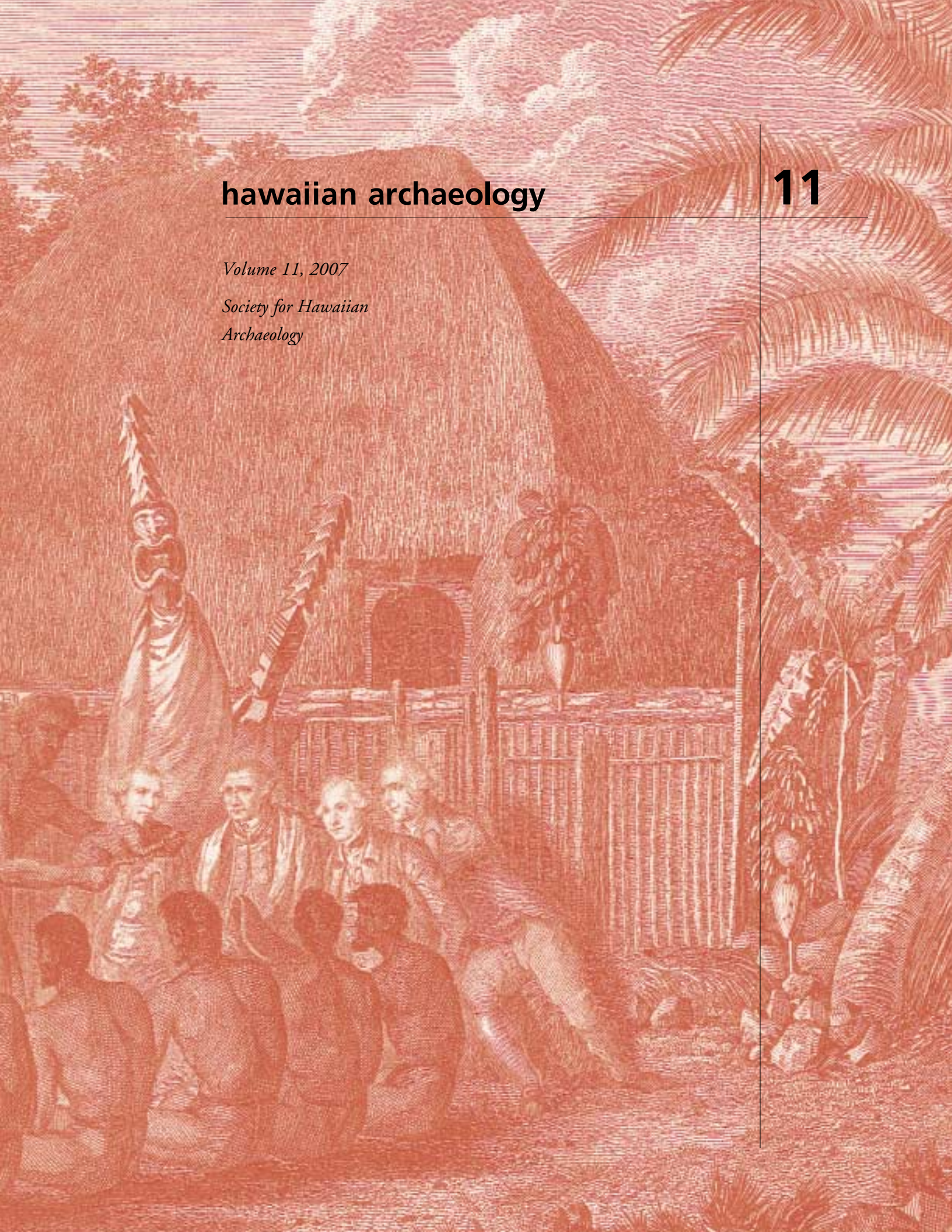


hawaiian archaeology 11

Volume 11, 2007

Society for Hawaiian Archaeology

hawaiian archaeology

Volume 11, 2007

Society for Hawaiian Archaeology

hawaiian archaeology 11

Michael Desilets and Mike T. Carson, Editors

ISSN 0890–1678

Contributor notes and subscription information can be found on the inside of the back cover of this volume.

Adze Production in Maui: Analysis of Lithic Materials from the West Rim of Haleakalā

Melanie A. Mintmier
Department of Anthropology,
University of Hawai'i at Mānoa

Introduction

Unlike some Hawaiian stone adze production sites (e.g., Mauna Kea, Hawai'i Island), detailed studies of adze manufacture at Haleakalā have never been conducted. Although not yet fully documented, a basalt quarry (Site 2510) exists between 2712 and 2804 m elevation (8900 to 9200 ft) along the *inner* west rim of the crater (Cleghorn et al. 1985; Somers 1988). Additionally, recent archaeological investigations (Carson and Mintmier 2006a) along the *outer* west rim have yielded evidence of adze manufacturing at several sites. Using lithic material from three of these sites, the analysis reported here serves as the first attempt to illuminate basalt adze production at Haleakalā, Maui.

The material examined comes from three sites (Sites 2509, 3603, and 3652) in the Haleakalā National Park, Maui, between 2460 and 2895 m elevation (8100 to 9500 ft) (Figure 1). The purpose of this research was to document basic manufacturing technology (e.g., reduction sequence, blank-type), production organization (e.g., intensity, spatial organization), and any changes over time. The results suggest that early reduction stages took place along the outer west rim, despite their location over extremely rough terrain up to 2 km from the nearest known quarry (Site 2510). Production intensity increased between A.D. 1400 and 1600 (see Carson and Mintmier 2006b), generally conforming to previous models of an expansion into, or more intensified use of, marginal areas by prehistoric Hawaiians (Kirch 1985:303–306).

A comparative approach was employed to begin integrating this new information from Maui into archipelago-wide discussions of stone adze production. Other

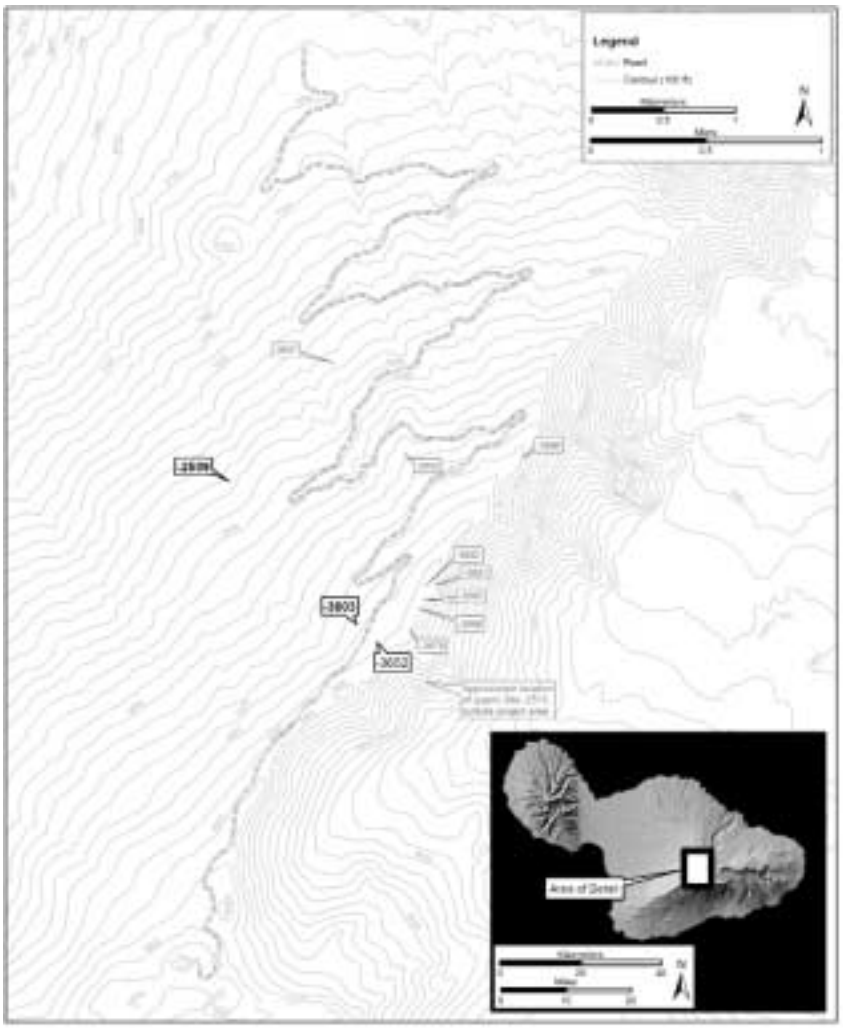


Figure 1. Distribution of sites with basalt debitage on the outer west rim of Haleakalā. Adze manufacturing assemblages from Sites 2509, 3603, and 3652 (bold) were selected for the present analysis.

Hawaiian islands (and elsewhere in the Pacific) have been more thoroughly researched (e.g., Leach and Leach 1980; Leach and Witter 1987; McCoy 1977; McCoy et al. 1993; Weisler 1990), as stone adze studies have long been an important part of Pacific archaeology. It is necessary, therefore, to outline germane archaeological research previously conducted in the Pacific. An overview of the study location and its tentative culture history are also presented. The research methods and results are summarized, followed by a discussion of the broader implications of this research.

Pacific and Hawaiian Adze Studies

Early Pacific adze studies often focused on typological analysis of finished adzes for the construction of culture histories or historical relationships between different geographic localities (Buck 1930; Buck et al. 1930; Duff 1959, 1970; Emory 1968; Green 1971; Green and Dessaint 1978; Skinner 1921). More recent investigations, however, have focused on technology, interaction and exchange, craft economies, and socio-political systems (Cleghorn 1986; Earle 1997; Kirch 1984; Lass 1994, 1998; Leach 1981, 1993, 1996; McCoy 1990; McCoy and Gould 1977; Sinton and Sinoto 1997; Turner 1992; but, see West 2000). Hawaiian adze production, in particular, has been the subject of intensive technological and economic analysis.

Research at the Mauna Kea adze quarry complex on Hawai'i Island represents some of the earliest technological studies in the Pacific (McCoy 1977, 1986, 1990; McCoy and Gould 1977). McCoy and colleagues conducted similar research at the Pu'u Moiwi adze quarry complex on Kaho'olawe (McCoy et al. 1993). Cleghorn's (1982; 1986; see also Lass 1994; Williams 1989) research provides a detailed technological study of the Mauna Kea adze manufacturing sequence, as well as a highly valuable set of experimental data. These data were used to test hypotheses about knapping skill, labor organization, and craft specialization. Such studies have yielded insights into adze production on Hawai'i (e.g., production intensity, degree and nature of standardization, labor organization) and the possible social, political, and religious influences on adze production (Cleghorn 1986; Lass 1994; McCoy 1990, 1999; Williams 1989). While adze manufacture on Hawai'i Island, particularly at Mauna Kea, has been studied more thoroughly than nearly anywhere else in the Pacific, other Hawaiian islands remain a mystery. This knowledge gap prompted the present analysis of adze manufacture at Haleakalā.

Before proceeding further, it is important to provide a general model of the Hawaiian adze reduction sequence. Hawaiian adze manufacture likely included seven basic steps (Table 1) (Cleghorn 1982; Kirch 1985; McCoy 1977, 1990; Williams 1989). The first was raw material procurement from sources of

Table 1. Ideal steps of quadrangular adze reduction in Hawai'i (adapted from Cleghorn 1982:217–220 and Williams 1989:49–61).

Step	Description
1	Raw material procurement
2	Primary reduction
3	Basic cross-section shape formation
4	Bevel and/or tang formation
5	Grinding
6	Polishing
7	Maintenance (resharpening, refurbishing)

appropriate stone (e.g., basalt outcrops). The second step was primary reduction; this served to remove excess material, often for easier transport away from the immediate extraction location. The third step consisted of shaping the adze's fundamental cross-section (e.g., quadrangular). Fourth, the bevel was formed, and (if desired) a tang. Smaller adzes, for example, were often left without a tang. Steps 3 and 4 frequently took place away from the immediate procurement area, though still within the general vicinity. For instance, many cave shelters near basalt quarries exhibit Step 2, 3, or 4 activities (McCoy and Gould 1977). Fully roughed-out adzes (preforms) were then transported, usually long distances, to habitation sites where they were ground (Step 5) and polished (Step 6) into finished form. Finally, Step 7 includes maintenance activities (e.g., resharpening), which likely occurred at habitation sites as well (for exception see Bayman and Moniz-Nakamura 2001). This seven-step model will be employed here to facilitate description and compare manufacturing activities evident at Hawaiian adze production sites.

Study Area

The present analysis stems from an archaeological investigation conducted under contract with the Haleakalā National Park (Carson and Mintmier 2006a). A total of 57 sites were documented, along with 243 associated surface features. Twenty-four excavation units yielded a variety of artifacts, animal bone, charcoal, and other materials. The three sites in this analysis (Sites 2509, 3603, and 3652) are located near the outer west crater rim of Haleakalā, Maui (see Figure 1). The environmental setting is harsh and inhospitable for human habitation, with strong winds from the north and east and cold nighttime temperatures (at times well below freezing with wind-chill factor). Whiteaker (1980) reports that the climate is dry and moderately warm in the summers, and windy, wet, and cold in the winters. Clouds are frequently present during mid-day in all seasons. An "inversion layer" (formed by the meeting of sinking and rising air masses) exists around 2134 m (7000 ft) elevation, often meaning warmer temperatures and less rainfall above this altitude (Zeigler 2002:76–79; see also Carson and Mintmier 2006a:8–9).

The ecological setting is alpine (cinder desert) and sub-alpine, with both endemic and introduced plant, insect, and bird species present (including the seasonally-nesting *'ua'u,* or Hawaiian dark-rumped petrel). No edible plants and very little water are available, especially at higher elevations. The sites analyzed here are situated between 2460 and 2895 m (8100 and 9500 ft) elevation in the alpine zone (Sites 3603 and 3652) and near the border of the alpine and sub-alpine zones (Site 2509) (Carson and Mintmier 2006a:28, 51, 85). Winds in this region are often fierce, making shelter during any time of year desirable. Likewise, decreases in oxygen at higher altitudes, especially within the alpine zone, increases the risk of hypoxia. Such harsh environmental conditions likely affected the spatial organization of adze manufacture at Haleakalā.

Several archaeological surveys were conducted in all or part of the study area during the 1960s and 1970s (Komori and Oshima 1977; Rosendahl 1978; Rosendahl and Dye 1977; Soehren 1963), but systematic lithic analyses were not attempted. The prior surveys included the documentation of site locations, completion of site records, description of lithic surface scatters (e.g., counting of debitage), and excavation of small test units (e.g., Soehren 1963).

SIHP Sites 50-50-11-2509, 3603, and 3652

Site 2509 includes two cave shelters, a surface scatter of basalt debitage, and a stone cairn (Figures 2 and 3). One of the cave shelters shows evidence of a basalt stone wall enclosure that may have been

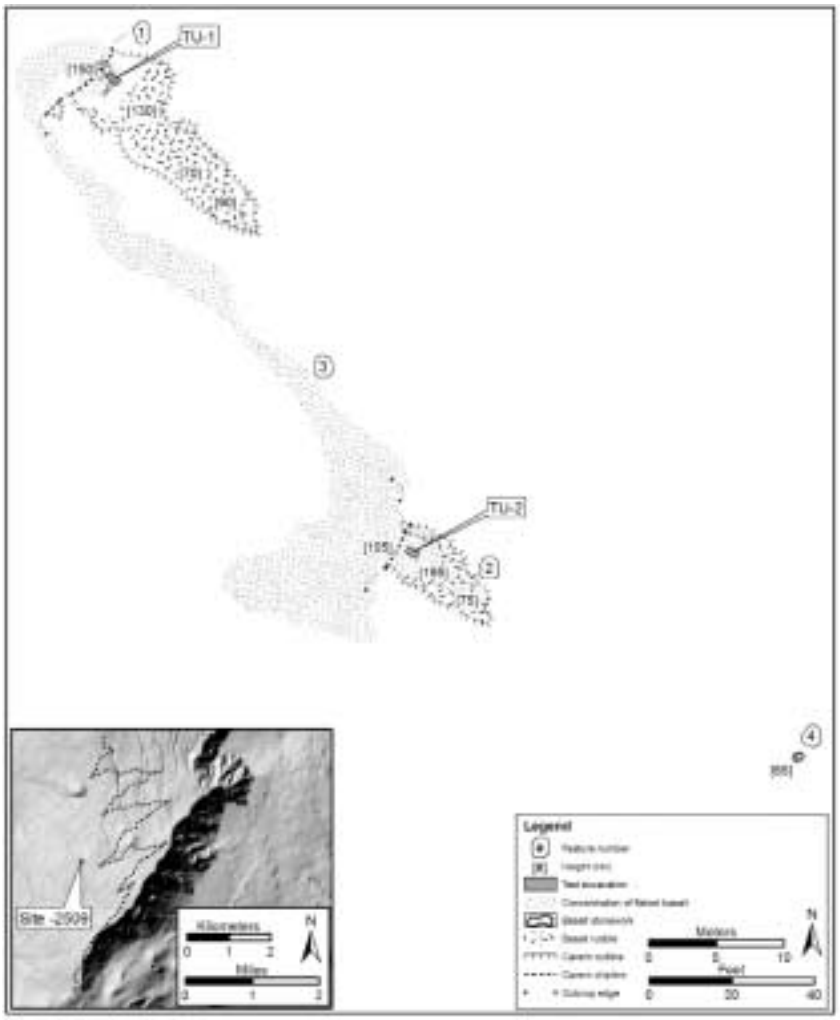


Figure 2. Map of Site 2509.

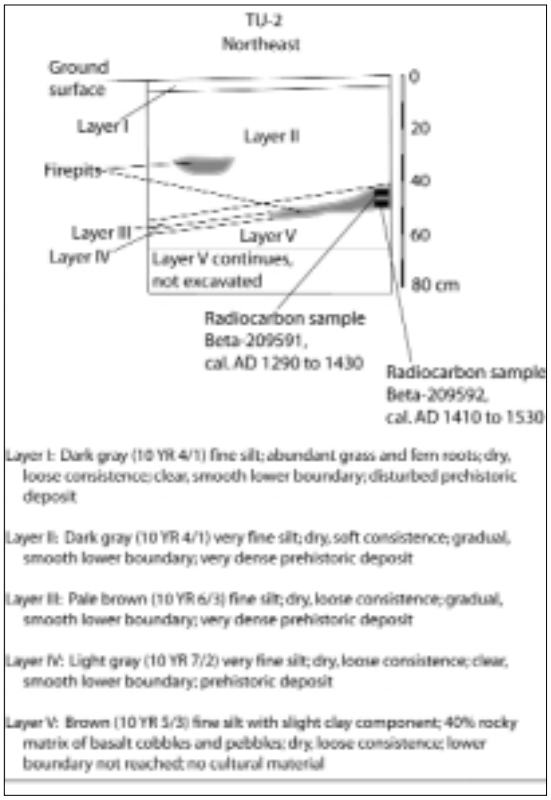


Figure 3. Profile of excavation unit at cave shelter feature 2 of Site 2509.

stacked at the entrance to retain heat and/or block wind. The site is located between 2468 and 2499 m (8100 and 8200 ft) elevation in the border area of the alpine and sub-alpine zones. This site has the most abundant basalt adze manufacturing evidence in the study area.

Site 3603 includes a cave shelter and a surface scatter of basalt debitage (Figures 4 and 5). This cave shelter also possesses evidence of a basalt stone wall enclosure at the entrance. The site is located in the alpine zone at 2832 m (9290 ft) elevation. Compared with Sites 2509 and 3652, this site contains the least amount of lithic material.

Site 3652 includes a cave shelter and a surface scatter of basalt debitage (Figures 6, 7, and 8). This cave shelter also shows evidence of a basalt stone wall enclosure at the entrance. The site is located in the alpine zone at 2889 m (9480 ft) elevation.

These three sites were chosen because they possessed a relatively high concentration of basalt materials—adze rejects (*sensu* Kooyman 2000:176; McCoy 1991:39), hammer-stones, and debitage—both on and below the surface. The prehistoric artifacts found at these sites include basalt adze rejects, debitage, hammer-stones, limited modified basalt flakes (possibly retouched or used), charcoal, marine shell, and bird bone (Carson and Mintmier 2006a). Site 2509 was probably used from the late A.D. 1200s to 1700s and possibly later, whereas Sites 3603 and 3652 were probably used from A.D. 1400 to 1700 and possibly later (see below for further detail).

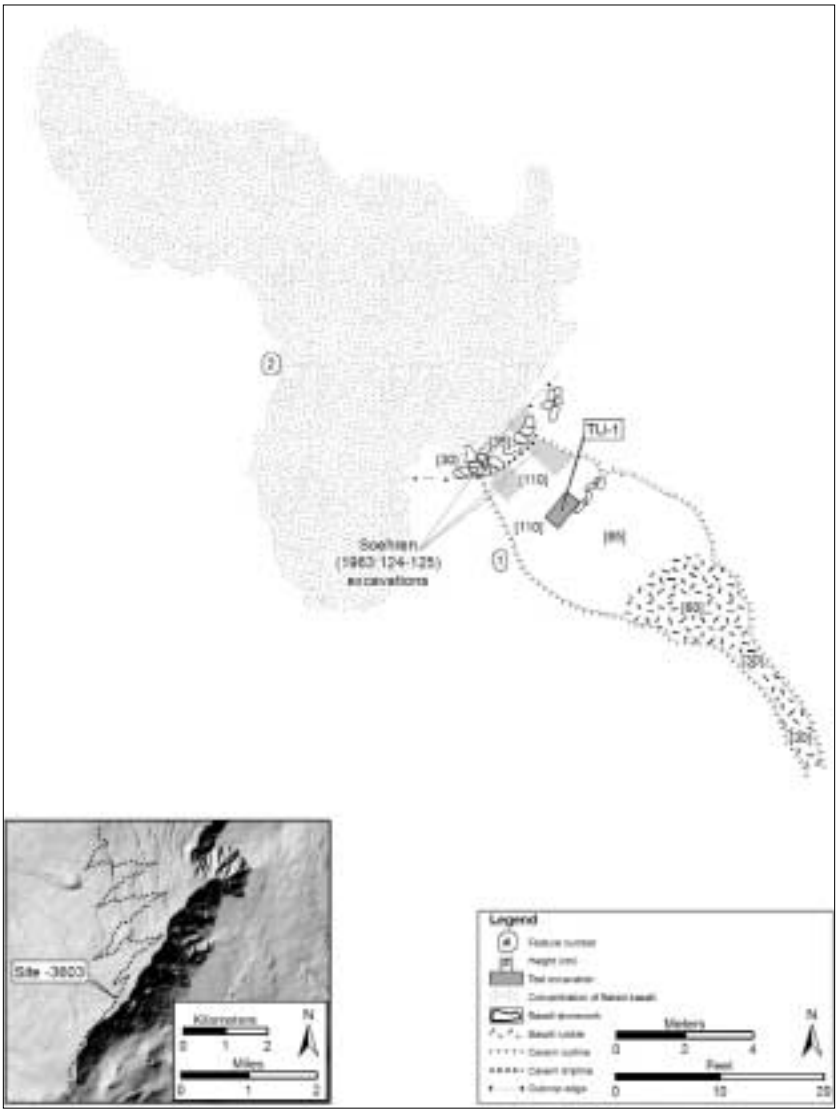


Figure 4. Map of Site 3603.

