indeed secondarily derived from upslope.

Identification of charcoal to species and assessment of species habitat preferences may also suggest primary or secondary status for charcoal found at an agricultural site.

The Luluku and Maunawili studies that produced the dates discussed here included identifications of charcoal from dated contexts (note: the fragments identified were not those submitted for dating analysis). Charcoal was identified for the following dated pondfield terraces in lower slope areas in Luluku and Maunawili (see Appendix 1): Site G5-85 Trench 3 Layers VIb, VIII; Site G5-85 Trench 4 Layer III; Site G6-51 Trench 2 Layer II; and Site G6-55 Trench 3 Layer IIb. The following taxa were identified with fair to good confidence for these contexts: *Abutilon* cf. *incanum*; *Acacia koa*; *Aleurites moluccana*; *Artocarpus altilis*; *Diospyros* sp.; *Ilex anomala*; *Psychotria* sp.; *Syzygium malaccense*; and *Syzygium* sp., probably *sandwicensis*. Site G6-56 Trench 1 Layer II, a pondfield layer in a terrace set that occupies a tributary streambed, produced insufficient charcoal for normal dating but yielded *Ilex anomala* and *Scaevola* cf. *mollis* identifications (Murakami 1987, in prep.; see discussion, Allen *et al.* 1987: 171–172).

Wood charcoal collected from a floodplain terrace in Maunawili (Site G6-69 Trench 4 Layer II) produced an erroneous 'modern' date but provided a *Hibiscus tiliaceus* identification. Another Maunawili floodplain pondfield layer, Site G6-70 Trench 3 Layer IIIa, produced *Acacia koa*, *Diospyros sandwicensis*, *Metrosideros polymorpha*, and *Syzygium malaccense* charcoal; Layer V was dated (Murakami in prep.; Allen [ed.] in prep.).

Aleurites moluccana (kukui), *Artocarpus altilis* (*'ulu*), *Hibiscus tiliaceus* (*hau*), and *Syzygium* (including *S. malaccense* [*'ōhi'a 'ai*]) grow commonly today in terraced areas in Luluku and Maunawili. *Kukui* and *hau* leaves and branches, as mentioned earlier, were traditional components of mulches added to taro fields; taro was often grown in clearings in *kukui* forest (Handy and Handy 1972). Pondfield soils in Hawai'i commonly contain *kukui* nut shells, which Handy and Handy (1972: 229) point out do not float. The nutshells may have been deposited by cultivators during mulching or may represent *kukui* forest remnants.

With one possible exception, all of the remaining charcoal taxa identified occupy, or include members that occupy, lower and midslope areas in wet to mesic windward forests (Neal 1965; Wagner *et al.* 1990) and probably grew in the areas where the charcoal was collected. The exception is *Abutilon*, which normally inhabits dry, leeward areas.

Wood weights and densities might suggest potential for transport and distant deposition by irrigation water. *Koa* and *Artocarpus* wood were used for canoes, and therefore float. The available information for the other taxa indicates only hardness. *Metrosideros*, for example, was named after iron because of its hardness. *Diospyros* and *Psychotria* are also hardwoods.

In summary, there is little reason to doubt that most charcoal recovered from a pondfield terrace was deposited either on that terrace or on another terrace very close at hand.

Some 'secondary' charcoal found in a pondfield complex may have originated in an *'auwai* within the complex. Nakuina (1893) describes the ceremonial *imu* (earth oven) that was dug at the junction of the stream and a new *'auwai* in preparation for consecration of the ditch. Each worker brought firewood; a pig and other foods were cooked and *'awa (Piper methysticum)* prepared; offerings were made; and a feast ensued beside the *'auwai*. When all the food had been eaten, the refuse was buried in the *imu*, and the *'auwai* dam was built and opened, allowing water to flow over the *imu* into the *'auwai*. Most charcoal deposited in a field system as the result of this ceremony should concentrate, like other secondary charcoal, in the uppermost terrace of the set.

DRYLAND AND PONDFIELD CHARCOAL CHARACTERISTICS

During the early days of archaeological research at agricultural sites in Hawai'i, charcoal in terraced pondfield soils, even in the presence of gleyed, homogeneous, silty to clayey soils, was often interpreted as representing dryland cultivation (e.g., Riley 1975a: 93–95; cf. Riley 1975b: 192–193). Primary charcoal recovered from dryland fields and charcoal recovered from *lo'i* (pondfields) possess distinct characteristics that reflect the two cultivation practices.

Dryland charcoal often includes small concentrations of relatively large, trunk-or branch-sized pieces, recovered from a variable, oxidised matrix that contains a range of particle sizes from clays to cobbles. Pondfield charcoal is finely fragmented. It occurs throughout the gleyed, finely-textured and well sorted pondfield matrix in the form of fragile, nearly unidentifiable pieces that have been broken down by stamping during preparation of the fields, by the mixing of soils during cultivation, and by the enhanced chemical and mechanical weathering that result from the alternating flooding and drying regimes that are part of pondfield technology.