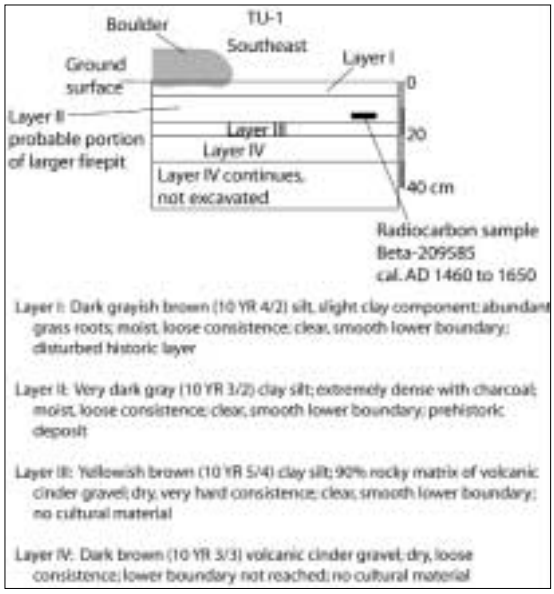


Figure 5. Profile of excavation unit at cave shelter feature 1 of Site 3603.

These adze production sites are located 0.5 to 2 straight-line kilometers (see Figure 1), over irregular and rocky terrain, from the nearest known basalt quarry (Site 2510), which is situated on the *inner* side of the crater rim (see Cleghorn et al. 1985:239; Somers 1988). Unfortunately, systematic archaeological work has not yet been completed at this quarry site, leaving many questions about adze procurement and production organization presently unanswerable. The present study of lithic material from adze manufacturing sites down-slope, however, provides necessary foundational information about adze production at Haleakalā, Maui.

Culture History of the West Rim of Haleakalā

The specific culture history of Haleakalā's west crater rim is outlined elsewhere (Carson and Mintmier 2006b; see also Carson and Mintmier 2006a: 17–18, 162–167) and is based on relative stratigraphy of 24 test excavations and 12 radiocarbon dates obtained from charcoal specimens of short-lived plant species, primarily *Styphelia tameaimeia (pukiawe)* (Figure 9). The following chronology is necessarily tentative and is in some ways a local refinement of Kirch's (1985:298–308) archipelago-wide sequence.

Archaeological evidence of human activity at Haleakalā prior to A.D. 1250 is limited (but, see Soehren 1963). Bird collecting and basalt adze manufacturing activities are apparent by around A.D. 1250 to 1400. At present this applies only to the *outer* west rim, as people traveling to the crater via the Ko'olau or Kaupō gaps may have been doing so earlier, owing to the more moderate terrain (Kirch 1985:137).

Around A.D. 1400 to 1600, an intensification of activity occurred in many sites along the outer west rim, particularly basalt adze manufacture. This period

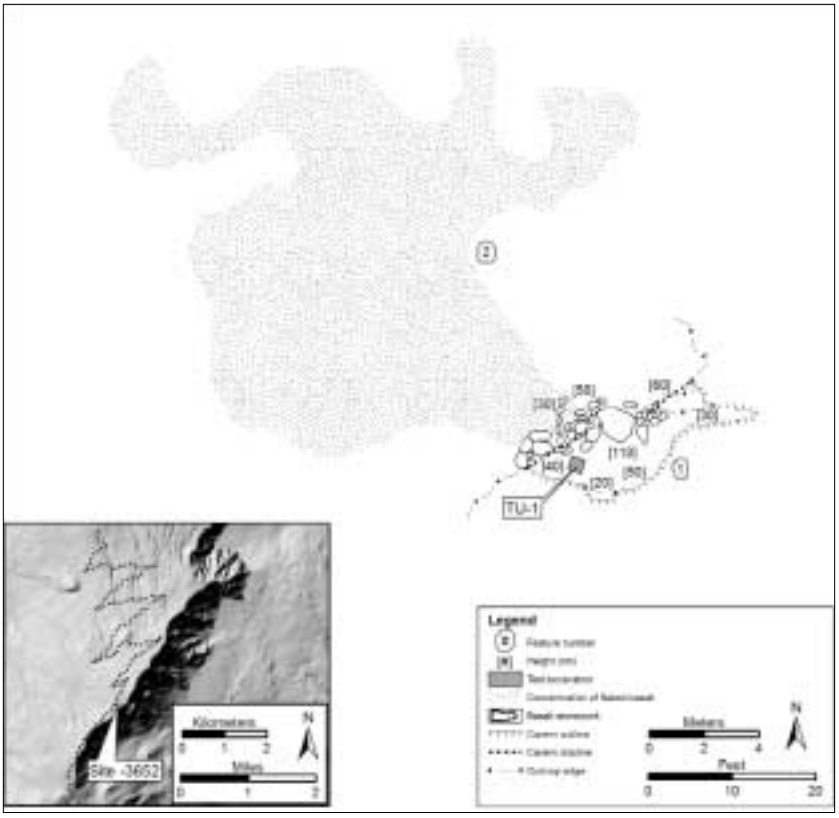


Figure 6. Map of Site 3652.

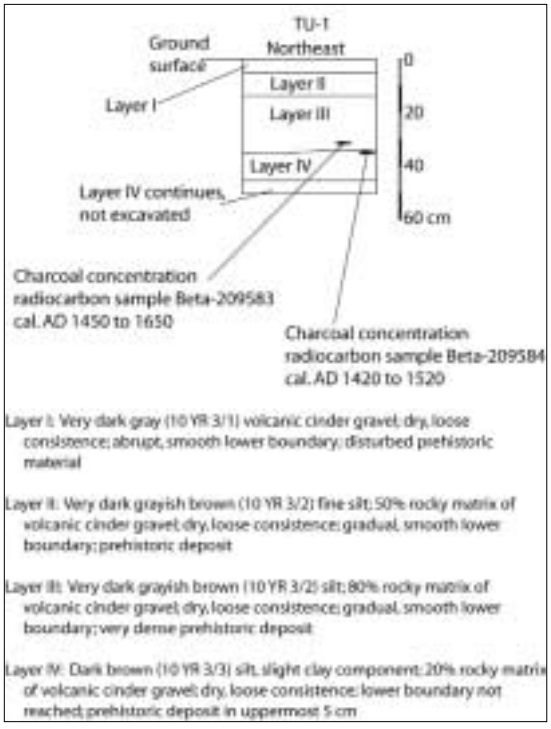


Figure 7. Profile of excavation unit at cave shelter feature 1 of Site 3652.

corresponds to the latter portion of Kirch's (1985: 303–306) Expansion Period, when archipelago-wide increases in population, more intensified use of marginal areas, and new socio-religious organization likely took place. Some researchers have proposed that the *ahupua'a* land division system was first established during the Expansion Period (Cordy 2004; Hommon 1976, 1986). It is difficult to assess the impact of this system on adze production at Haleakalā because of ambiguity in both *ahupua'a* boundaries in the crater area and shifts in control over time.

Following this period of intense use and continuing until European contact in A.D. 1778, adze production remained considerable at Haleakalā. Evidence of bird collecting activities decreased, however. Bird populations likely declined over time due to human exploitation and introduced species such as rodents (e.g., Athens et al. 1991; Athens et al. 2002).

Immediately after Contact (A.D. 1778) to about 1850, prehistoric activities like basalt adze manufacture and bird catching ceased in this area. During the early historic period, the west slope and summit region was traversed by sandalwood collectors and others traveling cross-island or to explore the crater and summit. Later historical use included limited cattle grazing (in lower elevations) and forest-planting experiments. Since 1916, the National Park Service has owned and managed the area to preserve Haleakalā's natural and cultural resources for their appreciation now and in the future.

With respect to adze production, this tentative culture history of Haleakalā differs somewhat from similar sites on Hawai'i Island, such as Mauna Kea, Pōhakuloa, and Pololū. The chronology of adze manufacture at Haleakalā (approximately A.D. 1250 to Contact) differs only slightly from that of the Mauna Kea adze quarry complex, used from about A.D. 1100 to 1750 (Cleghorn 1986:377; McCoy 1990:92). Pōhakuloa, on the other hand, was used between A.D. 1400 and 1800, with perhaps some activity in the early A.D. 1800s (Bayman et al. 2004; Bayman and Moniz-Nakamura 2001). At Pololū, adze manufacture ranged from A.D. 1650 to 1800; however, these dates are tentative due to a paucity of datable material from subsurface contexts (Lass 1994:33–34). With future research at the Haleakalā

Figure 8. Photograph of cave shelter feature 1 of Site 3652, view to southwest.

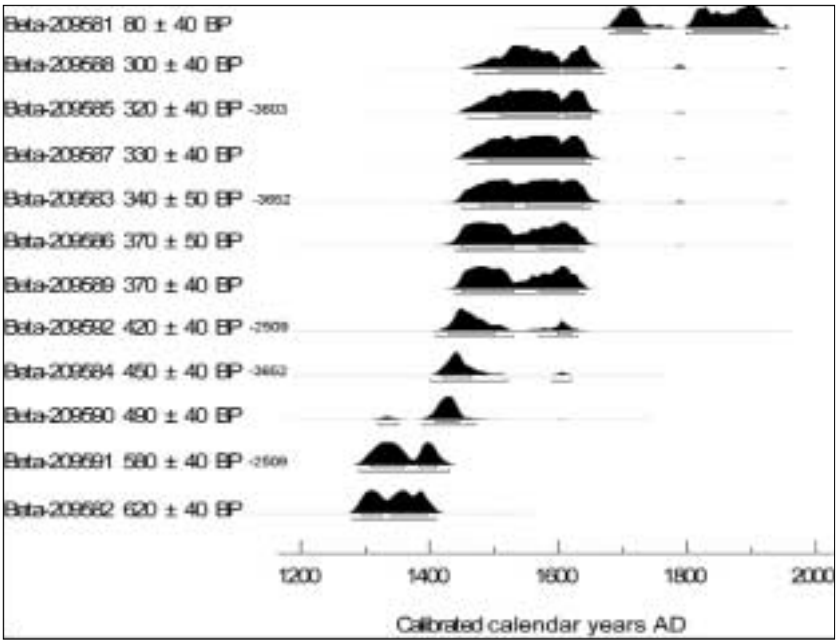


Figure 9. Distribution of calibrated calendar ranges for radiocarbon dates from the outer west rim of Haleakalā (Carson and Mintmier 2006).

quarry site (Site 2510), broader questions may be addressed pertaining to the use and abandonment of quarry-based sites versus expedient adze manufacturing sites (Leach 1993).

Methods

The basalt specimens included in this analysis consisted only of what was collected from small (50 x 50 cm and 50 x 100 cm) test excavations. The test units were excavated by 5 or 10 cm levels within natural strata, and 1.6 mm (1/16-inch) wire-mesh was used for screening. All 51 adze rejects (no ground, used, or refurbished adzes were recovered) from Sites 2509, 3603, and 3652 were analyzed, as was an approximately 6% selective sample of debitage (7,029 of a total 110,651). Sampling included arbitrarily selecting materials, whereby one or two bulk bags of debitage from each excavation level were chosen for inclusion.

Data collection for all adze rejects focused on seven attribute sets:

1) weight, length, width (midsection), thickness;
2) material color and texture;
3) basic cross-section shape (e.g., quadrangular, triangular);
4) presence and location of cortex;
5) blank type (flake, weather-worn cobble, or tabular block);
6) presence of bevel and/or tang; and
7) condition (whole, fragment).

These attribute sets were chosen to describe the assemblage's basic characteristics (e.g., average length, general morphology) and to facilitate comparison with other analyzed assemblages (Bayman and Moniz-Nakamura 2001; Cleghorn 1982; Lass 1994; McCoy 1991; Williams 1989).

For all diagnostic debitage flakes—those having evidence of a striking platform (Cleghorn 1982)—recorded attributes included:

1) count;
2) size grade (6 to 13 mm, 14 to 25 mm, 26 to 50 mm, 51 to 79 mm, and >79 mm); and
3) mass weights.

When collecting size grade data (Stahle and Dunn 1982), each flake was oriented on the size grade template in the same way: striking platform at the top of the square, ventral side facing up. The use of a size grade template proved highly efficient for processing such a large quantity of debitage flakes (n=7000+).

Within the general sample, a smaller sub-sample (approximately 12% of all diagnostic flakes analyzed) was arbitrarily selected for individual attribute recording, which entailed the collection of four attribute sets:

Table 2. Mean lengths of whole adzes from selected production sites in Hawai'i.

Site	No.	Mean length (mm)	References
Pōhakuloa, Hawai'i	2	82.5	Bayman and Moniz Nakamura (2001:247)
Kapohaku, Lāna'i	22	84	Weisler (1990:37)
Haleakalā, Maui	13	100	Present study
Pololū, Hawai'i	19	123.7	Lass (1994:42)
Mauna Kea, Hawai'i	63	176.2	Cleghorn (1982:182–183)

1) weight, length, width;
2) material color and texture;
3) presence and location of cortex; and
4) flake shape (e.g., parallel, divergent) (see appendix in Cleghorn 1982).

In addition to facilitating inter-assemblage comparison, these flake attribute sets allowed for inferences about production scale and general reduction steps. For instance, percentage of cortex in a debitage assemblage (Dibble et al. 2005) and general flake shape (Cleghorn 1982:267–268) can reflect certain reduction steps.

Analysis of recorded lithic attributes included basic statistical techniques, such as frequency distribution, percentage comparison, and mean calculation. Using established principles of lithic reduction technology (Andrefsky 1998, 2001; Kooyman 2000; Whittaker 1994) and data from adze manufacturing experiments (Cleghorn 1982; see also Williams 1989), inferences were made about production scale, reduction steps, and blank type characteristics.

Additionally, a comparative approach was employed in order to place these three adze manufacturing sites from Haleakalā into a wider geographic context. The results were compared to those from three sites on Hawai'i Island, namely Mauna Kea (Cleghorn 1982, 1986; McCoy 1977, 1986, 1990; Williams 1989), Pōhakuloa (Bayman et al. 2004; Bayman and Moniz-Nakamura 2001), and Pololū (Lass 1994). These sites were chosen because they 1) include subsurface materials, 2) provide data that facilitate some degree of comparison with the present study, and 3) are located outside Maui. It is hoped that this comparison will help increase Haleakalā's role in broader discussions of Hawaiian adze production.

Adze Reject Analysis

The cross-section shape of the majority (38 of 51) of the adze rejects is roughly quadrangular, with the other 13 being roughly lenticular, triangular, or irregular. They range in length from 24 to 205 mm (with a mean of 77 mm). Of these 51 adze rejects, 13 are whole and have a mean length of 100 mm (Table 2).

All but one or two were fashioned from fairly fine-grained, gray basalt. The remaining one or two rejects (one specimen is difficult to classify) likely represent failed attempts at working coarse, weather-worn cobbles found in nearby talus accumulations.

The majority (42 of 51) of the adze rejects were fashioned from flake blanks, or blanks produced by removing flakes from a parent core (Figure 10). Weisler (1990:34, 38–41) calls this a "flake series reduction strategy," noting that it is a dominant reduction strategy on Lāna'i and Moloka'i, as well as in New Zealand and Samoa (see Leach and Leach 1980; Leach and Witter 1987). Many flake blank adze rejects were small (50 mm or less), suggesting that they could have derived from the debitage of larger adze blanks (Leach 1981:174). One adze reject showed signs (cortex on all but one side and rectangular cross-section shape) of being fashioned from a tabular-block, similar to those found at Mauna Kea (Figure 11). The remaining eight were difficult to categorize, but were probably derived from large flake blanks which have had any signs of the original flake (e.g., bulb of percussion, striking platform) obliterated by subsequent adze shaping processes.

Twelve out of the 51 adze rejects possess cortex, signifying that at least for a portion of blanks, primary reduction (Step 2) took place at these sites. One adze reject (the tabular-block blank, see Figure 11) displays cortex on all but one side, suggesting the natural (though possibly limited) availability of this blank type. None of the adze rejects display any morphological features of tang formation, but some possess bevels. This likewise suggests that primarily

Figure 10. Photograph of flake blank adze rejects from cave shelter feature 2 of Site 2509.

Figure 11. Photograph of tabular-block blank adze reject from cave shelter feature 2 of Site 2509.

early-preform reduction activity took place at these sites (Steps 2, 3, and partial Step 4).

The main reasons for adze blank discard are "end-shock fracture" (31 adze rejects) and undesirable flake removal (8 adze rejects). End-shock "occurs when a blow directed at one side of the preform dislodges a chunk from the opposite side; it results from slight imperfections that interrupt the normal elasticity of the stone" (Crabtree 1972:60; McCoy and Gould 1977:239). It is presently unclear why the remaining 12 adze rejects were discarded.

As noted above, no ground adze rejects, flakes exhibiting polish, or grinding stones were discovered. This indicates that the final steps (5 and 6) of adze manufacture occurred at sites further downslope or nearer the coast, probably in residential areas.

Debitage Analysis

Over 110,000 pieces of bulk debitage (including countable flakes and shatter, excluding micro-debitage) were recovered from the three sites, most of which (99,375) were located at Site 2509 (see Figure 1). Given the homogeneous nature of the debitage, which proved evident in the similarity of attributes, samples are considered reasonably representative of the collected materials.

Based on two 50 x 100 cm test units (see Figure 2), estimates of debitage volume at Site 2509 are 137,068 items per cubic meter. This site is geographically farther (approximately 2 km) than the other two sites (0.5 and 0.75 km) from the nearest known quarry (see Figure 1), and it consists of two cave shelters with lithic concentrations inside and outside the drip line. The scale of adze production between approximately A.D. 1250–1400 and European contact (1778) appears to have been considerable at this particular site. Although the other sites yielded less debitage in comparison to Site 2509, the overall quantity recovered attests to a significant amount of adze production (Table 3) over the course of approximately 400–500 years.

From the abundant bulk debitage, an approximately 6% sample of diagnostic flakes (7,029 count) was sorted according to size grade (Table 4; Figure 12). The presence of relatively large flakes (size grades 51 to 79 mm and >79 mm) suggests that at least some large adze blanks were reduced at these sites, corrob-

Table 3. Count, weight, and volume estimates of bulk debitage for selected sites at Haleakalā.

Site	Count	Weight (g)	Volume Estimate (sq. m)
3603	593	734.40	3,953/1.0 m
3652	10,683	24,448.91	94,960/1.0 m
2509	99,375	177,139.03	137,068/1.0 m

Table 4. Size, grade, percentage, and frequency in sample of diagnostic flakes from selected sites at Haleakalā (note that Site 2509 contains two cave shelter features).

Size (mm)	Percent	Frequency	Size (mm)	Percent	Frequency
Site 3603 (cave shelter feature 1, 2831 m elevation)			*Site 2509 (cave shelter feature 1, 2468–2499 m elevation)*		
6–13	24.7%	52	6–13	9.9%	53
14–25	70.1%	126	14–25	45.6%	244
26–50	38.5%	61	26–50	36.8%	197
51–79	9.1%	14	51–79	6.4%	34
79+	0.8%	2	79+	1.3%	7
	Total	**255**		**Total**	**535**
Site 3652 (cave shelter feature 1, 2889 m elevation)			*Site 2509 (cave shelter feature 2, 2468–2499 m elevation*		
6–13	20.1%	629	6–13	12.2%	378
14–25	48.1%	1507	14–25	38.3%	1189
26–50	26.5%	832	26–50	36.8%	1143
51–79	4.6%	144	51–79	9.8%	303
79+	0.7%	23	79+	2.9%	91
	Total	**3135**		**Total**	**3104**

Figure 12. Photograph of representative diagnostic flakes from cave shelter feature 2 of Site 2509. Flakes arranged from smallest size grade to largest.

orating suggestions of early-stage adze reduction activity. The reasons for transporting heavy and largely unworked basalt blanks up to 2 km from the nearest procurement site are not yet fully understood, but hazardous climatic conditions at the nearest basalt quarry (e.g., intense wind, risk of exposure, steep and unstable terrain, and oxygen deprivation) most probably played a significant role (McCoy 1990:98). For instance, Site 2509 is located at the lower limit of the alpine zone and just above the local atmospheric inversion layer, making this site climatically more hospitable than either near the crater rim or further down-slope, where cloud cover and rain are common.

A smaller sub-sample of debitage flakes (approximately 12% or 861 of the 7,029 diagnostic flakes) was subject to individual attribute recording. These detailed data show that flakes possessing cortex make up approximately 13% (116 of 861) of the sub-sample, which also indicates that early stages of adze reduction occurred at these sites. Likewise, the majority (79% or 678) of the 861 sub-sample exhibit divergent or irregular morphology. As Cleghorn's (1982:267–268) experimentation and analysis show, these divergent and irregular flake shapes are associated primarily with general preform reduction (Steps 2 through 4).

Using the seven-step model of Hawaiian quadrangular adze manufacture (see Table 1), a tentative outline of the spatial organization of production can be proposed for Haleakalā. Adze makers procured basalt material (Step 1), presumably from Site 2510 (quarry), and transported it up and over the crater rim then slightly downslope for basic preform reduction (Steps 2 and 3) at cave shelter sites. Some evidence for bevel formation was present in the analyzed assemblage, indicating that partial Step 4 manufacturing activities took place. No definitive evidence of tang formation activities was found at these sites (e.g., rejects with tangs, certain flake shapes possibly associated with tang formation, see Cleghorn 1982: 268); however, it is possible that it occurred. Finish-

Table 5. Inter-site comparison of stone adze production characteristics from selected sites on Maui and Hawai'i Island.

Variable	Haleakalā (average of Sites 2509, 3603, and 3652	Mauna Kea (Cleghorn 1982; McCoy 1977, 1991; Williams 1989)	Pōhakuloa Site 5003 (Bayman and Moniz-Nakamura 2001)	Pololū Site 4981 (Lass 1994)
Production Scale	*Moderate*	*High*	*Low*	*Low*
	Total Debitage Count: 36,884	Various	Total Debitage Count: 729	Total Debitage Count: 3,500
	Volume estimate: 78,660/1.0 m^3		Volume estimate: 486/1.0 m^3	Volume estimate: 3,850/1.0 m^3
Reduction Steps Present	Primary: 2, 3	Primary: 1, 2, 3, 4	Primary: 1, 2, 3	Primary: 1, 2, 3
(see Table 1)	Limited: 1, 4 (bevel formation only)		Limited: 6, 7	Limited: 4 (bevel formation only)
Blank Types	Flake blank: majority	Flake blank: majority	Flake blank: few	Flake blank: minority
	Cobble blank: few	Cobble blank:minority	Cobble blank: few	Cobble blank: majority
	Tabular blank: one	Tabular blank: minority	Tabular blank: none	Tabular blank: none

ing activities (Steps 5 and 6) and maintenance (Step 7) took place elsewhere, most probably at sites further down-slope or closer to the coast.

Discussion

The selected Haleakalā adze manufacturing assemblages are fairly similar morphologically to those of other production sites in the Hawaiian Islands (Bayman et al. 2004; Bayman and Moniz-Nakamura 2001; Cleghorn 1982, 1984; Emory 1968; Kirch 1985:184–189; McCoy 1991; Weisler 1990). The majority of adze rejects are roughly quadrangular in cross-section shape. Bevel formation is evident, but there is no evidence of tang formation. Mauna Kea appears to be unique in this regard, with some tanged specimens present in the assemblage. Debitage consists largely of divergent-shaped flakes that are generally short and thick. End shock fractures, a common reason for discard at many adze manufacturing sites (McCoy and Gould 1977:239), are also prevalent in Haleakalā's adze reject assemblage. Production scale at these three sites, indicated by debitage amounts over time of use, falls somewhere between Mauna Kea (Cleghorn 1986; McCoy 1990) on one extreme and Pōhakuloa (Bayman et al. 2004; Bayman and Moniz-Nakamura 2001) on the other (Table 5). Further, production intensified around A.D. 1400–1600.

Unlike Pōhakuloa (Bayman et al. 2004; Bayman and Moniz-Nakamura 2001) and Mauna Kea (Cleghorn 1982, 1986; McCoy 1977; Williams 1989), production activity in cave shelters along the outer west rim of Haleakalā (see Figure 1) appears to include, if not center on, *early* preform reduction (Steps 2, 3, and partial Step 4). One probable implication is that the quarry site was primarily for extraction, with only limited blank reduction occurring at the quarry itself (Cleghorn, personal communication 2006). The quarry (Site 2510), located along the inner rim of the crater, likely exposed adze makers to particularly harsh environmental conditions, so perhaps comfortable working space was limited. Without more information from the quarry site itself, however, such speculations remain untested.

Inter-site comparison also reveals slight differences in the primary type of blank being fashioned into adzes (see Table 5). At Haleakalā, flake blank types are far more prevalent than either tabular-block

blank or cobble blank types. Cobble blanks were the predominant type used at the site of Lass's (1994:37) study at Pololū (a so-called expedient production site), where stone from an adjacent stream bed was the primary raw material. At Pōhakuloa (also a so-called expedient manufacturing site), flake blank types represent the main type, but in small overall quantity (Bayman and Moniz-Nakamura 2001). At Mauna Kea, all blank types are present, with flake blanks used slightly more often and for higher quality basalt material, as well as for smaller blanks (Cleghorn 1986:379). Additionally, basalt at Mauna Kea often erodes in tabular slabs, which were highly valued for the manufacture of larger, robust adzes, presumably for heavy-use tasks such as tree-felling (McCoy 1990:96). Quite reasonably, the nature of the available raw material heavily influences the blank type and, thus, the reduction strategy employed (and in some cases the form and perhaps even the function of the finished adze). Tabular-block blanks, for example, are more prevalent at manufacturing sites associated with basalt sources that erode into flat, tabular shapes. Not surprisingly, "flake series reduction" seems to be a general, and therefore more prevalent, manufacturing strategy used throughout the Pacific (Leach and Leach 1980; Weisler 1990).

Conclusions

Based on the present research, which is admittedly small in scope, it seems that adze production at Haleakalā does not easily fit in to Leach's (1993) "two-tier quarry system"; whereby certain quarry complexes in the Pacific (e.g., Mauna Kea in Hawai'i or Tatagamatau in American Samoa) are large and oriented for export, while others are much smaller and geared for local use. The evidence presented here supports a "continuum" model of adze production sites, at least for Hawai'i, with expedient manufacturing sites and large-scale quarry sites co-existing with moderate-scale production areas like Haleakalā. Data from Haleakalā's basalt quarry (Site 2510) and from geochemical sourcing studies must be gathered, however, before more definitive conclusions can be drawn about the nature of adze production on Maui and in the Hawaiian Islands.

Acknowledgments

The present analysis involved data collected during an archaeological survey project conducted by International Archaeological Research Institute, Inc. (IARII) under contract to the National Park Service in 2005 for Task Order T8298050002 of Indefinite Quantity Contract C8298030001. J. Stephen Athens was principal investigator for IARII. Elizabeth Gordon represented cultural resource management concerns for Haleakalā National Park. Their generous support of this analysis is greatly appreciated. Many thanks go to Mike T. Carson (IARII) for his guidance throughout the research and writing process. Likewise, this article is largely based on a paper submitted for my M.A. degree at the University of Hawai'i at Mānoa, and would not have been possible without the guidance of James M. Bayman, Barry V. Rolett, and Miriam T. Stark. Thanks also to Paul Cleghorn and two anonymous reviewers who provided valuable comments. I am solely responsible for any errors or omissions in this study.

References Cited

Andrefsky, W. J. 1998. *Lithics: Macroscopic Approaches to Analysis*. Cambridge University Press, Cambridge.

———. 2001. *Lithic Debitage: Context, Form, Meaning*. University of Utah Press, Salt Lake City.

Athens, J. S., M. W. Kaschko, and H. F. James. 1991. Prehistoric Bird Hunters: High Altitude Resource Exploitation on Hawai'i Island. *Bishop Museum Occasional Papers* 31:63–84.

Athens, J. S., H. D. Tuggle, J. V. Ward, and D. J. Welch. 2002. Avifaunal Extinctions, Vegetation Change, and Polynesian Impacts in Prehistoric Hawai'i. *Archaeology in Oceania* 37:57–78.

Bayman, J. M. 2003. Stone Adze Economies in Post-Contact Hawaii. In *Stone Tool Traditions in the Contact Era*, edited by C. R. Cobb, pp. 94–108. University of Alabama Press, Tuscaloosa.

Bayman, J. M., M.-N. J. J., T. M. Rieth, and C. K. Paraso. 2004. Stone Adze Production and Resource Extraction at Pōhakuloa, Hawai'i Island. *Hawaiian Archaeology* 9:83–104.

Bayman, J. M., and J. J. Moniz-Nakamura. 2001. Craft Specialization and Adze Production on Hawaii Island. *Journal of Field Archaeology* 28:239–252.

Buck, P. H. 1930. *Samoan Material Culture*. Bernice P. Bishop Museum Bulletin No. 75. Bishop Museum Press, Honolulu.

Buck, P. H., K. P. Emory, H. D. Skinner, and J. F. G. Stokes. 1930. Terminology for Ground Stone Cutting-Implements in Polynesia. *Journal of the Polynesian Society* 39:174–180.

Carson, M. T., and M. A. Mintmier. 2006a. *Archeological Survey in Front Country Areas in the Summit District of Haleakalā National Park, Maui Island, Hawai'i*. Draft report prepared for National Park Service. International Archaeological Research Institute, Inc., Honolulu.

———. 2006b. Radiocarbon Chronology of Prehistoric Campsites in Alpine and Subalpine Zones at Haleakalā. Maui Island, USA. *Radiocarbon* 48: 227–236.

Cleghorn, P. L. 1982. *The Mauna Kea Adze Quarry: Technological Analyses and Experimental Tests*. Ph.D. dissertation, Department of Anthropology, University of Hawai'i, Honolulu.

———. 1984. An Historical Review of Polynesian Stone Adze Studies. *Journal of the Polynesian Society* 93:399–421.

———. 1986. Organizational Structure at the Mauna Kea Adze Quarry Complex, Hawaii. *Journal of Archaeological Science* 13:375–387.

Cleghorn, P. L., T. Dye, M. I. Weisler, and J. Sinton. 1985. A Preliminary Petrographic Study of Hawaiian Stone Adze Quarries. *Journal of the Polynesian Society* 94:235–251.

Cordy, R. 2004. Considering Archaeological Indicators of the Rise of Appointed Chiefs and the Feudal Land System in the Hawaiian Islands. *Hawaiian Archaeology* 9:1–24.

Costin, C. L. 1991. Craft Specialization: Issues in Defining, Documenting, and Explaining the Organization of Production. In *Archaeological Method and Theory, Volume 3*, edited by M. B. Schiffer, pp. 1–56. University of Arizona Press, Tucson.

———. 2004. The Study of Craft Production. In *Handbook of Archaeological Methods*, edited by H. Maschner. Alta Mira Press, Lanham.

Deunert, B. 1995. *A Fundamental Basalt Flake Analysis: Based on Experimentally-produced and Used Flakes as Well as the Prehistoric Waikalua Material*. B.A.R. International Series 614. Hadrian Books Ltd., Oxford.

Dibble, H. L., U. A. Schurmans, R. P. Iovita, and M. V. McLaughlin. 2005. The Measurement and Interpretation of Cortex in Lithic Assemblages. *American Antiquity* 70:545–560.

Doelman, T. E. 2005. Tool Time: The Influence of Tool Manufacture, Use, and Discard on the Formation and Composition of a Quarry Assemblage. *Lithic Technology* 30:13–28.

Duff, R. 1959. Neolithic Adzes of Eastern Polynesia. In *Anthropology in the South Seas*, edited by J. D. Freeman and W. R. Geddes, pp. 121–147. Thomas Avery and Sons, Limited, New Plymouth.

———. 1970. *Stone Adzes of Southeast Asia: An Illustrated Typology*. Canterbury Museum Bulletin No. 3. Canterbury Museum, Christchurch.

Earle, T. K. 1997. Exchange in Oceania: Search for Evolutionary Explanations. In *Prehistoric Long-Distance Interaction in Oceania: An Interdisciplinary Approach*, edited by M. I. Weisler, pp. 224–237. Monograph No. 21. New Zealand Archaeologicial Association, Auckland.

Emory, K. P. 1968. East Polynesian Relationships as Revealed Through Adzes. In *Prehistoric Culture in Oceania: A Symposium*, edited by I. Yawata and Y. H. Sinoto, pp. 151–169. Bishop Museum Press, Honolulu.

Green, R. C. 1971. Evidence for the Development of the East Polynesian Adze Kit. *New Zealand Archaeological Association Newsletter* 14:12–44.

Green, R. C., and A. Y. Dessaint. 1978. *Measurements of Polynesian Adzes: Some Comparative Results from Samoa and New Zealand*. Oceanic Prehistory Records No. 5. University of Auckland Archaeological Society, Auckland.

Hommon, R. J. 1976. *The Formation of Primitive States in Pre-Contact Hawaii*. Ph.D. dissertation, Department of Anthropology, University of Arizona, Tucson.

———. 1986. Social Evolution in Ancient Hawai'i. In *Island Societies: Archaeological Approaches to Evolution and Transformation*, edited by P. V. Kirch, pp. 55–68. Cambridge University Press, Cambridge.

Kamakau, S. M. 1976. *The People of Old*. Bernice P. Bishop Museum Special PublicationNo. 51. Bishop Museum Press, Honolulu.

Kirch, P. V. 1984. *The Evolution of the Polynesian Chiefdoms*. Cambridge University Press, Cambridge.

———. 1985. *Feathered Gods and Fishhooks: An Introduction to Hawaiian Archaeology and Prehistory*. University of Hawai'i Press, Honolulu.

Komori, E. and N. Oshima. 1977. *Archaeological Reconnaissance Survey Report: Fencing West Boundary of Haleakalā National Park*. Prepared for the National Park Service. Department of Anthropology, B.P. Bishop Museum, Honolulu.

Kooyman, B. P. 2000. *Understanding Stone Tools and Archaeological Sites*. University of New Mexico Press, Albuquerque.

Lass, B. 1994. *Hawaiian Adze Production and Distribution: Implications for the Development of Chiefdoms*. Monograph 37. Institute of Archaeology, University of California, Los Angeles.

———. 1998. Crafts, Chiefs, and Commoners: Production and Control in Precontact Hawai'i. In *Craft and Social Identity*, edited by C. L. Costin and R. P. Wright, pp. 19–30. Archeological Papers No. 8. American Anthropological Association, Washington, D.C.

Latinis, D. K. 1995. *Lithic Workshops and Chipping Stations in the Philippines: A Re-analysis of the Busibus/Pintu Lithic Assemblage from Northern Luzon, Philippines*. M.A. thesis, Department of Anthropology, University of Hawai'i, Honolulu.

———. 1996. Prehistoric Lithic Technology, Workshops, and Chipping Stations in the Philippines. *Asian Perspectives* 35:27–50.

Leach, H. M. 1981. Technological Changes in the Development of Polynesian Adzes. In *Archaeological Studies of Pacific Stone Resources*, edited by F. Leach and J. Davidson, pp. 167–181. B.A.R. International Series 104, Oxford.

———. 1993. The Role of Major Quarries in Polynesian Prehistory. In *The Evolution and Organisation of Prehistoric Society in Polynesia*, edited by M. W. Graves and R. C. Green, pp. 33–42. Monograph No. 19. New Zealand Archaeological Association, Auckland.

———. 1996. Of Stone and Steel Adzes and Typological Tests. In *Oceanic Culture History: Essays in Honour of Roger Green*, edited by J. Davidson, G. Irwin, F. Leach, A. Pawley, and D. Brown, pp. 411–420. New Zealand Journal of Archaeology Special Publication, Auckland.

Leach, H. M., and B. F. Leach. 1980. The Riverton Site: An Archaic Adze Manufactory in Western Southland, New Zealand. *New Zealand Journal of Archaeology* 2:99–140.

Leach, H. M., and D. C. Witter. 1987. Tatagamatau "Rediscovered". *New Zealand Journal of Archaeology* 9:33–54.

Malo, D. 1996. *Ka Moolelo Hawaii: Hawaiian Traditions*. Translated by M. Chun. First Peoples Productions, Honolulu.

McCoy, P. C. 1977. The Mauna Kea Adze Quarry Project: A Summary of the 1975 Field Investigations. *Journal of the Polynesian Society* 86:223–244.

———. 1986. *Archaeological Investigations in the Hopukani and Liloe Springs Area of the Mauna Kea Adze Quarry, Hawai'i. A Data Summary Report*. Department of Anthropology, Bernice P. Bishop Museum, Honolulu.

———. 1990. Subsistence in a "Non-subsistence" Environment: Factors of Production in a Hawaiian Alpine Desert Adze Quarry. In *Pacific Production Systems: Approaches to Economic Prehistory*, edited by D. E. Yen and J. M. J. Mummery, pp. 85–119. Australian National University, Canberra.

———. 1991. *Survey and Test Excavations of the Pu'u Kalepeamoa site, Mauna Kea, Hawai'i*. Department of Anthropology, Bernice P. Bishop Museum, Honolulu.

———. 1999. Neither Here nor There: A Rites of Passage Site on the Eastern Fringes of the Mauna Kea Adze Quarry, Hawai'i. *Hawaiian Archaeology* 7:11–34.

McCoy, P. C., and R. A. Gould. 1977. Alpine Archaeology in Hawaii. *Archaeology* 30:234–243.

McCoy, P. C., A. Makanani, and A. Sinoto. 1993. *Archaeological Investigations of the Pu'u Moiwi Adze Quarry Complex, Kaho'olawe*. Consultant Report No. 14. Kaho'olawe Island Conveyance Commission, Wailuku.

Rosendahl, M. L. K. 1978. *Preliminary Overview of Archaeological Resources at Haleakalā National Park, Island of Maui*. Department of Anthropology, Bernice P. Bishop Museum, Honolulu.

Rosendahl, M. L. K., and T. Dye. 1977. *Intensive Archaeological Survey of a Portion of the West Rim of Haleakala Crater, Haleakala National Park*. Department of Anthropology, Bernice P. Bishop Museum, Honolulu.

Sinton, J., and Y. H. Sinoto. 1997. A Geochemical Database for Polynesian Adze Studies. In *Prehistoric Long-Distance Interaction in Oceania: An Interdisciplinary Approach*, edited by M. I. Weisler, pp. 194–204. Monograph No. 21. New Zealand Archaeological Association, Auckland.

Skinner, H. D. 1921. Culture Areas in New Zealand. *Journal of the Polynesian Society* 30:71–78.

Soehren, L. J. 1963. *An Archaeological Survey of Portions of East Maui, Hawaii*. Report prepared for the National Park Service. Department of Anthropology, Bernice P. Bishop Museum, Honolulu.

Stahle, D. W., and J. E. Dunn 1982. An Analysis and Application of the Size Distribution of Waste Flakes from the Manufacture of Bifacial Stone Tools. *World Archaeology* 14:84–97.

Turner, M. T. 1992. *Make or Break: Adze Manufacture at the Tahanga Quarry*. M.A. thesis, Department of Anthropology, University of Auckland, Auckland.

Weisler, M. I. 1990. A Technological, Petrographic, and Geochemical Analysis of the Kapohaku Adze Quarry, Lana'i, Hawaiian Islands. *New Zealand Journal of Archaeology* 12:29–50.

West, E. 2000. Prehistoric Voyaging and the Regional East Polynesian Homeland: A Study of Adzes from Eiao Island of the Northern Marquesas. University of Hawai'i Janet Bell Pacific Research Prize 2000. Pacific Collection, Hamilton Library, University of Hawai'i at Mānoa, Honolulu.

Whiteaker, L. D. 1980. *The Vegetation and Environment in the Crater District of Haleakalā National Park*. Technical Report 35. Cooperative National Park Resources Studies Unit, University of Hawai'i at Mānoa, Honolulu.

Whittaker, J. C. 1994. *Flintknapping: Making and Understanding Stone Tools*. University of Texas Press, Austin.

Williams, S. S. 1989. *A Technological Analysis of the Debitage Assemblage from Ko'oko'olau Rockshelter No. 1, Mauna Kea Adze Quarry, Hawai'i*. M.A. thesis, Department of Anthropology, Washington State University, Pullman.

Zeigler, A. C. 2002. *Hawaiian Natural History, Ecology, and Evolution*. University of Hawai'i Press, Honolulu.

Interpreting Activities in North Hālawa Valley, O'ahu: Adze Recycling and Adze Resharpening

Deborah I. Olszewski
Penn Museum and Department of Anthropology, University of Pennsylvania

Introduction

Basalt flaked lithic artifacts are one of the main categories of cultural materials recovered from pre-Contact Hawaiian sites.[1] They are found in a variety of contexts, ranging from habitations to quarry sites, and most often are in the form of relatively undistinguished flakes. High-quality (fine-grained) basalt, however, was used to manufacture tools, particularly adzes. These were fashioned by flaking a preform from a basalt nodule or large basalt flake. Subsequently such preforms were finished more finely through additional flaking, and, in the final stages of preparation, were ground to produce polished adzes. The sequential process of adze manufacture has been amply demonstrated through studies of Hawaiian quarry sites, most notably Mauna Kea, and through knapping debris from secondary sites away from quarries, as well as habitation sites (e.g., Bayman and Moniz-Nakamura 2001; Cleghorn 1982, 1986; McCoy 1990; Weisler 1990).

A number of researchers have studied basalt sources for adzes through petrographic and geochemical analyses (e.g., Cleghorn et al. 1985; Lass 1994; Weisler 1990), as well as the distribution of adzes both intra- and inter-island, in efforts to better understand pre-Contact Hawaiian social and political systems, as well as craft specialization (e.g., Lass 1994, 1998). It has also been widely noted that basalt adze manufacture was likely to be relatively specialized. This is particularly true for the Mauna Kea quarry which had and continues to have special religious significance for Native Hawaiians—Mauna Kea has shrines and rock art, in addition to the workshops, rockshelters, and open air shelters (McCoy 1990:96–97; 1999).

Not all adze manufacture, however, appears to be linked to the primary use of quarry sites, and thus to a potentially specialized network or system of production.

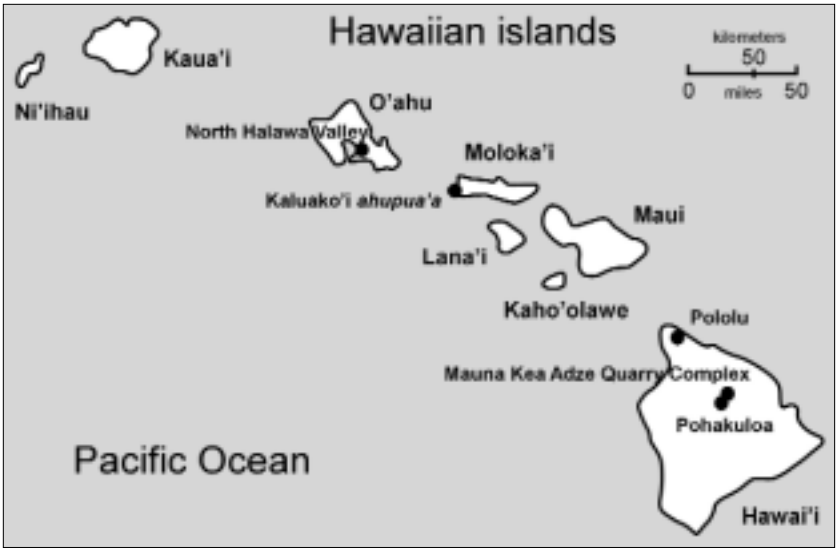


Figure 1. Location of areas in the Hawaiian islands.

Rather, there seem to be an increasing number of documented instances where adze manufacture can be described as much more highly localized—occurring either at habitation sites or nearby. Such highly localized manufacturing is an important consideration in the reconstruction of larger social and perhaps political systems. To examine adze manufacturing sites away from quarries, several lines of evidence are used below. The baseline data are derived from the classic quarry at Mauna Kea because this information can be used metrically and spatially to characterize basalt adze production, at least to the preform stage (Figure 1). These data are then compared to information from North Hālawa Valley, Oʻahu, to address the variables that characterize a sequence of adze manufacture away from quarry sites, as well as adze maintenance tasks. To augment the North Hālawa Valley context, comparisons with analogous situations on Molokaʻi and Hawaiʻi are also undertaken.

The Adze Quarry at Mauna Kea, Hawaiʻi

The Mauna Kea Adze Quarry Complex is a high altitude (2,622 to 3,963 masl) set of adze preform manufacturing sites, and associated activity areas, in a region of about 12 km^2 near the summit of this volcanic mountain on the island of Hawaiʻi (Cleghorn 1986; McCoy 1977). A nearly 4 km^2 area within this larger region documents intensive use of the high quality, fine-grain basalt source, which was formed by a volcanic eruption beneath an ice cap some 175,000 years ago (Porter 1979). Long-term habitation sites are not found, and all indications are that visits to the quarry complex were brief due to a variety of difficulties including availability of food resources, high altitude hypoxia, and cold temperatures (McCoy 1990: 91–92). Radiocarbon dating of various rockshelters, as well as ethnohistory, suggest that the quarry was used between about A.D. 1100 to A.D. 1750 (Cleghorn 1986:377)—use of the quarry may extend as early as ca. A.D. 800 (McCoy 1990:92).