AGRICULTURAL DATES AND CHANGING ARCHAEOLOGICAL MODELS

During the first three decades of radiocarbon dating, the 1950s to the 1970s, Hawaiian agricultural fields were occasionally 'dated' indirectly, by association with other, directly dated sites, especially habitation features; few charcoal samples collected from Hawaiian fields were submitted for dating analysis (for an exception, see Yen *et al.* 1972). The reasons for this omission were primarily two. First, as mentioned, charcoal found in agricultural fields was typically interpreted as secondary, derived from dryland fields upslope. Second, most research during the early years of Hawaiian archaeology focused on coastal areas, emphasising non-agricultural aspects of life (e.g., habitation patterns).

In contrast, much archaeological research today is conducted in inland areas, which suggest other avenues for investigation and offer evidence of different types. Two theoretical approaches in particular have fostered increasing research in agricultural fields: a geoarchaeological focus on landscape change; and interest in the role of agriculture in the emergence of the Hawaiian state system of government (Allen 1991; Allen *et al.* 1987; Kirch 1982a, 1982b).

The radiocarbon dates that have been processed as the result of the increasing emphasis on agricultural sites are represented in Figure 2 as two contrasting diagrams.

The first part of Figure 2 represents the six agricultural dates that were available to researchers during the 1970s, a decade that witnessed the publication of several important early models for cultural, including agricultural, developments in Hawai'i and Oceania (e.g., Brookfield 1972; Cordy 1981; Earle 1978; Hommon 1976; Kirch 1977, 1985; Kirch and Kelly 1975; Ladd and Yen 1972; Newman 1970; Riley 1975a, 1975b; Rosendahl 1972; Yen *et al.* 1972). The second part of Figure 2 represents all 84 agricultural dates and ranges processed up to 1990. Seventy-eight (93%) of the dates that are now available have been

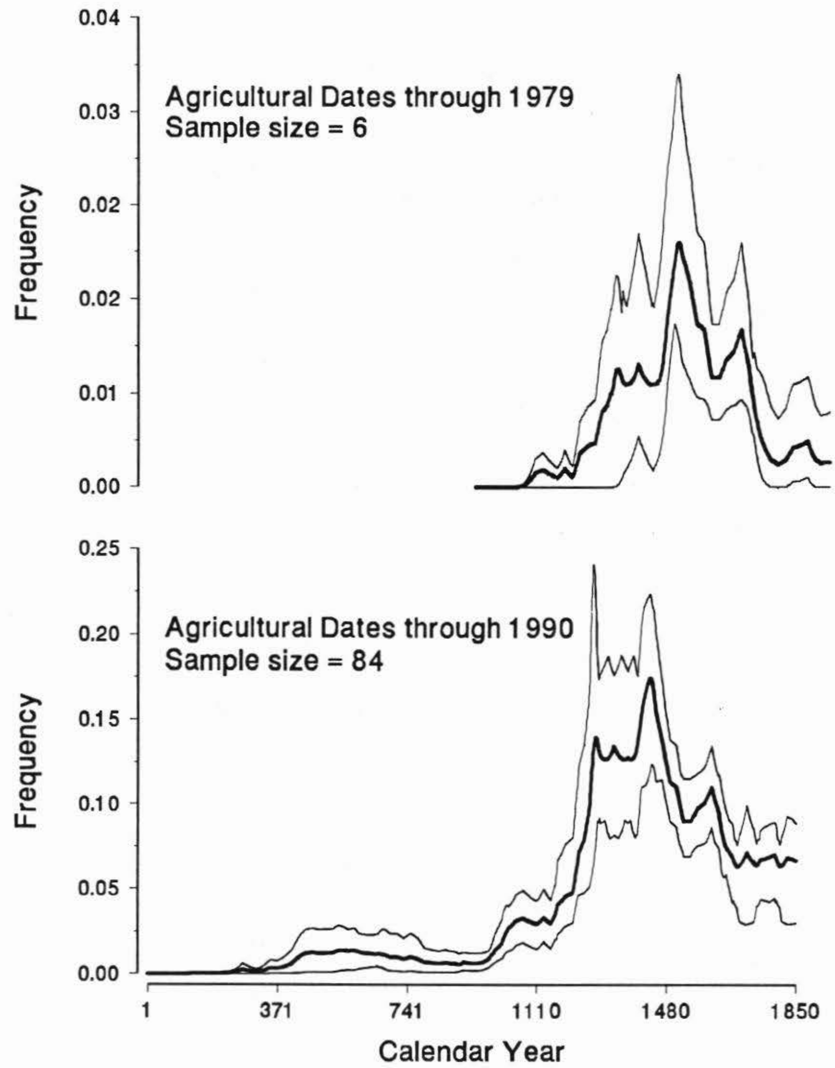

Figure 2: The first six agricultural radiocarbon dates obtained from Hawai'i contrasted with the 84 dates processed up to 1990.

processed since the publication of the early models, which inspired and helped generate later schemes.