Of the several types of sites present in the adze quarry complex, it is the lithic workshops that are most relevant here. These workshops include discrete chipping stations (Cleghorn 1982:95–104; McCoy 1990:96). Cleghorn (1982:96, 104) recorded four of these—ranging in size from 2.5 m^2 to 20 m^2—by mapping all large artifacts and collecting small flakes in bulk from discrete, marked areas within each chipping station. Examination of these collections showed the presence of all stages of flaking debris expected in a sequence leading to the production of adze preforms. And, importantly, despite the larger overall size of some of the chipping stations, most of the lithics at each station were concentrated in a much smaller area (ca. 4.5 m^2) (Cleghorn 1982:104).

Cleghorn (1982:221–341; 1986:379–384) also conducted 30 experimental replications of adze preform manufacture. Ten of these were directed toward study of the spatial distribution of lithic material as a knapper flaked basalt to make an adze preform. Cleghorn's experimental results show that 92% of the flaked material by weight falls within 50 cm of where a flake is struck, and 99% of all the flaked material falls within 1 m of where it is struck. This clustering allows for the interpretation of discrete individual work spots, as well as showing that this type of activity has the potential to be identified at sites other than quarries, should adze manufacturing occur elsewhere.

Moreover, Cleghorn developed a series of variables for debitage and adze reject/preform analyses. These have been used as a baseline by a number of researchers in Hawaiʻi (e.g., Bayman and Moniz-Nakamura 2001; Lass 1994; Olszewski 2004;

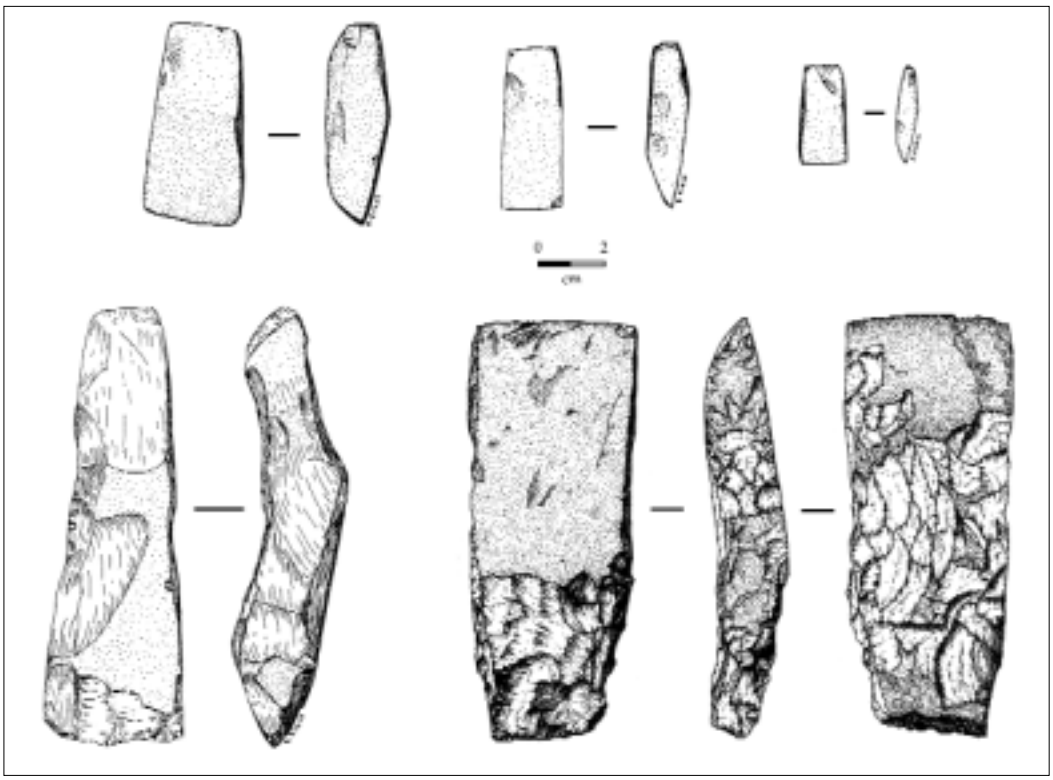


Figure 2. Examples of adzes and microadzes from North Hālawa Valley, O'ahu. Note the extensive evidence for reworking on the adzes in the bottom row. All adzes shown as originally drawn (drawings by Bradley M. Evans; with permission of Bernice P. Bishop Museum, Honolulu).

Williams 1989). Of particular interest to this study are the debitage variables, which include types (e.g., cortical, noncortical, nondiagnostic fragments), terminations (e.g., feather, step), and size categories developed from flake length and width.

Adze Assemblages in North Hālawa Valley, O'ahu

Archaeological investigations during inventory survey, data recovery, and monitoring phases of work associated with the construction of Interstate Highway H-3 on O'ahu uncovered 75 sites in the leeward valley of North Hālawa (Bishop Museum 2003, 2004). These sites span the period from about A.D. 1280 to the early post-Contact, and include habitation, ritual, specialized activity, and agricultural locales (Olszewski et al. 2003, 2004). Of these, 48 sites yielded lithic assemblages, totaling more than 47,300 artifacts—with basalt artifacts numbering in excess of 40,600 of this total (Olszewski 2003a, 2004). Studies identified several sites of interest with respect to adze resharpening or adze manufacture through recycling of old adzes—Sites 50-80-10-2014, 50-80-10-2016, 50-80-09-2094, 50-80-10-2098, and 50-80-10-5305 (Olszewski 2004:47–57).

Two of these, Sites 2014 and 2094, are permanent habitation sites, with more than 140 features including terraces (agricultural and habitation), enclosures, rock mounds, pits, pavements, walls, and alignments. Site 2098 contains mainly agricultural terraces, along with a few habitation areas (Olszewski 2003b). Site 2014 was occupied by about the 15th century, while Site 2094 had occupations beginning in the last quarter of the 17th century. Site 2098 dates to the late pre-Contact period, perhaps as late as the 18th century. The other two, Sites 2016 and 5305, are specialized activity locales and contain both fewer features and fewer feature types—mostly pits or post molds. Radiocarbon dates from Site 2016 suggest use beginning in the 17th century, while those from Site 5305 indicate quite late pre-Contact period use. Despite the differences in site type, all five sites share several characteristics. The basalt artifacts at each are tool quality (fine-grained); all sites yielded evidence for flakes with polish—that is, flakes from polished adzes—and, several contained

Table 1. Adze-related Assemblage Expectations (modified from Olszewski 2004:Table 3.1).

	Quarry Features	Recycling Features	Resharpening Features
Conchoidal Fracture	good to excellent	good to excellent	good to excellent
Spatial Patterning	discrete knapping locales	discrete knapping locales	possible activity areas
Debitage	no flakes with polish	moderate to high frequencies of all types of flakes with polish	high frequnecy of flakes with polish on platform
	moderate to high frequencies of cortical flakes*	no cortical flakes	no cortical flakes
	larger sized debitage**	moderate sized debitage, especially flakes with polish and noncortical flakes	moderate sized debitage, especially flakes with polish and noncortical flakes
	high frequency of small flakes and fragments	high frequency of small flakes and fragments	low to moderate frequency of small flakes and fragments
Tools	adze blanks	no adze blanks	no adze blanks
	adze preforms	adze preforms, microadze preforms	no adze or microadze preforms
	higher frequency of adze blank/preform fragmentation	higher frequency of adze preform fragmentation	higher frequency of finished adzes and microadzes
	no finished adzes	finished adzes and microadzes	finished adzes and microadzes
	no grindstones or whetstones	grindstones, whetstones	grindstones, whetstones
	hammerstones	hammerstones	hammerstones

* Initial selection of basalt material at sources will in most cases produce some number of flaked pieces that have unmodified exteriors (dorsal surfaces). Whether or not these are characterized specifically by cortex does not alter the fact that these types of flakes represent removals of the original surface of the piece during shaping of blocks or nodules. By convention, all are called cortical flakes here.

** Size of flakes is larger or smaller within a given assemblage and thus can be used as a partial measure for that assemblage. Potential differences in original source material sizes means that flake size comparisons between assemblages may or may not be useful.

highly patterned spatial distributions of basalt debitage (e.g., Leidemann and Gordon 2004; McGuirt 2004).

Finished adzes in Hawai'i exhibit a wide range of sizes, and it is the smaller adzes (including microadzes, those ≤60 mm) that are of particular interest here (Figure 2). While it might be expected that quarry sites tend to feature large preforms, which when ground and polished would result in relatively large sized adzes, this may be true only for those quarries in which nodules were the focus of reduction.[2] Smaller adzes thus are either imported from quarries where flakes are used as blanks or are manufactured at or nearby habitation sites. Expectations for evidence related to manufacture of adzes through recycling, as well as resharpening tasks, at the five North Hālawa Valley sites can be generated based on known characteristics of chipping stations at quarry sites (Table 1). It is assumed that most of the lithic manufacturing activity associated with adzes in North Hālawa Valley will reflect the fashioning of adzes either from imported preforms or existing adzes, or will represent maintenance of adzes through resharpening.

Adze manufacture from existing adzes (recycling) is a lithic reduction process in which one would not expect to find flakes with cortex on the exterior (dorsal) surfaces or unmodified exterior surfaces. On the other hand, there should be moderate to high frequencies of both flakes with polish (on any surface, including the striking platform), as well as noncortical flakes, as these by-products would be expected debitage as one reshaped and reduced an existing, polished adze. It is also expected that knappers manufacturing new adzes from old adzes would produce a knapping area or areas with spatial patterning similar to that recorded from chipping stations at quarry sites.

Adze resharpening is likely to be an activity more difficult to isolate at habitation, or even specialized activity, sites. The types of flaking by-products should include flakes with polish, including those that have polish only on the striking platform. Such flakes, on average, may be smaller than flakes with polish removed during the adze recycling process because resharpening is directed toward the refurbishment only of the edge of the adze bevel (bit). Flakes with polish are distinctive, but if the resharpening of an

Table 2. Examples of Debitage at Adze Recycling Contexts at North Hālawa Valley Sites.*

	Quarry Features	Recycling Features	Resharpening Features
Conchoidal Fracture	good to excellent	good to excellent	good to excellent
Spatial Patterning	discrete knapping locales	discrete knapping locales	possible activity areas
Debitage**	no flakes with polish	moderate to high frequencies of all types of flakes with polish	high frequnecy of flakes with polish on platform
	moderate to high frequencies of cortical flakes	no cortical flakes	no cortical flakes
	larger sized debitage	moderate sized debitage, especially flakes with polish and noncortical flakes	moderate sized debitage, especially flakes with polish and noncortical flakes
	high frequency of small flakes and fragments	high frequency of small flakes and fragments	low to moderate frequency of small flakes and fragments
Tools	adze blanks	no adze blanks	no adze blanks
	adze preforms	adze preforms, microadze preforms	no adze or microadze preforms
	higher frequency of adze blank/preform fragmentation	higher frequency of adze preform fragmentation	higher frequency of finished adzes and microadzes
	no finished adzes	finished adzes and microadzes	finished adzes and microadzes
	no grindstones or whetstones	grindstones, whetstones	grindstones, whetstones
	hammerstones	hammerstones	hammerstones

* Data used are from data recovery and monitoring phases.[12]

** Cortical flakes are those with dorsal surfaces with >90% cortex or unmodified dorsal surface; flakes with some cortex have 1%–90% cortex or unmodified dorsal surface; noncortical flakes have negligible cortex or unmodified dorsal surface; flakes with polish have polish on the dorsal surface; flakes with polish and polish on platform have polish on the dorsal surface and on the platform; flakes with polish on platform have polish only on the striking platform; small flakes are <25 mm; broken flakes are recognizable proximal, medial or distal pieces of flakes, not including step terminations (which are treated as complete flakes so that their terminations can be examined); fragments are chips and chunks unidentifiable as to form or type of debitage.

adze requires the removal of only a handful of flakes along the bit end of the tool prior to regrinding and polishing, then this small quantity may become submerged within a larger set of lithic tasks occurring at sites with multiple activities. Identification of spatial patterning associated with resharpening activities is thus rarely expected.

In the case of adze preforms brought into habitation or specialized activity sites, it is expected that only the later stages of adze manufacture will be represented. As with resharpening activities, if the remaining work on adze preforms is primarily grinding and polishing, then these processes will be largely invisible as distinct activity sets at sites. On the other hand, if adze preforms still require significant shaping prior to grinding and polishing, then there may be activity areas characterized by moderate to high frequencies of noncortical flakes, and possibly spatial patterning of debitage that is analogous to those of quarry chipping stations.

There is good evidence for both adze recycling and adze resharpening activities at some of the sites in North Hālawa Valley, with the best examples coming from the five sites identified above. Evidence for extensive reduction of adze preforms, however, was not identified as a distinct activity set at either habitation or specialized activity sites.

Adze Recycling Activities

Making new adzes from old adzes appears to have been an important activity at Sites 2016 and 5305. Based on the overall configuration expected for sites with adze recycling, Site 2094 may also have this activity, although the frequencies of flakes with polish are much lower than predicted from the expectations in Table 1. As the sites identified as associated with adze recycling/manufacture include both permanent and temporary habitation, as well as specialized activity locales, recycling adzes would appear to be a task that was not necessarily isolated from routine activities that characterized everyday life. Data on reduction by-products for several examples are shown in Table 2.[3] As can be seen from these data, many of the debitage predictions in Table 1 for adze recycling are met, although there is variability from site to site. Perhaps one of the most interesting trends is found at Site 2016, which includes several temporal periods in the later pre-Contact. Data from this site—as

Table 3. Terminations (%) of Flakes with Polish for Adze Recycling and Adze Resharpening

Site	Context	N*	feather	hinge	step/snap	overshot	Task
2014	Feature 15: II	31	64.5	16.1	16.2	3.2	resharpening
2016	II/C2	122	41.0	12.3	38.5	8.2	recycling
2016	II/C3	170	35.3	15.3	41.8	7.6	recycling
2016	II/C4	36	30.6	2.8	55.5	11.1	recycling
2098	Feature 29	15	13.3	40.0	26.7	13.3	resharpening
2098	Feature 29.03	14	50.0	14.3	21.4	14.3	resharpening
5305	Feature 1: I	35	45.7	11.4	40.0	2.9	recycling
5305	Feature 1: II/1	79	34.2	21.5	41.8	2.5	recycling
5305	Feature 1: II/2	27	11.1	33.3	51.8	3.7	recycling

* Includes all types of complete flakes with polish as identified in Tables 2 and 3.

Table 4. Terminations (%) of Noncortical Flakes for Adze Recycling and Adze Resharpening

Site	Context	N	feather	hinge	step/snap	overshot	Task
2014	Feature 15: II	20	35.0	20.0	35.0	10.0	resharpening
2016	II/C2	230	33.5	8.7	47.4	10.4	recycling
2016	II/C3	270	32.6	14.8	43.3	9.3	recycling
2016	II/C4	80	26.2	13.8	51.2	8.8	recycling
2098	Feature 29	28	46.4	21.4	25.0	7.1	resharpening
2098	Feature 29.03	12	33.3	33.3	16.7	16.7	resharpening
5305	Feature 1: I	50	30.0	12.0	44.0	14.0	recycling
5305	Feature 1: II/1	97	31.9	19.6	40.2	8.2	recycling
5305	Feature 1: II/2	39	41.0	15.4	38.5	5.1	recycling

well as the temporal placement of Site 5305 in the very late pre-Contact—indicate that adze recycling activities may have increased over time (Olszewski 2004:74).

Using the same examples as in Table 2, adze recycling areas had the following associated tools. Site 2016, Context II/C3, yielded two broken adze preforms, a reworked adze fragment, two grindstone fragments, a whetstone (fine-grained basalt used to hone adzes), six hammerstones, and various edge-altered and retouched flakes, as well as notched flakes and a chisel (a small stone tool with a sharp, beveled edge). Site 2094, Feature 1 (Level II), had one adze preform fragment, one finished reworked adze, one microadze preform, four hammerstones, and assorted notched and edge-altered flakes. Site 5305, Feature 1 (Level II/1), contained a microadze preform, two grindstone fragments, and edge-altered, retouched, and notched flakes. Compared to the expectations for adze recycling activities in Table 1, there is a relatively close match with the tools found at these North Hālawa Valley sites.

It is also possible to examine the terminations for flakes, which might be used as a guide to indicate adze recycling as opposed to adze resharpening. For example, experimental work has shown that when shaping the tang (butt) section of rectangular adze preforms,[4] there are high frequencies of flakes with step terminations (Cleghorn 1982:294).[5] Higher frequencies of step and hinge terminations have also been documented for the reworking of adze preforms that were transversely fractured (Turner and Bonica 1994:20–21), and this observation would have applicability to broken finished adzes that were reworked into new, smaller adzes. Such flakes are generated because of the preexisting sides with flaking angles approaching 90 degrees. If making new adzes from old adzes is an activity in North Hālawa Valley, then it might be expected that flakes with polish removed from the old adzes will feature step/snap terminations more frequently than feather terminations. This appears to be the case, as shown in Table 3. Interestingly, this pattern, while present, is somewhat less marked in noncortical flake terminations (Table 4), although these results may reflect Cleghorn's (1982:294) finding that feather terminations were the most frequent type for most stages of adze preform manufacture.

Table 5. Examples of Debitage for Adze Resharpening at North Hālawa Valley Sites.*

Site	Context	By-Products	Frequency
2014	Feature 15	cortical flakes	0.9
	(Level II)	flakes with some cortex	1.4
	[n=212]	noncortical flakes	6.6
		flakes with polish	12.7
		flakes with polish & polish on platform	6.1
		flakes with polish on platform	3.3
		small flakes	14.6
		broken flakes	39.6
		fragments	14.6
2098	Feature 29	cortical flakes	2.6
	(Level II)	flakes with some cortex	2.3
	[n=613]	noncortical flakes	4.6
		flakes with polish	2.9
		flakes with polish & polish on platform	0.3
		flakes with polish on platform	0.2
		small flakes	34.7
		broken flakes	24.3
		fragments	28.0

* Data used are from data recovery and monitoring phases.

Table 6. Averages (mm and g) for Flakes with Polish for Adze Recycling and Adze Resharpening (modifed from Olszewski 2004: Table 3.5).

Site	Context	N*	L	W	T	Wgt	Task
2014	Feature 15: II	31	13.2	15.5	3.7	2.2	resharpening
2016	II/C2	122	18.1	20.2	3.9	3.2	recycling
2016	II/C3	170	17.4	19.6	3.7	2.7	recycling
2016	II/C4	36	19.1	21.2	4.5	4.2	recycling
2098	Feature 29	15	13.9	16.0	3.5	1.9	resharpening
2098	Feature 29.03	14	14.2	14.7	3.2	1.5	resharpening
5305	Feature 1: I	35	18.5	19.0	3.9	3.1	recycling
5305	Feature 1: II/1	79	17.7	19.6	3.8	2.7	recycling
5305	Feature 1: II/2	27	16.9	18.0	3.9	2.0	recycling

* Includes all types of complete flakes with polish as identified in Tables 2 and 3.

On a larger scale, it is quite interesting that adze recycling at the North Hālawa Valley sites appears to yield spatial patterning similar to that documented at the Mauna Kea Adze Quarry Complex by Cleghorn (1982:104). In the case of Site 2016, for example, plotting of artifact density for each of the Layer II contexts (2, 3, and 4) shows that the basalt assemblages are densely concentrated within 1–2 m^2 (McGuirt 2004). Although the basalt assemblages are less dense at Site 5305, the same patterning holds true with debitage concentrated in 2–3 m^2 areas in the Feature 1 Layer II/1 and II/2 contexts (Leidemann and Gordon 2004).[6] The spatial distribution of basalt artifacts at both sites suggests that a knapper sat in one spot while manufacturing a new adze from an old adze, much as a knapper sat in one spot to make an adze preform from a nodule or large flake at a quarry site such as Mauna Kea. These data also indicate that post-occupation disturbance at the North Hālawa Valley sites tends to be minimal (excepting, of course, Interstate H-3 highway construction activities).

Adze Resharpening Activities

As can be seen in Table 1, many of the predictions for adze resharpening are the same or similar to those expected for adze recycling. Nevertheless, it is possible to suggest adze resharpening as a distinct activity at sites, particularly Site 2014 (Table 5). Based on debitage features alone, the evidence is less clear at Site 2098, where flakes with polish are relatively few, while small flakes are common (as at adze recycling locales). Associated tool assemblages include, for Site 2014, Feature 15 (Level II), an adze blank fragment,[7] an adze fragment, a finished microadze, a microadze fragment, an abrader, three grindstone fragments, two whetstone fragments, four hammerstones, one hammerstone fragment, an *'ulu maika*, and assorted notched and retouched flakes. Site 2098, Feature 29 (Level II), yielded an adze preform, a finished adze, a finished microadze, an anvil, an abrader fragment, a grindstone fragment, a broken polishing stone, five hammerstones, various notched and edge-altered flakes, a pounder, and an *'ulu maika*.

Preliminary study suggests that distinguishing adze resharpening from adze recycling might be discriminated using metric attributes for flakes with polish (Olszewski 2004:50–55). As can been seen in Table 6,

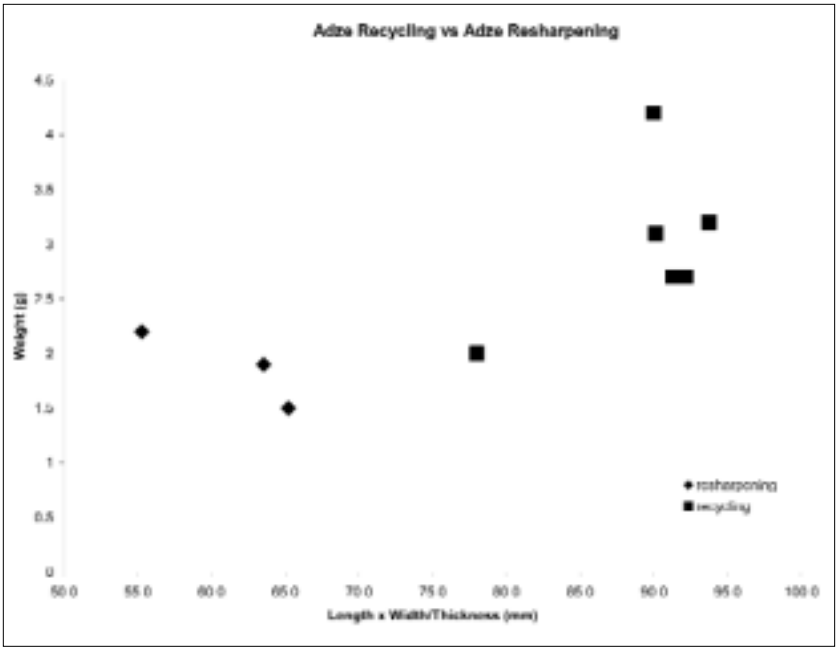


Figure 3. Flakes with polish can be used to discriminate between adze recycling and adze resharpening locales within sites. Each point represents an assemblage average from locales within various sites.

flakes with polish at locales identified as adze resharpening tend to be smaller in all dimensions. This is shown graphically in Figure 3. Generally speaking, if the intention is to resharpen an adze, then one might expect that removals from the bevel end of the adze will be relatively short and/or small. This is because the goal is to recreate a sharp bevel, and removals from bevels, which are relatively thin compared to the adze midsection and adze butt, cannot by default be excessively large without damaging the bevel—in which case, a large adze might have to be completely refashioned into a smaller version.

North Hālawa Valley Summary

Lithic processes associated with adzes can be documented at several of the North Hālawa Valley sites. These indicate both the resharpening of adzes, as well as the use of old adzes as blanks to manufacture new adzes. This latter process, a form of recycling, is one way to produce smaller sized adzes, as well as microadzes, for household related tasks. It also possibly reflects a strategy of "obtaining" basalt to make adzes, particularly if there are risks such as transverse fracture in adze manufacture (Turner and Bonica 1994: 24); alternatively, this activity could be related to social or political situations which limit access to basalt quarries.

The features which appear to be useful for separating adze resharpening from adze recycling include relative frequencies of particular types of debitage, spatial patterning of lithics that mimics quarry chipping stations, and metric and termination attributes of flakes with polish. The fact that these two activities cannot always be clearly separated along all such features may indicate that resharpening and recycling were not always spatially distinctive tasks. Interestingly, there is no evidence for significant flaking associated with adze blanks or preforms (other than, of course, the presence of grindstones and whetstones likely used in the final phases of grinding and polishing adzes).

Non-Quarry Adze Assemblages Elsewhere in Hawai'i

The manufacture of adzes in non-quarry contexts can be expected to have occurred at a variety of sites ranging from secondary knapping locales to temporary and permanent habitation sites associated with agricultural activities. Adze production in these circumstances could result from one of three scenarios. As in North Hālawa Valley, new adzes could be made from old adzes. On the other hand, it is possible that adze blanks or adze preforms brought into sites from quarry locations were flaked at these secondary sites into a finalized shape prior to the grinding and polishing phases. Finally, it may also be the case that adzes at habitation sites are manufactured from nearby secondary sources, such as basalt cobbles from stream beds, and thus the entire sequence of adze production will be present. Examples from Moloka'i and Hawai'i are examined below.

Moloka'i

An inventory survey project in southwest Moloka'i (Kaluako'i *ahupua'a*) in 1990 and 1991 identified numerous sites, many of which were lithic resource areas, lithic workshops, and habitation sites with lithic workshop areas (Dixon and Major 1993). One of the research questions of the project singled out

Table 7. Debitage from Site 50-MO-B6-185, Moloka'i.

Site	Context	By-Products	Frequency
185	Test Unit 1	cortical flakes	0.2
	(Level I)	flakes with some cortex	2.1
	[n=1293]	noncortical flakes	17.0
		flakes with polish	–
		flakes with polish & polish on platform	–
		flakes with polish on platform	–
		small flakes	32.7
		broken flakes	30.4
		fragments	17.6
185	Test Unit 1	cortical flakes	0.05
	(Level II)	flakes with some cortex	1.1
	[n=1680]	noncortical flakes	17.4
		flakes with polish	0.1
		flakes with polish & polish on platform	–
		flakes with polish on platform	–
		small flakes	32.3
		broken flakes	34.8
		fragments	14.2

Table 8. Terminations (%) of Noncortical Flakes at Site 50-MO-B6-185, Moloka'i.

Site	Context	N	feather	hinge	step/snap	overshot
185	Test Unit 1: I	220	45.5	10.5	41.8	2.2
185	Test Unit 1: II	292	38.0	14.0	43.5	4.5

these lithic resources, particularly in light of the exploitation of lithic resources as a specialized activity at the level of the household (Boyd and Major 1993: 24). Limited testing at Site 50-MO-B6-185,[8] a habitation complex with workshop areas, provides the data used here.[9]

Site 185 is a complex of 12 enclosures and five pits located slightly over 1 km inland from the present coastline. Significantly, there is a lithic resource area (Site 50-MO-B6-161), with adze blanks, cores and flakes, some 200–300 m away across a gully—Kamāka'ipō Gulch—to the south (Dixon and Major 1993:280, 342). Testing at Site 185 included two units (1 x 0.5 m each). Test Unit 1, placed inside a rectangular enclosure in a residential compound, yielded a large quantity of basalt artifacts in Layer I, along with ash, fish bones, and sea shells, as well as volcanic glass artifacts (Dixon and Major 1993:303–310). Given the proximity of Site 185 to lithic resources, the workshop at this site could be associated either with primary adze manufacture (the complete reduction process of making an adze) or shaping adze blanks or preforms to their final form prior to grinding and polishing.

The quality of the basalt from Site 185 is a mixture of both medium and fine grains, and thus differs somewhat from the basalt used for adzes in North Hālawa Valley, as well as the Mauna Kea Adze Quarry Complex, both of which are fine-grained basalts. Table 7 shows the distribution of the debitage types, and it is striking that there are few cortical elements and virtually no flakes with polish. This indicates that adze recycling and adze resharpening were not major activities here, and suggests that lithic reduction is not from cobbles (due to the paucity of cortical elements), but perhaps from adze blanks or preforms. The tool assemblage includes eight tools, of which one is a grindstone fragment from the surface, and one is a hammerstone fragment from Layer I. A scraper, notched and retouched flakes, and a graver/burin (small, flaked chisel-like tool) complete the tools from Layers I and II. Interestingly, no adze blanks, preforms, or finished adzes were recovered, although this sample may reflect limitations due to the small size of the excavated unit.

If the workshop at Site 185 represents the manufacture of adzes from blanks or preforms, then an examination of the flake terminations (compared to experiments recorded by Cleghorn 1982) might be illuminating. As seen in Table 8, noncortical flake terminations are about evenly split between feather and step/snap types. In a general sense, this is what is expected for lithic reduction sequences leading to adze preforms, based on Cleghorn's work at Mauna Kea and his experiments. Sorting the noncortical flakes into size categories (Table 9) and examining terminations shows that smaller flakes tend to have relatively high step/snap terminations.

The data from Site 185 are indicative of an adze production sequence that begins with either an adze blank or an adze preform, likely imported into this habitation site from nearby sources. Debitage from

Table 9. Terminations of Noncortical Flakes at Site 50-MO-B6-185 by Size Class (mm).*

Site	Context		10–20	21–30	31–40	41–50	51–100	Total
185	Test Unit 1	feather	57.1	33.3	51.1	41.6	50.0	(100)
	(Level I)	hinge	7.1	11.5	11.1	16.7	16.7	(23)
	[n=220]	step/snap	32.8	52.9	35.6	41.6	33.3	(92)
		overshot	2.9	2.3	2.2	–	–	(5)
		Totals	(70)	(87)	(45)	(12)	(6)	
185	Test Unit 1	feather	35.4	37.6	37.3	42.0	57.1	(111)
	(Level II)	hinge	18.2	10.1	11.8	21.1	14.3	(41)
	[n=292]	step/snap	42.4	49.5	41.1	31.6	28.6	(127)
		overshot	4.0	2.8	9.8	5.3	–	(13)
		Totals	(99)	(109)	(51)	(19)	(14)	

* Frequencies are calculated for each column.

this manufacturing process thus incorporates some early stage (from blank to preform) by-products, as well as some later phase (from preform to finished adze) debitage. It does not indicate a sequence of using old adzes to make new adzes.

Hawai'i

Because of the importance of the Mauna Kea Adze Quarry Complex, considerable research on Hawai'i has focused on adze production. Of particular note are studies of sites located on the slopes of Mauna Kea and along the coast, which are much lower in elevation than the quarry complex. Occupants of these sites did not face the physical and food resource constraints experienced by those who made the trip to the quarry complex, although access to fresh water may have been a limiting factor for sites in some regions.

North Kohala

Lass (1994:32–44) investigated the lithic assemblage from Site 50-10-03-4981 in the Pololū Valley in the northeastern part of Hawai'i. This open air site contained buried deposits (approximately 1.5 m below ground surface) with considerable amounts of basalt artifacts (up to 30 cm thick), and was described as an adze manufacturing site during excavations by the University of Hawai'i in 1974. A radiocarbon date places the earliest use of the site around A.D. 1400, while evidence from petrographic analysis of basalt adzes from various dated sites shows use of Pololū basalt as late as A.D. 1650–1800 (Lass 1994:33). Lass analyzed the lithics using the analytical categories and quantitative and qualitative attributes developed by Cleghorn (1982) for the Mauna Kea Adze Quarry Complex chipping stations, as well as several measures developed by Williams (1989) in a study of the lithics from the Ko'oko'olau Rockshelter at Mauna Kea.

The site yielded two hammerstones and 29 unfinished adzes (comprising blanks and preforms), as well as about 3,500 pieces of debitage. Lass examined all the unfinished adzes and a 10% sample of the debitage from each collected bag or box of artifacts. Of this sample, only flakes with platforms or bulbs of percussion were studied (n=142) (Lass 1994:34). Production of adzes appears to have been from large flakes struck from cobbles retrieved from the stream bed.

Based on flake metrics (small flakes are not as abundant as expected), Lass concludes that the Site 4981 assemblage reflects the earlier phases of adze manufacture, rather than later stages (Lass 1994:38–39). One interesting observation is the relatively low frequency (37%) of feather terminations on flakes compared to abrupt—presumably step/snap—which constitute some 63% (Lass 1994: 43). Lass interprets this as possible evidence for less skill in adze manufacture or possibly due to attributes of the basalt raw material used.

Pōhakuloa

In a recent article by Bayman and Moniz-Nakamura (2001), two locales in the Pōhakuloa area some 4.5 km downslope of the main adze quarry complex at Mauna Kea were examined for evidence of adze production activities. Analogous in tasks to the small scale adze manufacturing in North Hālawa Valley and the example from southwestern Moloka'i, these two Pōhakuloa locales are radiocarbon dated from the early 15th through late 18th centuries, with some occupation possibly occurring as late as the early 19th century (Bayman and Moniz-Nakamura 2001:247). One is open air (Sites 14638 and 12251), and the other a lava tube with stratified deposits (Site 5003). The two locales are next to Pōhakuloa Gulch, and the basalt cobbles used in adze manufacture may

derive from this secondary source (Bayman and Moniz-Nakamura 2001:248–249).

The open air context, which has an enclosure surrounded by three lava tubes, yielded 2,692 pieces of debitage, as well as hammerstones, adze rejects,[10] grindstone fragments, and abraders, while the lava tube (Site 5003) contained 700 pieces of debitage, along with three hammerstones, and two adze rejects (Bayman and Moniz-Nakamura 2001:243–244). In contrast to debitage parameters recorded by Lass at Pololū, Bayman and Moniz-Nakamura found mainly small flakes at both locales. They interpret this pattern as reflecting the later stages in adze manufacture. Interestingly, some 9.2% of the flakes from Site 5003 (lava tube) have cortex, suggesting that some earlier stage adze manufacture may also have occurred. Two flakes with polish may indicate a low level of adze maintenance (resharpening).

Discussion

The value of careful analysis of basalt assemblages from archaeological sites in the Hawaiian islands cannot be overstated. With respect to adze manufacture, many scholars for many decades have recognized the importance of documenting aspects of adzes because these tools are the main basalt tool type in lithic assemblages (Cleghorn 1982, 1986; Emory 1968; Lass 1994; Withrow 1991; among those focusing on Hawaiian adzes, and nearly every report or publication that documents adzes at Hawaiian archaeological sites), can be geochemically analyzed to basalt source (Bayman and Moniz-Nakamura 2001; Cleghorn et al. 1985; Dye et al. 1985; Sinton and Sinoto 1997; Weisler 1990), and were in some situations associated with ritual contexts (McCoy 1990, 1999). At classic quarry sites, such as Mauna Kea, such types of analyses have been relatively standard, particularly following the work of Cleghorn (1982, 1986) who demonstrated the interpretive potential of metric and qualitative attributes of flakes, as well as the more common focus on adze blanks and preforms. Adze manufacturing locales away from major quarry areas have also been remarked upon by many authors, especially in the often difficult to access "grey literature" of contract archaeology (e.g., Dixon and Major 1993) or even in various manuscripts in the possession of individual authors or institutions.[11]

Although adze preforms and finished adzes certainly are important products to study, both the manufacturing process and maintenance activities, such as resharpening, are best understood when detailed analyses of the basalt flakes are undertaken (e.g., Olszewski 2004; Turner and Bonica 1994). Isolating these activities at sites away from quarries allows for a better understanding of the behavioral repertoire of pre-Contact period Hawaiians, how these activities were organized (e.g., perhaps at the household level), and the contexts in which these behaviors were undertaken either within regions or at habitation or specialized activity sites. To perform such detailed analyses, however, it is necessary to categorize basalt debitage into types that have the potential to shed light on adze manufacturing or resharpening sequences. This entails more than calling flakes diagnostic or nondiagnostic. Rather, there must be a system of identifying flakes with varying amounts of cortex, those without cortex, flakes with polish (even if that polish is present only on the striking platform), as well as other products such as broken flakes (which can include broken flakes with and without a striking platform), and fragments. Additionally, as several studies have shown, the metric attributes of flakes can also lend great insight into manufacturing and resharpening processes, as do (to a somewhat lesser extent) flake terminations.

The detailed study of flake attributes presented in the examples above allow estimations of earlier versus later stage adze manufacture at sites away from quarries. In the Pololū example, Lass (1994) interprets activity at this specialized task site as representing the earlier stages of adze manufacture. In this scenario, adze preforms are manufactured and then transported elsewhere (perhaps to habitation sites) for the final stages of manufacture. Her adze petrographic analysis study shows that Pololū basalt was present at a number of sites on Hawai'i regardless of distance from this source, suggesting that this behavioral model is relatively accurate.

Sites with later stages of manufacture, however, need not always be greatly removed from the quarry areas, for example, those in the Pōhakuloa region. Here, Bayman and Moniz-Nakamura (2001:249) charac-

terize adze production as expedient and small scale, and interpret most activity relating to adzes as representative of the later stages of adze manufacture. Interestingly, this occurs in the context of what is likely limited habitation, perhaps connected to bird hunting, so that a wider range of tasks is represented in this context compared to the situation in Pololū.

The Pōhakuloa model appears to be broadly analogous to the example of Sites 161 and 185 from Moloka'i. These indicate limited movement of materials as partially finished products, for example, adze blank manufacture at Site 161, and transport of adze blanks over only a few hundred meters to sites such as Site 185 for manufacture into adze preforms, and perhaps finished adzes.

The situation in North Hālawa Valley offers further—and unusual—insight into adze manufacture away from quarries. Here, while there may be instances of the later stages of adze manufacture, that is, from adze preform to finished adze, it is the recycling of old adzes that is a significant activity. Locales where this task occurred include a variety of site types ranging from specialized activity to temporary habitation to permanent habitation sites. The characteristics of these locales mimic quarry chipping stations in the spatial distribution of the debitage—which is tightly concentrated within about 1–3 m^2. Relatively high concentrations of flakes with polish and the metric and termination attributes of flakes with polish and noncortical flakes, all suggest that the entire manufacturing process is present. The sequence, however, is from finished adzes (or broken finished adzes) used as blanks for the creation of new, smaller sized adzes, perhaps as small as microadzes (≤60 mm). This process would fit what Weisler (1990:46) describes as a household-level need for small adzes for everyday tasks. Equally important, however, is the fact that adzes being recycled in this manner may also reflect what Turner and Bonica (1994:24) describe as a conservation of time and effort that would be required if return visits to quarries were necessitated every time an adze broke and required replacement. There are also potentially interesting social implications if the recycling of old adzes is suggestive either of limited access to basalt sources or the increasing perceived value of basalt as a resource during the later centuries of the pre-Contact period. The fact that recycling of old adzes seems to increase as an activity through time in North Hālawa Valley may support this observation.

Detailed studies of flake attributes from the North Hālawa Valley sites has also indicated that it may be possible to identify adze resharpening as an activity separate from adze recycling. Adze resharpening is expected to generate far fewer flakes with polish than adze recycling and, because of the limitation of small samples, will continue to present interpretive challenges.

As the several examples above demonstrate, it is clear that adze production activities in the Hawaiian islands were not tasks performed only at quarry locales or only in specialized ritual contexts. In fact, small scale adze manufacture—perhaps tied mainly to household needs or organized primarily on a household level—is an important facet for better understanding socially organized behaviors in the later pre-Contact period. Certainly the increasing number of sites with small-scale production testifies to the fact that adze making in most situations is less likely to exemplify stereotypic craft specialization, and more likely to suggest other constraints such as time/effort management and access to basalt resources. Detailed studies of basalt artifacts, such as those presented here, might also be useful in risk minimization analyses, analogous to those often identified for agricultural strategies in the Hawaiian islands (e.g., Dixon et al. 1999; Ladefoged and Graves 2000).

Notes

1. Pre-Contact period is generally taken to mean the period prior to Captain James Cook's arrival in the Hawaiian Islands in A.D. 1778.

2. Smaller sized preforms, including ones for microadzes, might be expected when adzes are manufactured from large flakes rather than from nodules, for example, as at Kapohaku Adze Quarry, Lana'i (Weisler 1990:37).

3. In most cases, there is more than one adze recycling example at each of these sites.

4. The rectangular form is common to Hawaiian adzes of the late pre-Contact period (Emory 1968: 164; Kirch 1985:302–303).

5. Cleghorn's (1982:287–294) research also indicates that flakes with step terminations tend to be small or medium sized (≤50 mm).

6. Site 5305 was discovered during the monitoring phase, and surface scraping by bulldozers disturbed the upper portions of the cultural contexts by spreading lithics across the site. Densities of basalt assemblages thus represent only the lower portions of these activity locales, and are less than what would have been present if these features were undisturbed.

7. Adze blanks are flaked rough-outs for adze preforms; adze preforms have been more finely shaped than adze blanks.

8. This is the Bishop Museum site number.

9. Maurice Major encouraged the author to analyze the lithics from Site 50-MO-B6-185, which was accomplished in 1995, and reported here for the first time.

10. Adze reject is a term adopted by Bayman and Moniz-Nakamura (2001:247) from the work of McCoy (1999:30). It indicates discarded adzes in either the blank or preform stage.

11. This problem is particularly acute for researchers located away from the Hawaiian islands, who cannot easily access the reports filed with the State Historic Preservation Division. Some of this might be alleviated were such reports to be made available as downloads in, e.g., Adobe pdf format, much as has been done by Bishop Museum for many of the reports written for the archaeology of the Interstate H-3 project (e.g., Olszewski 2003a, b).

12. Lithic analyses of the inventory survey phase lithics were constrained by limitations imposed by the State Historic Preservation Division, and consequently the only flake categories were diagnostic flake, nondiagnostic flake, and flake with polish, which do not provide enough data to be included in the analysis presented here.

Acknowledgments

The review comments provided by Robert Bollt and Scott Williams on the original draft of this paper are much appreciated. Their suggestions have clarified several aspects.

References

Bayman, J. M. and J. J. Moniz-Nakamura. 2001. Craft Specialization and Adze Production on Hawai'i Island. *Journal of Field Archaeology* 28(3/4): 239–252.

Bishop Museum. 2003. *Imu, Adzes, and Upland Agriculture. Inventory Survey Archaeology in North Halawa Valley, O'ahu.* Report prepared for the Hawai'i Department of Transportation, U.S. Department of Transportation, State Department of Land and Natural Resources, and Office of Hawaiian Affairs. B. P. Bishop Museum Department of Anthropology, Honolulu. [available for download at: http://www.bishopmuseum.org/research/cultstud/h3reports.html]

Bishop Museum. 2004. *Activities and Settlement in an Upper Valley. Data Recovery and Monitoring Archaeology in North Halawa Valley, O'ahu.* Report prepared for the State of Hawai'i Department of Transportation, U.S. Department of Transportation, State Department of Land and Natural Resources, and the Office of Hawaiian Affairs. B.P. Bishop Museum Department of Anthropology, Honolulu.

Cleghorn, P. L. 1982. *The Mauna Kea Adze Quarry: Technological Analyses and Experimental Tests.* Ph.D. thesis, University of Hawai'i, Honolulu. University Microfilms, Ann Arbor.

Cleghorn, P. L. 1986. Organizational Structure at the Mauna Kea Adze Quarry Complex, Hawaii. *Journal of Archaeological Science* 13 375–387.

Cleghorn, P. L., T. Dye, M. Weisler, and J. Sinton. 1985. A Preliminary Petrographic Study of Hawaiian Stone Adze Quarries. *Journal of the Polynesian Society* 94(3):235–251.

Dixon, B., P. J. Conte, V. Nagahara, and W. K. Hodgins. 1999. Risk Minimization and the Traditional *ahupua'a* in Kahikinui, Island of Maui, Hawai'i. *Asian Perspectives* 38(2):229–255.

Dixon, B. and M. Major. 1993. *Kapukaheuhu to Pu'uhakina: An Archaeological Inventory Survey of Southwest Moloka'i, Hawai'i*. Report prepared for Alpha USA (Honolulu). B. P. Bishop Museum Department of Anthropology, Honolulu.

Dye, T., M. Weisler, and M. Riford. 1985. Adz Quarries on Moloka'i and Oahu, Hawaiian Islands. Prepared for Historic Site Section, Department of Land and Natural Resources, State of Hawai'i. Report on file, Bernice P. Bishop Museum, Honolulu.

Emory, K. 1968. East Polynesian Relationships as Revealed Through Adzes. In *Prehistoric Culture in Oceania*, I. Yawata and Y. Sinoto (eds.), pp. 151–169. Bishop Museum Press, Honolulu.

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

Ladefoged, T. N. and M. W. Graves. 2000. Evolutionary Theory and the Historical Development of Dry-Land Agriculture in North Kohala, Hawai'i. *American Antiquity* 65(3):423–448.

Lass, B. 1994. *Hawaiian Adze Production and Distribution*. Monograph 37, Institute of Archaeology, University of California, Los Angeles.

Lass, B. 1998. Crafts, Chiefs, and Commoners: Production and Control in Precontact Hawai'i. In *Craft and Social Identity*, C.L. Costin and R.P. Wright (eds.), pp. 19–30. Archaeological Papers of the American Anthropological Association no. 8, Arlington, VA.