As Figure 2 indicates, no pre-A.D. 1000 ranges were known until after 1979. The earliest accepted date available during the 1970s (from windward, coastal Moloka'i) represented the period around A.D. 1250. The curve peaked around 1450 and descended abruptly, disappearing before Contact.

The six dates available up to 1979 include a thirteenth century date (Appendix 1: HRC 182) from a coastal dryland field in Hālawa, Moloka'i (Kirch 1975a, 1975b); four pondfield dates (HRC 734–737: one fourteenth, two fifteenth, and one seventeenth/eighteenth century) from inland Mākaha, O'ahu (Ladd and Yen 1972); and a fifteenth century dryland field date (UH-16) from inland Lapakahi, leeward North Kohala, Hawai'i Island (Newman 1970). (A seventh, 'less than' date [Ayres 1970] is not considered.)

The thirteenth century date from Hālawa, Moloka'i, the only representative of either a windward or a coastal context, comes from a dryland field. The remaining dates available during the 1970s represent inland, leeward, dryland and irrigated fields, all postdating A.D. 1300.

The current curve incorporates thirteen pre-A.D. 1200 dates, six predating A.D. 800. The curve rises steeply after A.D. 1000, to peak between 1250 and 1400; descends to a moderate height by A.D. 1650; and maintains that height into the nineteenth century. The earliest dates represent dryland and irrigated fields, as well as intermediate fields (a type discussed below), in coastal and inland windward localities.

The thirteen pre-A.D. 1200 dates suggest that inland localities were in use approximately as early as coastal areas. Inland fields are represented in Hanalei, Kaua'i (HRC 337: 1 pondfield date, *ca.* A.D. 700); Luluku, O'ahu (HRC 744 and 895/896: 2 dates from a single pondfield, *ca.* A.D. 500 and 670; and HRC 1180, a dryland date, *ca.* A.D. 540); Punalu'u mauka, O'ahu (HRC 743, 1186: 2 dryland dates, *ca.* A.D. 1170); and Maunawili, O'ahu (HRC 1104, 1107: 2 pondfield dates, *ca.* A.D. 1140, 1170). Coastal localities include Kawai Nui, O'ahu (HRC 332, 333: 2 probable dryland agricultural dates *ca.* A.D. 550, 790) and West Loch, O'ahu (PHR 347, 348: 2 pondfield dates, *ca.* A.D. 1020, 1200). The final pre-A.D. 1200 field date (HRC 450), *ca.* A.D. 1140, represents a field of intermediate type in Kamuela, upland Hawai'i Island. Possible problems concerning the Hanalei and Luluku pondfield dates and the Kawai Nui dates will be discussed.

INTENSIFICATION AND INLAND EXPANSION

Most researchers agreed early on that the earliest Polynesian colonists of the Hawaiian Islands had arrived with knowledge of both dryland and irrigated agricultural technologies. But evidence from some localised areas during the 1970s often suggested that irrigated fields had developed later than dryland fields in those areas (e.g., Riley 1975a), and that initial clearing had accompanied dryland, not irrigated, cultivation.

The dates available at the time also suggested that agricultural expansion inland—either irrigated or dryland—had postdated A.D. 1200 in most areas. The Hawaiian people had apparently remained near the coast, which permitted fishing and gardening around houses, for perhaps the first millennium. While it was recognised that movement into inland areas at some point had been critical to the development of the *ahupua'a* (the basic Hawaiian land tenure unit, usually wedge-shaped, extending from mountains to sea) and the traditional land tenure system (e.g., Hommon 1976, 1986), many researchers assumed that inland settlement had taken place relatively recently.

In 1980, the first three pre-A.D. 800 radiocarbon dates from agricultural contexts appeared in the literature. Jeff Clark (Kelly and Clark 1980) published sixth to eighth century dates for two charcoal concentrations associated with dryland agriculture on a slope beside (coastal) Kawai Nui Marsh, O'ahu. Rose Schilt (1980) obtained an eighth century date from an inland pondfield in Hanalei, Kaua'i.

These three dates have been questioned many times (e.g., Athens 1983: 33–34, 46; Athens and Ward 1991: 17–18; Hammatt *et al.* 1990: 24; Neller 1982: 30–32), largely because they may represent secondary charcoal. Nonetheless, they suggested dryland cultivation beside Kawai Nui Marsh and pondfield cultivation in Hanalei by A.D. 800, either at or near the test localities. The dates also strengthened the case made by a tiny body of non-agricultural dates (both radiocarbon and volcanic glass) that suggested settlement before A.D. 800 on Hawai'i and O'ahu Islands (e.g., Emory and Sinoto 1969; Green 1971; Pearson *et al.* 1971; Tuggle *et al.* 1978).

The current data base includes six pre-A.D. 800 dates: three pondfield and three dryland dates from inland (3) and coastal (2) locations in windward O'ahu; and one from inland windward Kaua'i. The earliest (HRC 744: *ca.* A.D. 500) represents an inland Kāne'ohe pondfield buried 120–130 cm below surface; the fourth earliest date (HRC 895/896: *ca.* A.D. 670), from the same layer, is the Beta Analytic date for the sample that was split between Beta and Teledyne: as discussed earlier, Teledyne produced an A.D. 1410–1955 range.