Leidemann, H. H. and Gordon, I. P. 2004. Site 50-80-10-5305. In *Activities and Settlement in an Upper Valley. Data Recovery and Monitoring Archaeology in North Halawa Valley, O'ahu, Vol 2c*, pp. 1–19. Report prepared for the State of Hawai'i Department of Transportation, U.S. Department of Transportation, State Department of Land and Natural Resources, and the Office of Hawaiian Affairs. B. P. Bishop Museum Department of Anthropology, Honolulu.

McCoy, P. C. 1977. The Mauna Kea Adze Quarry Project; A Summary of the 1975 Field Investigations. *Journal of the Polynesian Society* 86(2): 223–244.

McCoy, P. C. 1990. Subsistence in a "Non-Subsistence" Environment. Features of Production in a Hawaiian Desert Quarry. In *Pacific Production Systems: Approaches to Economic Prehistory*, D. E. Yen and J. Mummery (eds.), pp. 85–119. Australian National University, Canberra.

McCoy, P. C. 1999. Neither Here Nor There: A Rites of Passage Site on the Eastern Fringes of the Mauna Kea Adze Quarry, Hawai'i. *Hawaiian Archaeology* 7:11–34.

McGuirt, M. D. 2004. Site 50-80-10-2016. In *Activities and Settlement in an Upper Valley. Data Recovery and Monitoring Archaeology in North Halawa Valley, O'ahu, Vol 2a*, pp. 1–44. Report prepared for the State of Hawai'i Department of Transportation, U.S. Department of Transportation, State Department of Land and Natural Resources, and the Office of Hawaiian Affairs. B. P. Bishop Museum Department of Anthropology, Honolulu.

Olszewski, D. I. 2003a. Lithic Assemblages. In *Imu, Adzes, and Upland Agriculture. Inventory Survey Archaeology in North Halawa Valley, O'ahu, Volume 1: Overview, Recommendations, and Appendices*, pp. 135–182. Report prepared for the Hawai'i Department of Transportation, U.S. Department of Transportation, State Department of Land and Natural Resources, and Office of Hawaiian Affairs. B. P. Bishop Museum Department of Anthropology, Honolulu. [Available for download at: http://www.bishopmuseum.org/research/cultstud/h3reports.html]

Olszewski, D. I. 2003b. Site Synopses. In *Imu, Adzes, and Upland Agriculture. Inventory Survey Archaeology in North Halawa Valley, O'ahu, Volume 1: Overview, Recommendations, and Appendices*, pp. 29–54. Report prepared for the Hawai'i Department of Transportation, U.S. Department of Transportation, State Department of Land and Natural Resources, and Office of Hawaiian Affairs. B. P. Bishop Museum Department of Anthropology, Honolulu. [available for download at: http://www.bishopmuseum.org/research/cultstud/h3reports.html]

Olszewski, D. I. 2004. Activity, Space, and Time: The Lithic Assemblages. In *Activities and Settlement in an Upper Valley. Data Recovery and Monitoring Archaeology in North Halawa Valley, Oʻahu, Vol 1: Overview and Appendices*, pp. 39–90. Report prepared for the State of Hawaiʻi Department of Transportation, U.S. Department of Transportation, State Department of Land and Natural Resources, and the Office of Hawaiian Affairs. B. P. Bishop Museum Department of Anthropology, Honolulu.

Olszewski, D. I., S. P. McPherron, S. A. Lebo, L. L. Hartzell, H. A. Lennstrom, and P. C. Klieger. 2003. Discussion. In *Imu, Adzes, and Upland Agriculture. Inventory Survey Archaeology in North Halawa Valley, Oʻahu, Volume 1: Overview, Recommendations, and Appendices*, pp. 293–371. Report prepared for the Hawaiʻi Department of Transportation, U.S. Department of Transportation, State Department of Land and Natural Resources, and Office of Hawaiian Affairs. B. P. Bishop Museum Department of Anthropology, Honolulu. [available for download at: http://www.bishopmuseum.org/research/cultstud/h3reports.html]

Olszewski, D. I., S. P. McPherron, S. A. Lebo, L. L. Hartzell, and H. A. Lennstrom. 2004. North Hālawa Valley Overview. In *Activities and Settlement in an Upper Valley. Data Recovery and Monitoring Archaeology in North Halawa Valley, Oʻahu, Vol 1: Overview and Appendices*, pp. 267–307. Report prepared for the State of Hawaiʻi Department of Transportation, U.S. Department of Transportation, State Department of Land and Natural Resources, and the Office of Hawaiian Affairs. B. P. Bishop Museum Department of Anthropology, Honolulu.

Porter, S. C. 1979. Hawaiian Glacial Ages. *Quaternary Research* 12:161–187.

Sinton, J. M. and Y. H. Sinoto. 1997. A Geochemical Database for Polynesian Adze Studies. In *Prehistoric Long-Distance Interaction in Oceania: An Interdisciplinary Approach*, M.I. Weisler (ed.), pp. 194–204. New Zealand Archaeological Asociation Monograph 21, Auckland Museum, Auckland.

Turner, M. and D. Bonica. 1994. Following the Flake Trail: Adze Production on the Coromandel East Coast, New Zealand. *New Zealand Journal of Archaeology* 16 5–32.

Weisler, M. 1990. Technological, Petrographic, and Geochemical Analysis of the Kapohaku Adze Quarry, Lanaʻi, Hawaiʻian Islands. *New Zealand Journal of Archaeology* 12:209–205.

Williams, S. 1989. *A Technological Analysis of the Debitage Assemblage from Koʻokoʻolau Rockshelter No. 1, Mauna Kea Adze Quarry, Hawaiʻi*. M.A. thesis. Washington State University, Pullman.

Withrow, B. 1991. Prehistoric Distribution of Stone Adzes on the Island of Hawaiʻi: Implications for the Development of Chiefdoms. *Asian Perspectives* 29: 236–250.

A Hypothesis Regarding the Absence of the Pecking Technique in Hawaiian Adze Making

Robert Bollt, Eric Ferraro, and Jarib Porter
Department of Anthropology,
University of Hawai'i at Mānoa

Introduction

The absence of the pecking technique in adze manufacture in Hawai'i is a curious anomaly in East Polynesia. By the late 18th century, pecking was used to some degree in adze making almost throughout East Polynesia, but in Hawai'i it was completely absent. Different models have been suggested to account for the distribution of the pecking technique in Polynesia, but the issue remains unresolved. Although not employed in Hawaiian adze manufacture, the technology of pecking was known there, as it was throughout Polynesia, for the manufacture of artifacts such as sinkers, food (*poi*) pounders (in East Polynesia) and *'ulu maika* gaming stones (specific to Hawai'i). It was not an innovative technology that somehow never reached Hawai'i, but rather a manufacturing method deliberately not applied to Hawaiian adzes.

Let us define the terms used in the process of adze manufacture as set forth by Buck et al. (1930:180). *Chipping* is defined as "The process of removal, by blows, of flakes large or small." Here the term "chipping" is used rather than "flaking," although the two are largely interchangeable. *Pecking* is defined as "The process of striking blows on a surface with a pointed implement, each blow leaving a small pit." *Grinding* is defined as "The process of removing roughness by rubbing with sandstone or similar material." The additional processes of *bruising* (a form of pecking) and *polishing* are not applicable in the present study.

Stokes (1930:139–140) was first to address the problem in detail:

> Pecking is absent or very rare in Hawaiian, Samoan, and Pitcairn Island adzes, so far as well authenticated specimens indicate [in fact, it is completely absent in Hawaiian adzes]; it is present, but rare in Tongan and Marquesan adzes;

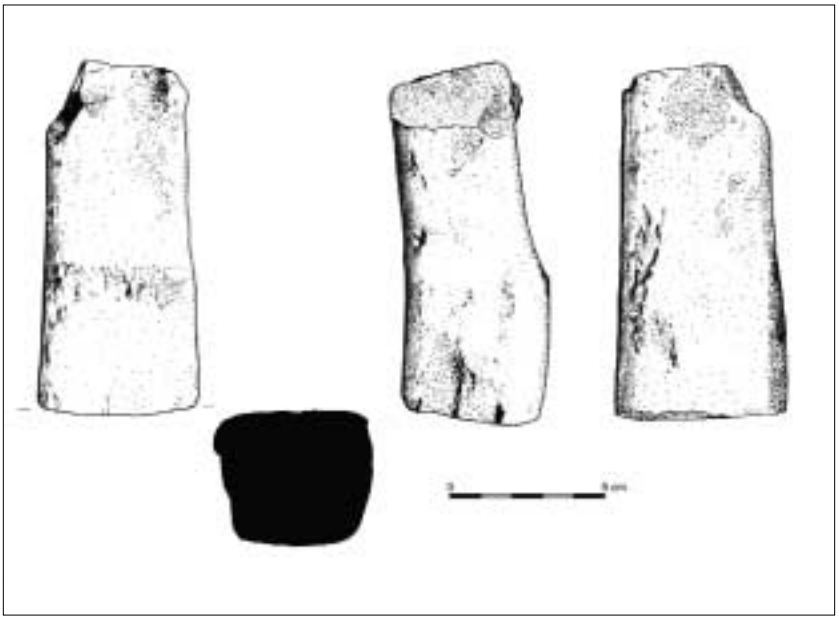


Figure 1. Butt of pecked Duff Type 1A adze with lugs on poll (Bollt 2005a:Figure 9.3).

> both technics [sic] are present, though pecking is dominant, in adzes from Easter Island, the Society Islands, Tubuai, Rapa, the Cook Islands, and New Zealand. In islands where pecking predominates, most of the pecked adzes are superior in form, symmetry and finish to the unpecked ones.
>
> This distribution may indicate different cultural elements in Polynesia. The focus of the pecking process seems to have been the Cook, Austral, or Society islands, where it accompanies a non-pecking process surviving in some marginal areas like Samoa. On the other hand, adzes show that the pecking process was important in Easter Island . . . a marginal point screened, as it were, from the Society Islands, by non-pecking localities such as Pitcairn, Mangareva, and possibly the Marquesas. [Pecking was definitely present in the Marquesas; see Figueroa and Sanchez 1965:201] However, Polynesia cannot be regarded as an isolated area, for in Melanesia, from Fiji westward, both technics [sic] were present, but Melanesian adzes are characterized by an excess of grinding, so that the importance of the pecking process, where present, cannot well be determined.

Figueroa and Sanchez (1965:200) used Stokes' hypothesis as a starting point in an analysis of 971 surface collected adzes from Easter Island, Pitcairn, Ra'ivavae, Mangareva, Rapa, and the Marquesas. They found that pecked adzes tend to have a rounded cross section and are of rather limited distribution compared to those with more angular cross sections, mostly unpecked (Figueroa and Sanchez 1965:200–201; see also Sinoto 1970). Basically confirming what Stokes (1930) had proposed, Figueroa and Sanchez (1965) concluded that pecking originated in central East Polynesia (Tahiti, Southern Cooks, Australs) in the late prehistoric period and then diffused outward while remaining predominant in the central area. The antiquity of the pecking technique in central East Polynesia dates at least to the 13th to 14th centuries A.D., as attested by at least one excavated example of a pecked Type 1A adze butt recovered from Rurutu in the Austral Islands (Figure 1; see Bollt 2005a, 2005b).

By the 1980s, experimental archaeology began to suggest independent invention rather than diffusion of Polynesian adze manufacture techniques, especially in Hawai'i. Cleghorn (1984:410) noted, "Even accepting Stokes' distribution (which is difficult to evaluate as sample sizes are not given), an alternative explanation might be found by looking for a correlation between the distribution of the pecking technique and the distribution of raw materials that are difficult to flake. A positive correlation between these factors might best be explained by independent solutions to similar problems, rather than by cultural relationships." Cleghorn (1984:411) concluded from his experiments that "it requires much less effort to shape a water-worn basalt cobble by pecking than by flaking; the rounded contours make the flaking of tough basalt difficult. Thus, if water-worn cobbles are the dominant form of material associated with the pecking technique, then the form of the raw material might be used as an explanation for the distribution of this manufacturing technique." In addition to these observations, the type of raw material may be a factor in determining adze form, in terms of a rounded or more angular cross section (Cleghorn 1982, 1984:411; see also Bellwood 1970:98). Figueroa and Sanchez (1965: 200) had earlier addressed the availability of different types of stone in determining the presence or absence of pecking, but concluded that "the nature of the stone employed does not seem to have been important in determining the distribution of the two basic

adze manufacturing techniques. Rather, this distribution apparently is the result of complex cultural and historical causes."

Hypothesis of the Present Study

The distribution of pecking throughout East Polynesia is very likely linked to both basalt type and adze form (e.g., cross section), as Cleghorn (1982, 1984) and Bellwood (1970) previously noted. A comparative study of assemblages from multiple island groups would be very useful in this respect, but it is far beyond the scope of the present study. Also, it would not explain why pecking was not used for adze making in Hawai'i. Could the choice have been related less to the raw stone material than to the material used to grind it? Why is Hawai'i an anomaly? Could it have been, as Figueroa and Sanchez (1965: 201) suggested, that "central area developments" did not reach Hawai'i, or were other factors that make Hawai'i unique involved? Our hypothesis takes such factors into account, focusing on black sand and possibly olivine sand.

Black sand beaches exist in a variety of types. McDonald et al. (1983:272) wrote:

> Some black sand beaches, for example those of Kalapana (Kaimu) and Punaluu on Hawaii, consist of glassy volcanic debris from littoral explosions. Others, however, such as some on the south shore of Molokai, consist of the grains of the heavy black minerals magnetite and ilmenite, eroded out of the lava rocks. Still other black, gray, and brownish gray beaches consist largely of fragments of lava rock.

In West Polynesia, black sand is present in limited quantities in Fiji (Viti Levu) and Samoa (Upolu). Figueroa and Sanchez (1965:200) noted that in West Polynesia "pecking is rare and probably diffused from Fiji." If adze-pecking was an East Polynesian innovation as Stokes (1930) and Figueroa and Sanchez (1965) suggested, then its near-absence in West Polynesia is to be expected and may not be connected to the presence of black sand.

In terms of East Polynesia, however, the entire absence of pecking in Hawai'i is difficult to explain, given its presence (if not dominance) in virtually every other part of East Polynesia. Black sand is most abundant in Hawai'i, is limited in both the Societies (Tahiti) and the Marquesas (Nuku Hiva, Hiva Oa), and totally absent in the Cooks, Australs, and Tuamotus. New Zealand, which has black sand, will remain outside the scope of the present study because the types of stone there, such as greenstone and greywacke, are far more varied than elsewhere in East Polynesia, opening an entirely different set of questions regarding manufacturing technique.

Olivine sand also is restricted to the Hawaiian archipelago, most notably at Hanauma Bay (O'ahu) and Papakolea (5 km northeast of South Point, Hawai'i Island). McDonald et al. (1983:272–3) wrote:

> At both places the sand consists primarily of green crystals of olivine, separated out of the volcanic rocks by erosion. At Hanauma Bay the rock supplying the olivine is tuff belonging to the row of cones extending northeastward from Koko Head. At Papakolea the olivine is derived from Puu Mahana, a littoral cinder cone formed where an ancient aa lava flow entered the ocean.

Is it possible that the abrasive quality of these noncalcareous sand types made pecking virtually obsolete for adze making in Hawai'i? Could black or olivine sand have been prized enough to become an item of trade between islands and valleys?

The Experiment

To test our hypothesis, we constructed an experiment to compare the abrasiveness of black, olivine, and calcareous white sand, by means of a weight-reduction experiment. The experiment took place on the University of Hawai'i at Mānoa campus in April 2006 (Table 1; Figures 2 and 3). We prepared a basalt grinding stone with a surface area of approximately 50 cm^2 on which we ground a variety of adze preforms, flattening and smoothing the surface. A quadrangular piece of fine-grained tabular prismatic basalt was then selected for the experiment from the Kapa'a quarry area on O'ahu. One surface was ground flat and smooth before the formal experimentation began in order to obtain a uniform surface. The sides were then ground flat to ensure uniform reduction.

Table 1. Results of weight reduction experiment.

Sand type	Starting weight (g)	Weight of stone after 20 minutes (g)	Total weight reduction (g)
Olivine sand	183.26	181.26	1.80
Black sand	181.26	178.93	2.53
White sand	178.93	178.34	0.59

Figure 2. Porter (left) grinds the sample while Ferraro (right) works on a preform.

Figure 3. Close-up of Porter grinding the sample.

By the end of preparation, the specimen weighed 183.26 g.

Grinding of the stone proceeded in 20-minute sessions with the three different types of sand: olivine sand (from Green Sand Beach, Hawai'i Island), pure black sand (from Punalu'u Beach, Hawai'i Island), and calcareous white sand (from Hawai'i Kai, O'ahu Island). The grinding time was divided between Ferraro and Porter, each grinding for ten minutes. To begin, 500 g of sand was spread over the surface of the grinding stone. Following this, 100 ml of fresh water was added and mixed by hand over the grinding surface. Neither the sand nor water was renewed during the 20-minute period. During the course of the three grinding phases, every effort was made to grind in as even a pace as possible. At first, we attempted to establish a set tempo using a metronome, but this proved cumbersome and produced an unnatural rhythm. We decided that monitoring one another by sight was preferable. To ensure relatively even pressure during the sessions, the stone was ground with one hand at a time using the same body position so that body weight was distributed the same way. Grinding was done in a back and forth motion, as opposed to circular, to ensure consistency in the amount of surface area of the grindstone being covered by each stroke (see Figures 2 and 3). However, during our earlier informal experiments with grinding, we soon learned that every different motion type is actually used in practice. Grinding is an extremely monotonous activity, and changing motions regularly makes it less so. Ideally, the grinding in an experiment such as ours should be done with a mechanical device whose rate and pressure could be precisely measured and controlled, but such was beyond our resources. At the end of each grinding session, the specimen was washed and weighed. One potential problem can arise from this procedure: given that we smoothed the surface of the piece before the experiment, the efficiency of each sand type may be under-represented, as there were no "high" points or irregularities to be removed. However, this potential under-representation should apply to all three types of sand, and thus the overall bias should be lessened. The results are listed in Table 1.

Results and Discussion

Black sand was the most successful abrader, reducing the weight of the specimen nearly five times more effectively than white sand. Olivine sand was almost four times more effective than white sand, and it rendered a smoother, more polished surface than black sand. Our personal, informal impressions of the different types of sand should also be noted. Grinding with black sand, especially of the Punalu'u Beach type (glassy volcanic debris), feels very different than white sand. The black sand crunches like glass underneath the preform, and it remains coarse much longer than white sand. Olivine sand does not have the same glassy quality, but it also remains coarse longer than white sand. Both black and olivine sand *feel* more effective than white sand while grinding, making the tedious process seem faster and more bearable. The subjective experience of producing a stone tool cannot be emphasized enough.

Our results suggest the possibility that black sand may have been favored as an abrader in prehistoric Polynesia. As black sand is more abundant in Hawai'i than anywhere else in Polynesia, it conceivably contributed to the absence of the pecking technique in adze making there. However, the fact that black sand is unevenly distributed among the Hawaiian Islands, being abundant on Hawai'i Island and scarce on the others, complicates the issue. Significantly, black sand is not readily available in central East Polynesia where pecking became the predominant technique (e.g., the Cooks, Societies, and Australs), being extremely limited in its distribution (Tahiti). The availability of black sand in Hawai'i may also have contributed to the predominance of the quadrangular adze there, whose flat surfaces are far more easily ground than pecked. Other, subtler factors may have been present, perhaps including cultural preference, pride of workmanship, and display of skill.

This experiment is a pilot study intended to open new avenues of research into an issue that warrants further investigation. The abrasive qualities of different types of sand should be tested under more controlled conditions, mechanically if possible, and for longer grinding times. Additionally, a wide variety of basalt from quarries around Polynesia should be used.

Acknowledgements

This study grew from a class (Lithic Analysis in Archaeology) taught by lead author at the University of Hawai'i at Mānoa in Spring 2006. We thank Paul Cleghorn for providing some of the inspiration for this project and for giving us the olivine sand for our experiment. We thank Jo Lynn Gunness for her ideas, input, and assistance in helping us coordinate our activities during the semester. We thank Mike Carson for his comments and suggestions during the experimentation process and for his editorial labors. Finally, we thank Michael Graves who put sufficient departmental funds at our disposal for this project.

References Cited

Bellwood, P. 1970. Dispersal Centers in East Polynesia, with Special Reference to the Society and Marquesas Islands. In *Studies in Oceanic Culture History, Volume 1,* edited by R. C. Green and E. M. Kelly, pp. 93–104. Pacific Anthropological Records No. 11. Department of Anthropology, Bernice P. Bishop Museum, Honolulu.

Bollt, R. 2005a. Peva: the Archaeology of a Valley on Rurutu, Austral Islands, East Polynesia. Ph.D. dissertation, University of Hawai'i at Mānoa, Honolulu.

———. 2005b. Recherches sur le Site de Peva. *Bilan de la Recherche Archéologique en Polynésie Française 2002–2003, Dossier d'Archéologie Polynésienne.*

Buck, P. H., K. P. Emory, H. D. Skinner, and J. F. G. Stokes. 1930. Terminology for Ground Stone Cutting Implements in Polynesia. *Journal of the Polynesian Society* 39:174–80.

Cleghorn, P. L. 1982. The Mauna Kea Adze Quarry: Technological Analysis and Experimental Tests. Ph.D. dissertation, University of Hawai'i at Mānoa, Honolulu.

———. 1984. An Historical Review of Polynesian Stone Adze Studies. *Journal of the Polynesian Society* 93:399–420.

Duff, R. 1956. *The Moa-Hunter Period of Maori Culture*. R. E. Owen, Government, Wellington.

———. 1970. *Stone Adzes of Southeast Asia*. Bulletin No. 5. Canterbury Museum, Christchurch.

Figueroa, G. and E. Sanchez. 1965. Adzes from Certain Islands of East Polynesia. In *Reports of the Norwegian Archaeological Expedition to Easter Island and the East Pacific. Monographs of the School of American Research and the Kon Tiki Museum, No. 24, pt. 2, Report 12*, edited by T. Heyerdahl and E. N. Ferdon, pp. 169–254. Rand McNally and Company, Chicago.

Heyerdahl, T. and E. N. Ferdon. 1965. *Reports of the Norwegian Archaeological Expedition to Easter Island and the East Pacific*. Monographs of the School of American Research and the Kon Tiki Museum, No. 24, Parts 1 and 2 Rand McNally and Company, Chicago.

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

Macdonald, G. A., T. Abbott, F. L. Peterson. 1983. *Volcanoes in the Sea: the Geology of Hawaii.* Second edition. University of Hawai'i Press, Honolulu.

Sinoto, Y. H. 1970. An Archaeologically-based Assessment of the Marquesas Islands as a Dispersal Center in East Polynesia. In *Studies in Oceanic Culture History, Volume 1*, edited by R. C. Green and M. Kelly, pp. 105–32. Pacific Anthropological Records No. 11. Department of Anthropology, Bernice P. Bishop Museum, Honolulu.

Stokes, J. F. G. 1930. Stone Implements from Tubuai. In *Ethnology of Tubuai*, edited by R. T. Aitken, pp. 130–64. Bernice P. Bishop Museum Bulletin 70. Bishop Museum Press, Honolulu.

Indigenous Hawaiian Fishing Practices in Kahikinui, Maui: A Zooarchaeological Approach

Sharyn Jones
Department of Anthropology,
University of Alabama Birmingham

Patrick V. Kirch
Department of Anthropology,
University of California Berkeley

Introduction

> Fishing was one of the constant, necessary occupations. Everyone knew how to obtain fish by various techniques. The slave, the commoner, the lesser chiefs, the high chiefs, men, women and children got food from the sea by their own efforts. (Titcomb 1972:3)

Hawai'i's rich archaeological and ethnographic records provide an opportunity to investigate the lifestyles and foodways of the people of all social ranks and genders, (including elites, priests, non-elites, women, and men) in this highly stratified society. Throughout the islands, indigenous Hawaiian foodways depended heavily on marine harvests, including fish, shellfish, and seaweeds. The sea provided the primary protein-contributing elements of the diet across social classes. However, marine foods may have been especially important to non-elites who had less access to domestic animals such as pigs and dogs for fat and protein (Kirch and O'Day 2003; Titcomb 1972). Ethnohistorically, Hawaiian marine resource exploitation strategies were recorded in some detail (Buck 1957; Handy et al. 1991; Titcomb 1972 [1952], 1978; Valeri 1985). Titcomb (1972:1) argued: "The sea was a great reservoir of food for Hawaiians and they were fond of a wide variety; probably everything was consumed."

The present study provides a comparative analysis of zooarchaeological evidence from household and ritual sites in the leeward district (*moku*) of Kahikinui, East Maui, Hawai'i (Figure 1). Interpretations of prehistoric behaviors are drawn from these archaeological data and expanded through the use of ethnographic accounts. This work builds on a prior study that focused on broad trends in subsistence practices

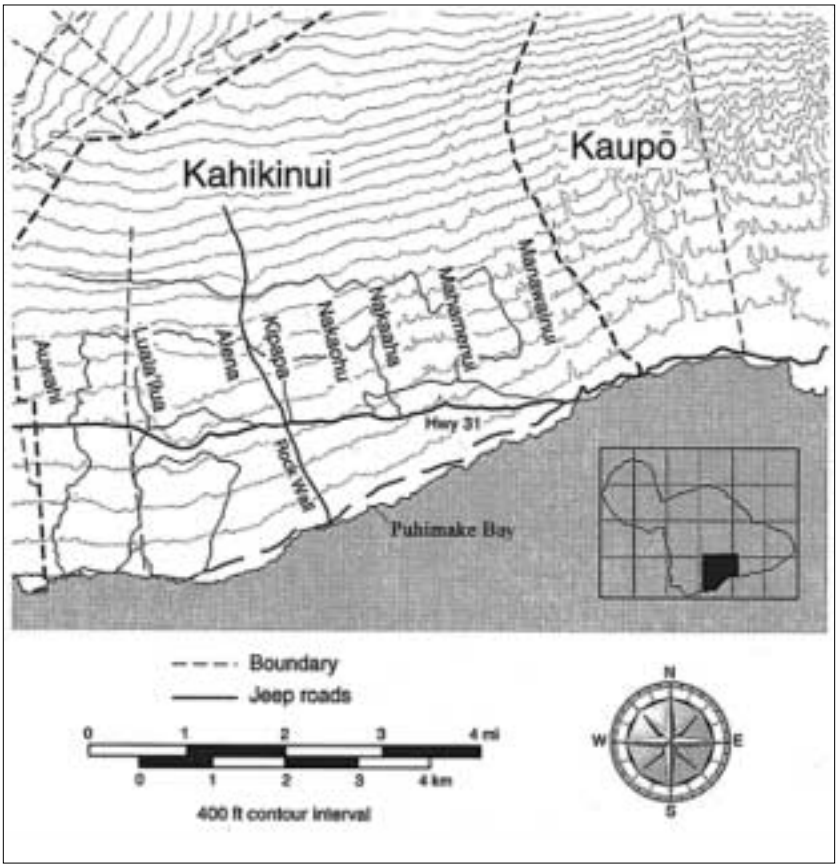


Figure 1. Map of the district of Kahikinui, Maui.

in Kahikinui and explored how zooarchaeological remains illuminate status variations between elite and commoner households when viewed as luxury foods (Kirch and O'Day 2003). The new treatment presents both new data and more detailed information on the exploitation of marine resources, including both vertebrates and invertebrates. Materials are compared and contrasted from Hawaiian elite and non-elite household complexes (*kauhale*), individual household features, and shrines or temples (*heiau*) of the late prehistoric and early historic periods in Kahikinui. A brief overview of the project setting and inter-site faunal material variability establishes the context of the investigation. Ethnographically and archaeologically recorded fishing behaviors that may be associated with specific environments and site assemblages are reviewed. Finally, a comparative analysis of the various faunal assemblages is presented using zooarchaeological techniques to explore inter-assemblage variation.

Setting

The district of Kahikinui has been described as a marginal "environmental mosaic" of geological substrates that are varied in terms of age and chemical composition (Kirch et al. 2004:9936). It incorporates an expanse of geologically youthful volcanic substrates, dating from 3,000 to 226,000 years in age, on the vast southern flank of Haleakalā Volcano (Kirch et al. 2004). The terrain ranges from rough *ʻaʻa* lava flows on the youngest substrates, to slightly dissected and weathered flow slopes on the oldest substrates; the region is arid and rainfall is largely confined to *kona* storms in the winter months. In keeping with its geological youth, the coastline is dominated by sea cliffs that range in height from 1 m to over 50 m. These sea cliffs restrict access to the coast to a few areas where basalt cobble beaches occur in protected bays or coves, which one can reach from the lava slopes above. Not surprisingly, archaeological sites are frequently clustered around these bays and beaches where coastal access is possible.

Local environmental conditions undoubtedly made fishing from canoes and collecting along the littoral zone difficult at times for the prehistoric inhabitants of Kahikinui. Wind and high surf pound Kahikinui's coast year-round. Kona storm waves ranging 3 to 5 m are common in late winter and early spring (but they may be present less frequently at other times), and southern swells hit in the summer and early autumn with waves about 0.5 to 1.25 m (Armstrong 1983:59–60). The ʻAlenuihaha Channel, known for strong near-shore tidal and surface currents and rough seas, runs parallel to the Kahikinui shore, between Maui and the north end of Hawaiʻi Island.

The *moku* of Kahikinui is divided into traditional political subdivisions (*ahupuaʻa*) whose boundaries are aligned from the uplands (*mauka*) to the sea (*makai*). Each of these *ahupuaʻa* exhibits a slightly varied ecological character that can best be described in terms of specific areas and zones (see O'Day 2004a). This ecological variability within the *moku* means that *ahupuaʻa* are not environmentally homogenous, and indeed intra-*ahupuaʻa* variation can be striking. For example, Haleakalā's volcanic eruptions have produced isolated flows that cover certain

areas but leave adjacent patches exposed, thus relatively fresh lava may abut much older volcanic substrates. Faunal composition is undoubtedly affected by such geomorphic variability. The sites analyzed in this study are located in the central *ahupua'a* of Kipapa and Nakaohu, and in the westernmost *ahupua'a* of 'Auwahi.

According to historic records, native Hawaiian perceptions about landscape and space were fundamentally enmeshed with divisions of *mauka* and *makai*, or landward and seaward. Sahlins (1992:19) argues: "These categories were ubiquitous in Hawaiian thought and practice, as significant in ritual as in the organization of production." The oppositional relationship between land and sea divisions expresses environmental and social inequality inherent in Hawaiian ideology and practice. Seaward areas were privileged in some contexts; for example, chiefly residences were often located *makai*. People had unequal access to sea-based divisions within the *ahupua'a* and certain marine resources and activities were regulated at times to particular social classes (Kamakau 1992[1976]; Kawaharada 1992; Titcomb 1972). Restrictions on marine exploitation for conservation and hierarchically regulated distribution are recorded in Hawaiian myth and history (Kamakau 1992). In Kahikinui, strictly regulated zones likely would have included well developed tide pools and bays that contain abundant and varied fauna (O'Day 2004). A select group of preferred fish and shellfish, such as large limpets, cowries, and cones presumably would have been harvested from these environments before other less desirable fauna.

Numerous recent publications have focused on Kahikinui, providing a foundation to reconstruct ancient Hawaiian settlement patterns, demographics, and agricultural practices in this traditional district (Dixon et al. 1999, 2002; Kirch 2004; Kirch and Sharp 2005; Kirch et al. 2004; Kirch and Van Gilder 1996; Vitousek et al. 2004). Based on a large sample of radiocarbon dates (Kirch, unpublished data), Kahikinui was first inhabited relatively late in Hawaiian prehistory, beginning around A.D. 1400. More than 3000 archaeological features have been documented in four *ahupua'a* intensively surveyed to date. Excavation data and radiocarbon evidence suggest that peak population density occurred during the final century prior to European contact (A.D. 1700 to 1800) and during this time may have reached a density level between 43 and 57 persons per km^2 in the lowland zone below 1000 masl (Kirch et al. 2004:9936). The distribution of household complexes over the landscape provides evidence that Kahikinui's inhabitants focused their residential sites inland, rather than along the coast. This pattern suggests positioning of households around environmental zones that were suitable for the cultivation of dryland crops, especially sweet potato (*Ipomoea batatas*).

Site Variability

Kirch and Van Gilder (1996) described a general pattern of site distribution across the Kipapa-Nakaohu landscape, with three broad zones paralleling the coastline, each correlated with key environmental attributes (Table 1). The three zones are described as coastal (*makai*), intermediate (*waena*), and upland (*mauka*).

The coastal zone (*makai*) is approximately 200 to 350 m wide, stretching from the seaward edge of land and moving inland. Site density is high, and occupation was definitely associated with marine exploitation. Based on excavations in several coastal complexes, most of the coastal occupations date to about A.D. 1820 to 1860, following European contact (Kirch et al. 2004), although a few are pre-contact. Five of the sites or site complexes selected for analysis are positioned *makai*, including the Kipapa Rockshelter, the Nakaohu Kai complex (Sites 331, 334, and 335, a pre-contact cluster), Site M11 (with both pre- and post-contact components), the 'Auwahi residential complex (AUW-14, 20, 24, and 31), and the 'Auwahi *heiau* and shrines (AUW-6, 9, 10, and 11). Most of these coastal sites are located within 100 m of the shoreline.

The intermediate zone (*waena*) extends from the edge of the coastal zone to approximately 250 to 300 m above sea level, and site density is low. The *waena* zone is primarily characterized by small C-shaped shelters, free-standing walls, and cairns. None of the excavated sites used for the present analysis lies within the *waena* zone.

The upland or *mauka* zone extends from approximately 250 to 700 m elevation, where rainfall and

soil nutrient status were adequate to support dryland cultivation, including staples such as sweet potato and taro (Kirch 1997:18; Kirch et al. 2004). Several residential complexes considered in the present analysis (Sites KIP-44, 45, 46, 48, 117, 725, 726, 728, 755, and 1301) are located in this *mauka* zone. None of the selected sites and features exhibited signs of post-depositional disturbance or significant taphonomic impacts, thus this zooarchaeological sample provides a sound basis for the following interpretations.

As indicated in Table 1, the sites considered in this study are distributed between coastal and inland zones, and they represent different functional categories. Many of the sites consist of residential clusters or complexes (*kauhale*), and they appear to represent both commoner (*maka'ainana*) and elite (chiefly or priestly) residences. Independent evidence (including site location, architecture, and artifact content) led to these functional interpretations, and this information will be reviewed extensively elsewhere. Our interpretations about status were based on architectural complexity, size, and elaboration, the presence or absence of fine-grained lithics and the character of the faunal assemblages. Most of the sites included in our analysis are characterized by shallow cultural deposits (typically 10–20 cm thick), representing a single period of occupation that is coeval with the construction and use of the surface architecture. Stratigraphic profiles that relate the occupation deposits to the surface architecture make us confident that the subsurface deposits do not predate the surface architecture. Sites M11 and 728 Kipapa are exceptions, which each yielding two stratigraphic components (dating to pre- and post-contact periods, respectively). Site 728 Kipapa is the only location that represents a functional change over time; its two temporal zooarchaeological components were analyzed separately for MNI calculations, as will be discussed below.

During the Great Māhele (1846–1854) historic records indicate that the majority of Kahikinui *moku* was awarded to Prince Lot Kamehameha (later King Kamehameha V), who immediately arranged to have the land transferred to the Government in exchange for other more desirable lands (Kirch 1997:4). The exception was the westernmost *ahupua'a* of 'Auwahi, which was awarded to Princess Ruta (Ruth) Ke'elikolani during the Māhele (Sterling 1998:210); Ke'elikolani kept this *ahupua'a*, which was later sold to 'Ulupalakua Ranch. That 'Auwahi was awarded to this very high-ranking chiefess suggests it had special status within the *moku*, which may relate to its enjoying the largest and most protected bay, and best canoe landing. Clustered around this bay are unusually large residential sites which we hypothesize to have been associated with the chiefs, or more likely their resident *konohiki* (land agents) who controlled Kahikinui District.

Site KIP-117, in the *mauka* zone, is closely associated spatially with several *heiau* situated on an isolated ridge and apart from any other residential sites; we interpret this structure as the residence of a priest (*kahuna*). Site KIP-755 consists of an unusually large and complex set of residential terraces unlikely to be a chiefly residence, but which may have been occupied by a household of considerable prominence. For comparison, the present analysis also includes several shrines and *heiau* at 'Auwahi.

Methods

Faunal materials were collected using nested sieves with 1/2-inch, 1/4-inch, and 1/8-inch mesh and identified using comparative collections from the Florida Museum of Natural History, University of Florida, and collections which are held at the University of Alabama, Birmingham, and in the Oceanic Archaeology Laboratory, University of California, Berkeley. Over 2000 reference skeletons representing multiple individuals of common taxa and a broad array of species from the tropical Pacific were used to identify the Kahikinui material. Zooarchaeological methods follow techniques developed by Reitz and Wing (1999). Faunal specimens were identified to the lowest taxonomic level possible. All faunal material was counted and weighed, and modifications such as cut marks or burning were recorded. The number of identified specimens (NISP) is the basic specimen count used. The minimum number of individuals (MNI) was determined by paired elements and estimated sizes for fish. Following Reitz and Wing (1999:194), MNI was defined as the smallest number of individuals that is necessary to account for all skeletal specimens of a given species within the as-

Table 1. Selected Kipapa and Nakaohu site descriptions with environmental zones, features, locations, and excavated areas indicated.

Zone	Complex/Site	Site Type	Approximate date of occupation and site features	Excavate d (sq. m)
Makai	**Nahoku Kai**	***Kau hale***	**A.D. 1478–1648**	
	Site 331	Linear Shelter	One informal combustion feature	4
	Site 334	Rectangular Enclosure	No Features	3
	Site 335	L-shaped shelter	No Features	4
Makai	**Kipapa Rock Shelter**	***Kau hale* feature**	**A.D. 1775**	
	Site 1137	Rock shelter	Interior *imu*, two informal combustion features on terrace	2
Makai	**M11 Makai**	**Residence and midden**	**Post-contact structure overlying pre-contact midden (A.D. 1470–1640)**	
	Site M11	Notched rectangular enclosure	Interior waterworn cobble paving, historic period house enclosure	7
Mauka	**Kipapa Uka**	***Kau hale***	**Terminal Proto-historic (ca. A.D. 1690)**	
	Site 44	Rectangular enclosure	(ca. A.D. 1690)	13
	Site 45	Linear shelter	Two slab-lined hearths	13
	Site 46	U-shaped enclosure	Partially stone paved interior	8
	Site 48	L-shaped enclosure	No features	5
Mauka	**Kipapa Swale Residential**	***Kau hale***	**A.D. 1720–1780**	
	Site 725	L-shaped shelter	Interior *imu* at the east wall	12
	Site 726	Linear shelter	Interior *imu* at the east wall	14
	Site 1301	C-shaped shelter	Slab-lined oven	2
Mauka	**728 Kipapa**	**Post-contact residence**	**Post-contact residence overlying pre-contact *heiau***	
	Site 728	Notched rectangular enclosure		9
Mauka	**755 Terrace**	**Habitation complex**	**A.D. 1640–1800**	
	755	5 adjacent terraces	Each terrace supports separate structures with distinct activity areas	20
Mauka	**117 Elite Residence**	**Elite/Priest's pre-contact residence**	**A.D. 1650–1800**	
	Site 117	L-shaped structure, walls, and terrace	Internal divisions, hearth, NE corner niche with waterworn stone cache	18
Makai	**'Auwahi Residential**	**Elite Residential Complex**	**Historic**	
	AUW 15	Large residential enclosure		1
	AUW 24	Circular structure in *kau hale* complex		1
	AUW 31	Rockshelter on ridge above complex		0.5
	AUW 20	Large ridge-top elite residence		1
Makai	**'Auwahi, Heiau, and Shrines**		**Historic**	
	AUW 6	*Heiau* with copious branch coral		1
	AUW 9	*Heiau* near fishing shrines		1
	AUW 10	Shrine with interior *imu*		0.5
	AUW 11	Shrine	ca. A.D. 1650	0.25

Table 2. Summary of marine vertebrate taxa identified from selected sites, Kahikinui, Maui.

	Kipapa Rock Shelter		Nakaohu Kai		Kipapa Uka		M11		Kipapa Swale		Site 728		Site 755		Site 117 Elite Residence		Auwahi Residential		Auwahi Heiau	
Taxon	g	MNI	g	MNI	g	MNI	g	MNI	g	MNI	g	MNI	g	MNI	g	MNI	g	MNI	g	MNI
Cheloniidae																	0.5	2	10	2
Chelonia mydas									0.6	1										
Carcharhinus sp.	0.12	2									0.05	1			1.4	1				
Muraenidae			0.5	1													0.2	1	0.3	2
Holocentrinae	0.05	1																	0.2	1
Perciformes																	0.2		5.8	
Serranidae																			0.1	1
Epinephelis spp.					0.2	1	0.3	2	1.1	1					0.5	1				
Kuhlia sandvicensis	0.11	2																		
Carangidae	0.1	1					1	2											0.1	
Caranx spp.	0.2	2							8.5	2									26.7	3
Scomberoides sp.	0.04	1																		
Lutjanus spp.	0.82	2					0.1	1	0.1	1					0.11	1	0.1	1		
Monotaxis grandoculis	0.03	3					0.55	1	0.3	1					0.63	2			0.3	1
Mullidae																	0.1	1	0.1	1
Mugil cephalus	0.1	1																		
Labridae	0.18	4					0.5	3	0.32	4	0.1	1			0.7	1	0.2	2	1	2
Bodianus sp.																	0.3	1		
Scaridae							8.25	5	0.5	0			0.5	2	0.2	3	0.5	1		
Calotomus sp.	1.2	3	2.1	4	0.05	1			0.81	3	4.5	2			1.04	0	0.4	2	1.2	3
Scarus spp.	0.44	5	1.4	2					2.1	3	1.05	3							2.6	1
Acanthuridae																	2.5	2	1.7	1
Acanthurus spp.	2.46	3					0.1	1	0.51	3					1.15	2			0.2	1
Naso spp.			2.05	2							0.8	1							0.2	1
Balistidae	0.02	1	0.3	1	0.1	1	0.05	1			0.2	1			0.03	1	0.6	1	0.7	2
Diodontidae																			3.7	1
Total	**5.9**	**31**	**6.4**	**10**	**0.4**	**3**	**10.9**	**16**	**14.8**	**19**	**6.7**	**9**	**0.5**	**2**	**5.8**	**12**	**5.6**	**14**	**54.2**	**22**

semblage. When estimating MNI, each provenience (i.e., unit or feature) was considered separately, with attention to stratigraphy when appropriate. For example, the assemblage from site 728 Kipapa that had with two temporal components was divided stratigraphically for MNI estimates.

We present our vertebrate data in Table 2 by MNI and mass. In our 2003 publication, focused on some of the same data described here, we compared commoner and elite households based on NISP (Kirch and O'Day 2003). We recognize that much debate surrounds the choice of a basic counting unit in zooarchaeological analysis (Grayson 1984; Nagaoka 1994); thus our basic counting unit is NISP, but we also recorded MNI and mass.

In an effort to control for sample size differences for inter-site comparisons, a concentration index (CI) was calculated for each sample, following methods we applied previously (Kirch and O'Day 2003). For marine vertebrates, the calculated MNI was divided by the total area excavated (m^2) while for invertebrates, the NISP was divided by the total excavated area (m^2), to derive the CI. Although CI is typically calculated for volume, we have used area because the Kahikinui sites are all characterized by uniformly shallow cultural deposits. A high concentration index indicates a comparatively high frequency of faunal remains.

Results

The total weight, count, and calculated MNI of invertebrate and fish remains from the sites or site complexes varies considerably. Tables 2 and 3 present a detailed summary of the identified marine taxa (Appendices A and B list common and scientific family names). A similar range of core taxa are present at most of the sites, although the frequencies differ for each. Overall, invertebrate remains dominate the deposits, comprising 53 to 98% of the total identified faunal assemblage by weight and a majority of the NISP. The exception is the Kipapa Uka household complex, where invertebrate fauna by weight constitutes only 18% of the zooarchaeological deposit. However, comparing the vertebrate and invertebrate fauna by weight and count is potentially misleading because invertebrates generally contribute more weight (in the form of shell remains) to an assemblage but less meat to the diet than vertebrates. The relative dietary contribution (of meat or soft tissue) from the skeletal weight of archaeological specimens may be calculated by sample biomass equations (e.g., O'Day 2001:284). These calculations provide information on the quantity of meat potentially supplied by an animal based on allometric principles that an animal's body mass, skeletal mass, and skeletal dimensions change in proportion with body size increases (Reitz et al. 1987).

Marine Vertebrates

The marine vertebrate assemblages include a total of 111.2 g and 138 MNI. The assemblages from Sites KIP-728 and 755 contained little fish overall, about 3.5% and 1% of the total weight of the recovered fauna respectively. Unlike Sites 728 and 755, fish remains comprised a much larger portion of the overall faunal assemblage at Nakaohu Kai and Kipapa Uka (10% and 1% of overall faunal weight for each complex, respectively). Fish bones from the remaining sites contribute a larger portion to the overall assemblages, between 25% and 50% of the total MNI. A core group of taxa comprises the majority of identified fishes across sites, representing the families Serranidae, Carangidae, Lethrinidae, Labridae, Scaridae, Acanthuridae, and Balistidae.