Figure 3 compares current annual frequency distributions by field type. Only 73 dates are included; the remaining 11 (Appendix 1: entries designated "c") cannot be assigned to field type with confidence.

Figure 3 includes, in addition to information from pondfields and dryland fields, dates from intermediate fields, which demonstrate both dryland and pondfield characteristics (e.g., homogenised, silty, well terraced soils, in oxidised, not gleyed colours; minor ditch development) and were irrigated only periodically. Historically, Nakuina (1893: 83) describes the irrigation of *kula* fields during summers of surplus rainfall. Archaeologically, intermediate fields are known in areas near Kamuela, upland Hawai'i Island, and Maunawili, O'ahu, both areas of high rainfall (Allen [ed.] in prep.; Clark and Kirch 1983).

Four of the six pre-A.D. 800 dates that are currently available represent pondfields. As indicated, three date ranges have been suggested for the Layer VIII pondfield in Luluku (A.D. 250–660, 410–1000 [Beta], and 1410–1955 [Teledyne]); the Beta ranges, which overlap and appear consistent with stratigraphic and cultural evidence, are considered reliable. The Luluku ranges are the earliest yet known for agricultural contexts in Hawai'i.

Pondfields were apparently in use at least as early as permanent dryland fields. The intermediate field curve suggests relatively late development, which probably reflects the relatively inaccessible locations of these fields.

As discussed, the data also suggest that inland areas were cultivated shortly after colonisation, with well developed fields in use by A.D. 750 in Luluku and Hanalei. Suggestions that only coastal areas were settled for several centuries after colonisation, with expansion into inland areas postdating A.D. 1000 or even 1200, appear unsupported.

Non-agricultural dates (e.g., Williams 1989) from *imu* and firepits in upland Kāne'ohe are also beginning to suggest that inland expansion took place centuries earlier than had been thought initially.

Mauka-makai (mountain to sea) socio-economic networks, precursors of the *ahupua'a*, may have emerged soon after colonisation. Also, significantly, landscape transformation through burning and other deforestation techniques, cultivation, terracing, and abandonment, has taken place in Hawai'i over a period perhaps one millennium longer than had been thought.

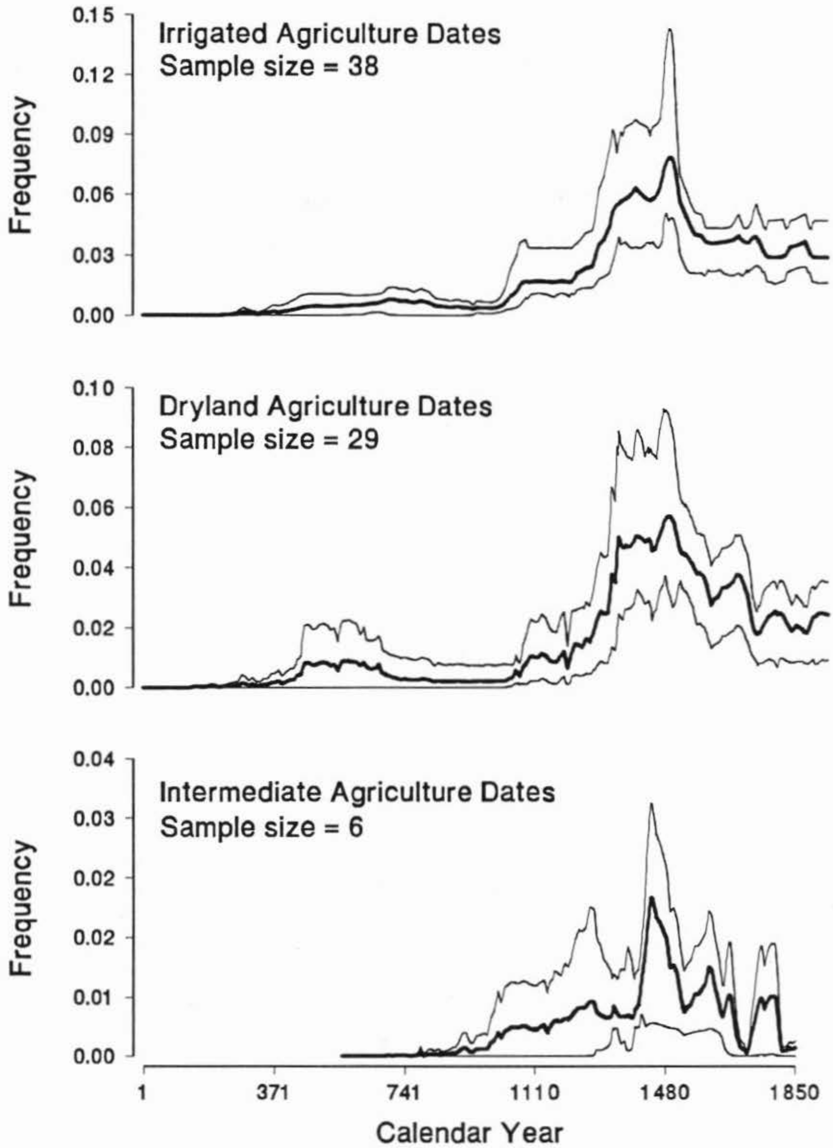

Figure 3: Radiocarbon dates from irrigated, dryland, and intermediate fields in Hawai'i.

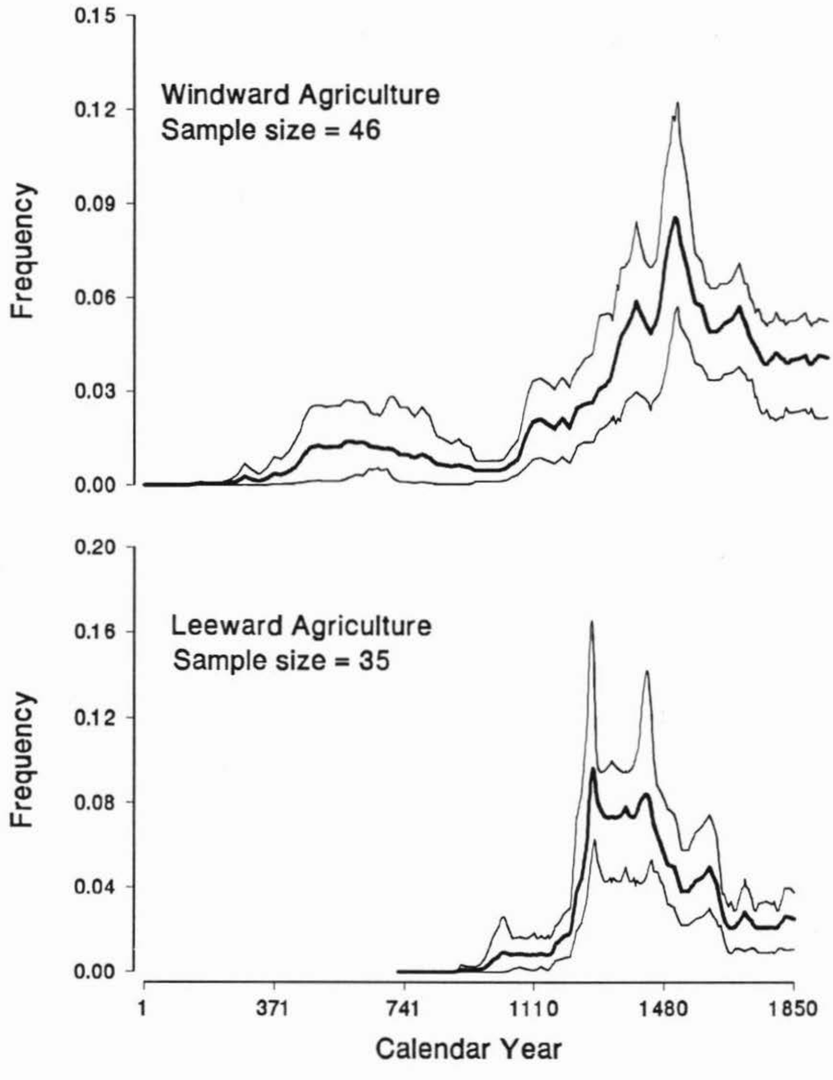

Figure 4: Radiocarbon dates for windward agriculture on Kaua'i, O'ahu, and Moloka'i, and leeward agriculture on O'ahu, Moloka'i, and Hawai'i.

THE WINDWARD AND LEEWARD AGRICULTURAL CHRONOLOGIES

Figure 4 compares 81 radiocarbon dates for windward (46) and leeward (35) locations throughout the 4 islands; 3 upland Hawai'i Island dates (Appendix 1: Lālāmilo and Section 4) are omitted. Figure 5 compares dates for windward and leeward O'ahu, the only island for which substantial data are available for both subsets.

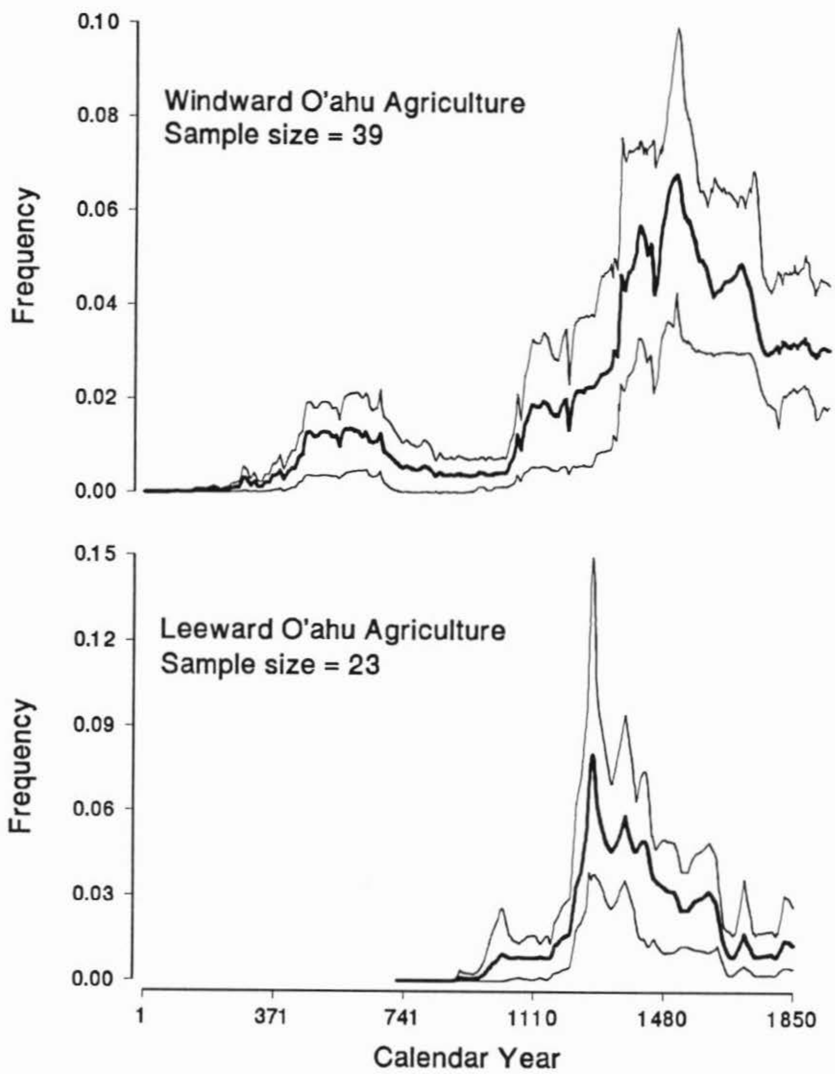

Figure 5: Radiocarbon dates for windward and leeward areas, O'ahu.

Early researchers suggested that settlement in the Hawaiian Islands had involved first windward areas, which offered adequate rainfall, full streams, and lush forests; and, only later, the drier, leeward coasts. The agricultural dates support that model, with pre-A.D. 1000 pondfield and dryland cultivation focusing on the windward coasts, and later fields occupying both windward and leeward valleys and slopes. On O'ahu, late fields appear well established in both windward Ko'olau Poko District and drier Kona, Ewa, and Wai'anae Districts by A.D. 1300.

CONCLUSION

Areas that offered both farming fields and fishing grounds were quickly occupied by the settlers of Hawai'i. The earliest agricultural dates come from areas that not only offered stream terraces or well watered slopes, but large, protected bays. Luluku and Punalu'u mauka, although inland locations, are less than 2 km from Kāne'ohe Bay. The Kawai Nui basin very probably held a lagoon when the first Polynesians arrived, which would have made the surrounding slopes coastal (see Allen *et al.* 1987: 258–260). The early Hanalei pondfield lies within walking distance of Hanalei Bay.

Perhaps the most tantalising of the pre-A.D. 1200 dates is that from West Loch, on O'ahu's dry, leeward side but associated with Pearl Harbor, which has recently produced artefacts of early types. Pearl Harbor is an enormous, well protected bay which, although much modified during the modern era, may yet produce the earliest evidence for Polynesian colonisation in the islands.

The agricultural expansion that took place after A.D. 1200, as the leaders of expanding Hawaiian polities required more and more foodstuffs as tribute, taxes, and as support for increasing numbers of retainers, apparently did not involve simple shifts inland. Both inland and coastal agricultural complexes presumably expanded; the remaining sites in both areas should show archaeological evidence of enlargement through time.

Farming was a central focus in the lives of Hawaiians. Taro was the staff of life, and Hawaiians considered themselves agriculturalists first and foremost. Although this article concerns only agricultural occupation, it is becoming increasingly clear, as more and more subsurface features are discovered near buried fields, that agricultural exploitation of an area generally involved at least temporary habitation nearby.

Agriculture was a primary consideration in settlement shifts and land use patterns; the diagrams presented here for agricultural sites are expected to anticipate both the locations of sites of other types and their dating sequences.

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APPENDIX 1

AGRICULTURAL RADIOCARBON DATES

Cat. No	*Lab. No*	*Site/Context/Material*	*Type*	*CRA*	$\delta^{13}C$
Hanalei, Kaua'i					
336	B-1239	D10-12?/TP4,LIII/ch	p.fal.?	380±80	-25.0†
337	B-1240	D10-12/TP1c,LIV/ch	p.	1290±95	-25.0†
388	B-2807	" /TrB,LV/ch	p.	80±50	-25.0†
389	B-2808	" /TrB,LIII/ch	c.	460±60	-25.0†
390	B-2809	" /TrC,LV/ch	p.	210±50	-25.0†
562	B-4157	" /TrC,LV/ch	p.	120±70	-25.0†
Ha'ikū Valley, He'eia ahupua'a, O'ahu					
1025	B-28498	G4-38/TU3,on facing rock/ch AMS	p.	410±60	‡
1080	B-30504	" /TU9,LIII/charred *kukui*	p.	250±60	-25.8
1081	B-30505	" /TU7,LII/uncharred *kukui*	p.	400±120	-25.2
1084	B-30508	" /TU3 Fe13,LII/uncharred *kukui*	p.	130±60	-25.5
Kea'ahala, Kāne'ohe ahupua'a, O'ahu					
1092	B-30516	G5-91/TU1 Fe8,LII-1/ch	d.	50±70	-28.4
Punalu'u mauka, Kāne'ohe, O'ahu					
743	B-13476	G5-86/Tr5,LII/ch	d.	880±90	-25.78
1034	B-28927	" /C2,below IIa/ch	d.	330±50	-27.8
1184	B-33678	" /C1,LII/ch	d.	490±80	-31.4
1185	B-33679	" /D2,LII/ch	d.	160±60	-27.9
1186	B-33680	" /C4,LII/ch	d.	880±70	-26.8
Luluku, Kāne'ohe, O'ahu					
717	B-12559	G5-85/Tr1,LVI/ch	p.	590±110	-26.56
718	B-12560	" /Tr2,LVI/ch	p.	620±70	-12.10
719	B-12561	" /Tr2,LVIIa/ch	d.	640±80	-26.26
721	B-12563	" /Tr3,LVIb/ch	p.	780±90	-17.14
720	B-12562	" /Tr2,LV/ch	p.	540±60	-32.59
744	B-13477	" /Tr3,LVIII/ch	p.	1560±100	-25.92
745	B-13478	" /Tr3a,LIII/ch	p.	430±100	.26.29
746	B-13479	" /Tr4,LIII/ch	prob.p.	610±90	-26.36
747	B-13480	" /TP2,LIII/ch	c.	290±60	-25.71
878,879,880	B-16264	" /Tr1,LIIIb/*kukui*	p.	300±80	-25.23
885	B-16265	" /Tr1a,LVIIIb/soil&ch	c.	160±60	-22.0
893	I-14558	" /Tr3,LVIb/ch	p.	310±140	-24.2
895,896	B-16266	" /Tr3,LVIII/ch	p.	1330±150	-25.41
895,896	I-14520	" /" "/ch	p.	260±130	-23.9
913	B-16267	" /TP2,LVI/ch AMS	p.	190±80	‡
1180	B-33377	G5-106/Tr11,LII/ch	d.	1530±60	-27.6
Kawai Nui, Kailua ahupua'a, O'ahu					
332	B-1137	G6-32/TP2,LI/ch	d.(s.)	1210±215	-25.0†
333	B-1138	" /TP7,LIa/ch	d. "	1500±145	-25.0†
419	B-3344	G6-39//TrB,LIV/*kukui*	p.	560±90	-25.0†
420	B-3345	" /TrB,LIV-V/*kukui*	p.	230±80	-25.0†

Maunawili, Kailua, O'ahu					
919	B-19453	G6-44/Tr1,LII/ch	d.	30±90	-25.29
922	B-21392	G6-48/Tr1,LIIa/ch	prob.d.	350±90	-22.7
923	B-21393	" /Tr1,LIIb/ch	prob.i.	380±110	-29.6
1096	B-30411	G6-49/Tr1,LIIb/ch	prob.i.	700±120	-20.0
1097	B-30412	G6-51/Tr2,LII/ch	prob.i.	420±60	-27.6
1099	B-30414	G6-55/Tr3,LIIb/ch	p.	50±80	-28.1
1100	B-30415	" /Tr2,LIIc/ch	d.	490±100	-27.5
1104	B-30419	G6-68/Tr4,LII/ch	p.	870±100	-24.1
1107	B-30422	G6-70/Tr3,LV/ch	p.	940±90	-26.2
Fort Shafter, Kona, O'ahu					
USACE 4A	B-17852	Terrace #4A/20-25cmbs/ch	p.	490±50	-16.71
North Hālawa, O'ahu					
1035	B-29274	B1-85/TU5,Fe16,LIII-1/ch	prob.d.	580±100	-27.4
1041	B-29280	B1-99/ST1,LIII/ch	prob.c.	20±50	-26.5
1043	B-29282	B1-98/ST4,LII/ch	prob.d.	360±70	-26.4
1044	B-29283	B1-90/TU6,LI(-2,-3)/ch	prob.d.	690±90	-25.3
1200	B-34091	B1-83/ST1,W.half,LII/ch	prob.d.	360±60	-23.4
1284	B-37631	B1-94/ST1,LII,IIa,andIII/ch	prob.d.	600±70	-27.1
1289	B-37636	B1-127/ST1,LIII/ch	prob.c.	690±80	-27.6
1290	B-37637	B1-128/LIII/ch	prob.c.	330±50	-28.0
1296	B-37643	B1-109/ST15,LII/ch	p.	610±70	-26.6
West Loch, 'Ewa, O'ahu					
PHR344	B-23722	?3324/Area2/BT7,140-150cmbs/ch	c.	30±80	-20.2
PHR346	B-23724	" /Area1/BT12,LIII/ch	p.	760±60	-21.0
PHR347	B-23725	" /Area1/BT12,LIII/ch	p.	850±70	-18.5
PHR348	B-23726	" /Area3/BT1,160-180cmbs/ch	p.	990±60	-21.3
PHR349	B-23727	" /Area3/BT4,LII/ch	p.	630±60	-23.6
PHR350	B-23728	" /Area1/BT14,130-140cmbs/ch	p.	730±70	-19.8
PHR353	B-23731	" /Area2/BT30,LIII/ch	c.	720±50	-24.2
PHR358	B-23736	" /Area2/BT7,130-140cmbs/ch	c.	340±70	-22.6
PHR360	B-24116	" /Area3/BT7,70-90cmbs/ch	p.	210±70	-23.0
Mākaha, Wai'anae, O'ahu					
734	I-4823	C4-286/T1,upper cult.(LV)/ch	p.	200±95	-25.0¶
735	I-4824	" /T1,lower cult.(LVI)/ch	p.	445±95	-25.0¶
736	I-4827	" /T3,lower cult.(LV)/ch	p.	405±90	-25.0¶
737	I-4825	" /T2,facing fill/ch	p.	565±110	-25.0¶
Hālawa, Moloka'i					
182	GaK-2744	A1-4/GUB, Bed 1/ch	prob.d.	750±90	-25.0¶
Kaunakakai ahupua'a, Moloka'i					
ACRS-AG001	B-27391	Mo887,Tr2/StrII/ch	d.	560±110	-27.4
Lapakahi, North Kohala, Hawai'i Island					
UH-16	I-4184	?/A12-B horizon boundary/ch	d.	405±95	-25.0¶
Puakea Bay, North Kohala, Hawai'i Island					
PHR4 RC4	B-4995	?/F4,TP,35-45cmbs/ch	d.	310±60	-25.0†
PHR3 RC5	B-4996	?/F4,TP,45-66cmbs/ch	d.	230±80	-25.0†
Waimea-Kawaihae, Hawai'i Island - Lālāmilo					
384	B-2718	Site 9178.1/TT1,LII/ch	prob.i.	200±40	-25.0†

Waimea-Kawaihae, Hawai'i Island - Section 4					
430	B-3590	" " /BHT,*'auwai* base/ch	prob.i.	430±90	-25.0†
450	B-4114	" " /TTr8,LII/ch	prob.i.	900±130	-25.0†
Waimea-Kawaihae, Hawai'i Island - Section 3					
375	B-2709	E2-126(5945B)/LI,lower/?	c.(s.?)	580±50	-25.0†
529	B-4124	" " /LI,lower/?	c.(s.?)	420±50	-25.0†
Waimea-Kawaihae, Hawai'i Island - Section 2					
499	B-3598	E3-432(8879K)/LI/?	prob.d.	170±70	-25.0†
500	B-3599	" " " /LI/?	prob.d.	710±70	-25.0†
Kona Field System, Hawai'i Island					
PHR405	B-27661	6601(10985)/FeA,TU1,I-1/ch	d.	520±80	-28.8
PHR407	B-27662	" "/FeC,TU4,LI-1/ch	d.	130±60	-27.3
Above Kailua-Kona, Hawai'i Island					
515	W-5031	D7-66/F62,BT4,LIIb/ch	d.g.	480±80	-25.0¶
516	W-5033	" /F61,TP6,LI/ch	d.g.	120±60	-25.0¶

Cat. No	Numbers are Bishop Museum (HRC) Nos unless otherwise designated;		
	ACRS	=	Marshall Weisler, for Moloka'i Ranch;
	PHR	=	Paul Rosendahl;
	UH	=	University of Hawai'i;
	USACE	=	U.S. Army Corps of Engineers.
Lab. No	B	=	Beta Analytic Laboratories;
	GaK	=	Gakushuin Laboratory, Japan;
	I	=	Teledyne Isotopes (earlier, Isotopes);
	W	=	Meyer Rubin and Richard Moore, U.S.G.S.
Type	c.	=	cultivated by unknown technology;
	d.	=	dryland;
	d.g.	=	small, dryland garden plot;
	i.	=	intermediate;
	p.	=	pondfield;
	p.fal.	=	pondfield, fallow-period soil;
	prob.	=	probably;
	s.	=	secondary.
Material	ch	=	wood charcoal;
	AMS	=	Accelerator Mass Spectrometry date;
	kukui	=	candlenut *Aleurites moluccana*.
CRA		=	Conventional Radiocarbon Age.

Status of $\delta^{13}C$ value

-25.0†	=	value known to have been estimated
‡	=	AMS date, no value given
-25.0¶	=	assumed but not verified that value was estimated