When the marine vertebrate taxa are grouped according to families and concentration indices are calculated for each class according to weight and MNI, it is evident that the ʻAuwahi *heiau* and shrines and Kipapa Rockshelter contexts have a great variety and frequency of fishes (Table 4, Figure 2). Certain trends are also apparent when the sites are grouped according to contexts of our hypothesized "elite" (Site KIP-117 and the ʻAuwahi residential sites), "non-elite" (Kipapa Rockshelter, Nakaohu Kai, Kipapa Uka, Site M11, Agricultural Complex, KIP-728, and KIP-755), and "ritual" (the ʻAuwahi shrines and *heiau*). The putative non-elite residences exhibit the highest concentration of parrotfishes, wrasses, jacks, tangs, and emperorfishes (see Figure 2). Putative elite contexts produced more sharks, while ritual sites yielded more turtles, eels, and porcupinefish. Shark teeth are among the relatively unusual elements recovered from elite and non-elite

Table 3. Summary of identified invertebrate taxa from selected sites in Kahikinui, Maui.

	Kipapa Rock Shelter		Nakaohu Kai		Kipapa Uka		Site M11		Kipapa Swale Residential		Site 728		Site 755		Site 117 Elite Residence		Auwahi Residential		Auwahi Heiau	
Taxon	g	NISP	g	NISP	g	NISP	g	NISP	g	NISP	g	NISP	g	NISP	g	NISP	g	NISP	g	NISP
Acanthochiton spp.	0.6	2																		
Cellana spp.	12.7	54	148.8	387	0.6	10	98.5	306	18.1	51	7.4	34	5.5	9	23.9	55	98.8	213	42.3	92
Cellana exarata	43.2	65	6.7	7			27.2	96	5.8	15	79.7	3			19.5	69	183.2	175	30.3	57
Cellana sandwicensis	28.5	70	79.5	80			134	420	4.7	17	13.2	10	0.3	2			9	34	11.6	9
Trochidae			0.4	1																
Nerita picea	76.1	368	278	1145			397.3	430	15.3	57	2.8	20	0.4	3	49	257	136.3	535	52.6	339
Nerita plicata			0.3	2									2.3	14						
Littorina pintado	7.8	46	118.4	608			8.2	67	2.5	17	0.2	1	0.3	1	10	58	39.4	111	10.4	40
Nodilittorina picta			2	8													0.1	1		
Planaxis sp.																	11	76	1.8	5
Strombus spp.	0.1	1					0.4	4									2.1	7	0.2	1
Hipponicidae							12.1	108									0.3	3		
Cypraea spp.	43.3	42	832	1045	2.2	4	382	556	92.4	517	79.7	243	59.3	155	143.8	255	35.6	23	55.7	56
Cypraea caputserpentis	287.7	605	161.2	40	1.4	1	127	140	154.3	366	4.9	15	30.1	61	122.2	263	99.8	128	92.7	98
Cypraea childreni							10.5	13												
Cypraea chinensis							0.5	1												
Cypraea mauritiana	24.6	3													4.6	1	72.3	5		
Cypraea maculifera			83.7	16															5.9	3
Cypraea leviathan			1.4	1									15	1						
Cypraea erosa			0.4	4																
Cymatiidae							0.7	6					0.1	1						
Naticidae			1.3	3																
Tonnidae			1.3	2																
Thaididae	80.4	219	428	833	0.9	18	174	361	91.1	190	17.4	82	17.8	39	53.9	164	55.4	87	26.4	45
Thais intermedia			27.5	3													6.6	1		
Drupa spp.	11.6	13					81.5	95	10	29					4	8	1.3	1		
Drupa ricina			41.1	29	0.3	5	4.4	2	3.2	3					2.7	2				
Drupa morum	10.9	7	33.2	26			8.3	7	6.5	8	0.7	1			16.3	17	13.3	6	2	1

Table 4. General summary of marine vertebrate taxa by site, weight, and MNI.

	Kipapa Rock Shelter		Nakaohu Kai		Kipapa Uka		M11		Kipapa Swale		Site 728		Site 755		Site 117 Elite Residence		Auwahi Residential		Auwahi Heiau	
Taxon	g	MNI	g	MNI	g	MNI	g	MNI	g	MNI	g	MNI	g	MNI	g	MNI	g	MNI	g	MNI
Turtle									0.6	1							0.5	2	10	2
Shark	0.1	2									0.05	1			1.4	1				
Eel			0.5	1													0.2	1	0.3	2
Grouper					0.2	1	0.3	2	1.1	1					0.5	1			0.1	1
Jack	0.3	4					1	2	8.5	2									27	3
Snapper	0.8	2					0.1	1	0.1	1					0.1	1	0.1	1		
Emperor	0.03	3					0.6	1	0.3	1					0.6	2			0.3	1
Mullet	0.1	1																	0.2	2
Wrass	0.2	4					0.5	3	0.3	4	0.1	1			0.7	1	0.4	2	1	3
Parrotfish	1.6	8	3.5	6	0.05	1	8.3	5	3.4	6	5.6	5	0.5	2	1.2	3	0.4	2	4	4
Tang	2.5	3	2.05	2			0.1	1	0.5	3	0.8	1			1.2	2	2.5	2	2.1	3
Triggerfish	0.02	1	0.3	1	0.1	1	0.05	1			0.2	1			0.03	1	0.6	1	0.7	2
Porcupinefish																			2	1
Other	0.2	3	0.5		0.05		0.05								0.04				9.5	1

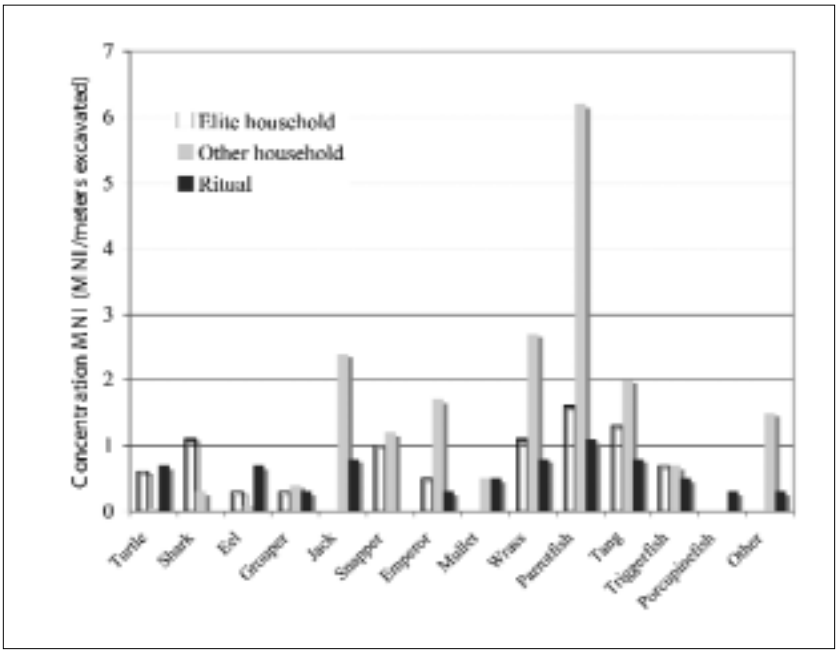


Figure 2. Marine vertebrate fauna concentration indices by MNI, Kahikinui, Maui.

contexts. This finding does not provide direct evidence for the consumption of sharks, but rather it may indicate that shark teeth were used for ornaments, ritual purposes, or possibly for knives used in food preparation or as parts of implements of war (Titcomb 1972:108–109; Valeri 1985:118)

A total of 143 fish vertebrae was recovered from the selected sites (Table 5). The anterior widths of these elements were measured as a proxy for fish size, following the assumption that the fish vertebrae (identified and unidentified) provide a representative cross-section of the identified species (O'Day 2001; Wing 1998). The assemblages from Sites KIP-728 and 755 and from the Nakaohu Kai and Kipapa Uka households lacked fish vertebrae. The Kipapa Swale residential complex produced a collection of vertebrae that superficially appears to represent large individual fishes with an average anterior width of 6.9 mm, but a single vertebra measuring 20.8 mm inflated the mean and the standard deviation. The vertebrae from 'Auwahi households, Site KIP-117, and ritual contexts were generally slightly larger than those from non-elite contexts. Ethnohistoric accounts

Table 5. Summary of fish vertebral centra widths (mm) from selected sites in Kahikinui, Maui.

Provenience	N	mean	standard deviation	range
Kipapa Rock Shelter	64	2.9	0.8	1.0–5.8
Kipapa Swale Residence	14	6.9	5.1	2.8–20.8
117 Elite Residence	38	3.8	1.3	1.9–8.9
ʻAuwahi habitations	10	3.6	0.4	2.4–4.6
ʻAuwahi *heiau* and shrines	17	5.6	2	2.4–20.4
Overall	**143**	**4.5**	**1.7**	**1.0–20.8**

describe large fishes as highly valued and in some contexts certain species and large individuals were reserved for priests and elites (Titcomb 1972:14; Valeri 1985:15–16, 204, 283). However, these accounts note that restrictions did not apply to some small juvenile fishes inhabiting tide pools, including surgeonfishes (*Acanthurus* spp. and *Naso* spp.), parrotfishes (*Scarus* spp.), and goatfishes (Mullidae), which might explain their common occurrence in a variety of site types associated with groups of different social ranks.

Invertebrates

All identified invertebrates are of marine origin, and the dominant families of mollusc occur commonly along Kahikinui's littoral basalt shoreline. Of the 35 taxa identified to genus or species, 29 are gastropods, three are bivalves, and three are echinoids (see Table 3). Most of the gastropod species are limpets or *ʻopihi* (*Cellana* spp.), black nerites (*Nerita picea*), cowries (*Cypraea* spp.), and thaidids or rocksnails (Thaididae). By weight and count, the most abundant invertebrate taxon is cowry (*Cypraea* spp.). *Cypraea* remains occur in all of the faunal assemblages and undoubtedly constituted an important part of the pre-contact diet. Further, numerous indigenous Hawaiian names are recorded ethnohistorically for various species of cowries, indicating that this group of shellfish was economically important not only for food but also for ornaments, tools, and fishing lures (Buck 1957:358; Kay 1949:119–121; Titcomb 1978:340–343).

Concentration indices at the family level by NISP confirm the abundance and frequency of *Cypraea*, especially at the Kipapa Rockshelter, Nakaohu Kai, and Site M11 (Table 6). Rocksnails were the second most abundant identified group, identified from all of the sites. Titcomb (1978) reports that rocksnails were consumed raw or cooked, depending on the species. For example, *Thais intermedia* was eaten raw to savor the natural bitter taste, which would be destroyed in cooking (Titcomb 1978:345).

Table 6. Summary of invertebrate concentration indices (NISP/meters excavated) by site and NISP.

Taxon	Kipapa Rock Shelter	Nakaohu Kai	Kipapa Uka	M11	Kipapa Swale Residence	728	755	117 Elite Residence	ʻAuwahi Residential	ʻAuwahi Heiau
Limpet	94.5	43.2	0.3	117.4	3.8	5.2	0.6	6.8	157.2	49
Nerite	184	104.3	0	61.4	2.6	2.2	0.9	14.3	183.2	111
Periwinkle	23	56	0	9.6	0.8	0.1	0.05	3.2	41.2	13.1
Cowry	325	100.5	0.1	101.4	40.1	28.7	10.9	28.8	59.6	43.7
Rocksnail	135.5	89.2	0.6	70.3	10.6	10	2	11.3	45.2	23.2
Cone	2	2.7	0	17.9	0.3	0	0.1	0.7	2.8	0.8
Crustacea	4	0	0	0	0	0	0	0	8.4	2.1
Echinoidea	131	5.8	0	33.4	20.7	0	0.4	10.3	13	30
Other	8	1	0	23.3	0.2	0	0	0	33	3.2

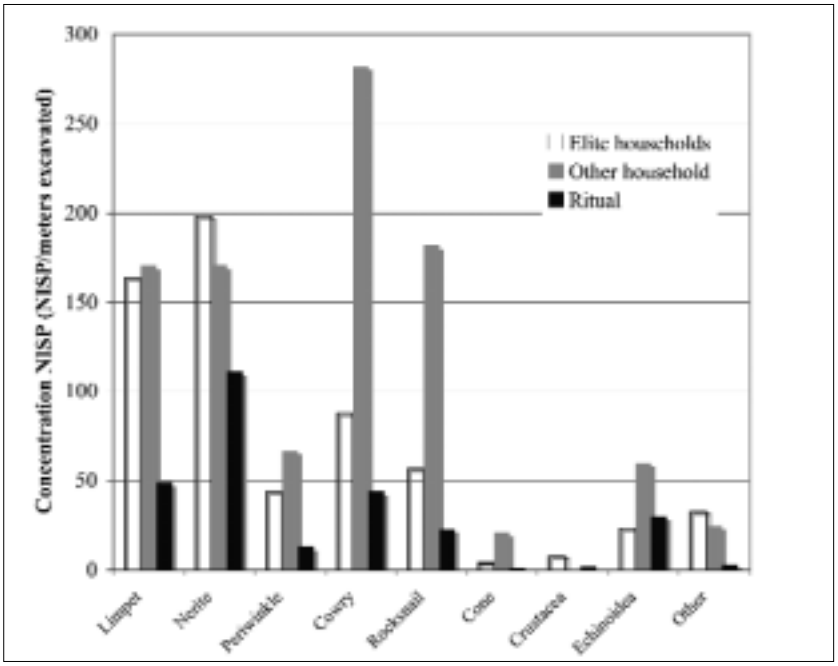


Figure 3. Invertebrate faunal concentration indices by NISP, Kahikinui, Maui.

When grouped according to social status, invertebrate faunal concentration indices illustrate the variable distribution of taxa (Figure 3). Invertebrates are most densely concentrated in putative non-elite households. Putative elite households produced more nerites, crustaceans, and a variety of less abundant species grouped as "other" (including strombids, *C. mauritiana*, *Drupa rubusidaeus*, and bivalves). By NISP, nerites dominate the elite and ritual contexts. These contexts also contained a small amount of crab and lobster remains (crustacea), a class of animals that is conspicuously absent from the other sites (with the exception of the Kipapa Rockshelter). A common crab in Kahikinui's archaeological deposits and along the modern shorelines, the *ʻāʻama* (*Graspus tenuicrustatus*) was used ethnohistorically in healing and sacrificial rituals. It was "offered in sacrifices so that the gods would loosen (*ʻāʻama*) and grant the request" (Pukui and Elbert 1986:3). When it was used as a food item, the *ʻāʻama* was generally eaten raw and salted.

Cellana spp. (ʻ*opihi*) were found in all of the assemblages. However, the identified species differs depending on the context, as discussed by Kirch and O'Day (2003:493). Within the presumed non-elite archaeological assemblages the majority of identified *Cellana* specimens (by NISP and weight) are *C. sandwicensis*, the yellow foot ʻ*opihi*. Conversely, within presumed elite and ritual contexts *C. exarata*, the black foot *ʻopihi*, is more abundant. *C. exarata* inhabits areas of the shoreline that are higher (more landward) than that inhabited by *C. sandwicensis*, which typically inhabits areas of thick coralline algae, constantly splashed by waves or spray at zero tides (Kay and Magruder 1977). Both species of *Cellana* thrive in the physical environment of the Kahikinui coast. Limpets living farther from shore (or farther from land) are typically larger than those found closer to the shoreline, making large individuals more dangerous and difficult to collect. It is possible that limpet-gathering often coincided with lower tides.

Limpets are said to have been one of the most favored and frequently consumed marine foods (Kay 1949:120; Kay and Magruder 1977:5; Titcomb 1978:343). They were typically prepared raw, salted, and served with seaweed. Many tales are associated with this family of invertebrates. Mary Pukui, Titcomb's collaborator and informant, recounted beliefs about *ʻopihi*, explaining that "It was kapu for anyone to eat *ʻopihi* on shore while a companion was out gathering more. If one broke this *kapu,* the one still collecting would be pounded by the sea . . . Gathering the *ʻopihi* is so dangerous that it was called the fish (creature) of death (*he iʻa make*) (Pukui)" (Titcomb 1978:343).

The distribution and frequencies of limpets is interesting. Although *C. exarata* would have been easier to collect, it is less common than *C. sandwicensis* in the presumed non-elite archaeological assemblages. *C. exarata* occurs most frequently than *C. sandwicensis* in the elite contexts, suggesting that elites may have had first access to shellfish exploitation or preferred *C. exarata*.

The shellfish distribution across sites reveals a pattern of higher frequencies of invertebrates encompassing more diversity in non-elite residential sites. The data indicate that for elites and non-elites, certain types of shellfish were heavily relied upon while others were consumed in much lower quantities. *Nerita*, *Cypraea*, Thaididae, *Littorina*, and *Cellana* appear to form a core or base group, making up the

largest portion of invertebrate remains. The exception to the aforementioned pattern is found in material from the Kipapa Uka *kau hale* that produced few invertebrate remains. This disparity may be explained by gender differences in this household. In the ethnographic accounts shellfishing is described as primarily women's work. If the family occupying Kipapa Uka lacked female members who were able to collect in the littoral zone they may have eaten relatively few invertebrates.

Discussion and Conclusions

Our analysis of the ten zooarchaeological assemblages has resulted in the identification of three patterns that illuminate subsistence and ritual activities associated with marine exploitation in Kahikinui. First, our research indicates that the inhabitants of Kahikinui exercised a selection bias in the collection of marine resources including marine vertebrates and invertebrates. These biases relate to issues of rank, gender, and food preference. Second, the identified fish species and the relatively small sizes of the individuals represented archaeologically suggest that a variety of methods were employed in their capture. Third, the fauna identified from ritual contexts may differ from material recovered in residential contexts. Particular marine species were important in ritual sites due to various factors including the literal translation of the item's name.

Titcomb (1978:327) describes shellfish collection in Hawai'i as women's work, painting a scene in which women and children combed the reef for hours, collecting "everything edible." Based on these accounts and archaeological evidence, some have assumed that prehistorically Hawaiians gathered shellfish indiscriminately. If such were the case, then relative frequencies of invertebrate remains should resemble the frequencies of these species in nature.

The selected Kahikinui assemblages, however, do not closely reflect modern frequencies (by number of individuals) of marine invertebrates along the Kahikinui shoreline, based on evidence gathered in a recent marine biological survey of the littoral zone (O'Day 2004a). The main disparity is found in the sheer abundance of *Cypraea* (and especially *Cypraea caputserpentis*) archaeologically. The zooarchaeological sample differs from the modern faunal community, where *Cypraea* occurs infrequently. Additionally, while the abundance and frequency of *Nerita picea* and the periwinkle (*Littorina pintado*) are mirrored archaeologically and presently, the diversity of thaidids and other gastropods was not found in the modern faunal assemblage. Another disparity is apparent in the extant ratios of the black foot *'opihi* (*Cellana exarata*) to the yellow foot *'opihi* (*C. sandwicensis*), wherein *C. exarata* was found to be much more abundant than *C. sandwicensis* (ratio 147:2). Conversely, within the selected archaeological assemblage, 77% of identified *Cellana* specimens (by NISP) are *C. sandwicensis*, while only 22% were identified as *C. exarata*. These data certainly suggest a selection bias or a tendency for Kahikinui's occupants to select certain species of limpet and other shellfish (assuming that the modern faunal frequencies are similar to what existed prehistorically). A selection bias, however, does not preclude the possibility that some Hawaiians were engaged in a generalized or broadly based exploitation scheme.

We argue that the disparity between archaeological and modern species distributions is likely due to intentional human selection rather than natural and anthropogenic causes. Kahikinui assemblages are subject to relatively minimal preservation bias for two reasons. First, archaeological occupations in the *moku* were both late in prehistory and relatively short. Second Kahikinui's arid leeward environment likely has better preservation then wet windward areas of the Hawaiian Islands. Most of the excavated materials were in good condition, exhibiting little if any indication of preservation bias across contexts. We recognize that our sample sizes are relatively small and thus our conclusions should be tested and supported in the future with larger samples.

The identified fishes could have been collected using a variety of methods and technologies selective of both size and species. Parrotfishes, surgeonfishes, triggerfishes, squirrelfishes, jacks, groupers, and snappers can all be caught using nets, traps, and spears. A hook and hand-line targets carnivores including triggerfishes, squirrelfishes, jacks, groupers, and snappers. A single species may occupy multiple habitats depending on its life cycle stage, as well as seasonal or tidal variations. Small young individuals,

such as those most commonly identified in Kahikinui household deposits typically frequent the littoral zone. Given the small size estimates provided by the vertebral centrum widths, nets and traps are the most likely methods of capture.

Throughout the Kahikinui assemblages, parrotfishes, surgeonfishes, and wrasses are the most frequently represented marine vertebrates. Pacific Island assemblages often contain these taxa in addition to some of the major groups listed in Table 4 (triggerfishes, porcupinefishes). Zooarchaeologists have assumed that these fishes are easily identified due to the highly diagnostic and durable nature of certain special elements (spines and mouth parts, for example), and they are therefore over-represented in Pacific archaeological sites (Dye 1996:80; Nagaoka 1994:4). The high frequency of these fishes is probably not due simply to preservation issues and ease of identification, because scarids, labrids, and acanthurids are abundant in the living assemblage identified through modern marine faunal surveys along the Kahikinui coastline (O'Day 2004a). These taxa may have been specifically targeted by Hawaiians in inshore reefs and littoral tide pools along Kahikinui's coastline where they are copious (O'Day 2004a). These fishes can be captured using a variety of methods such as netting, hook and hand line, traps, spearing, and poison (Buck 1957; Titcomb 1972; Tinker 1978). Moreover, ethnographic accounts from Hawai'i and elsewhere in the Pacific Islands explain that these fishes were savored for their culinary properties (Titcomb 1972; O'Day 2004b). In pre-Contact and historic period Hawai'i, a variety of acanthurids (*kala*) were used for sacrifice, and in fact the *kala* was said to be the god Lono's fish (Titcomb 1972:86).

In order to interpret ritual-associated assemblages and understand how they differ from residential contexts, it is helpful to examine the motivations for offerings. Offerings and some of their components "must evoke not only the deity and the sacrifier, but also the results sought by the sacrifier. The evocative power may reside in the name of the species chosen to function as the offering, in its physical properties, or in a combination of the two" (Valeri 1985:50).

Valeri (1985:50–51) and Handy and Pukui (1998: 81–82) refer to the importance of "verbal magic" and offerings that were chosen at least partially due to the literal translation of an item's name. Some of the species that evoke Lono include shrimp (*mahiki*, any shrimp used ceremonially, literally translated "to peel off"), seaweed or surgeonfish (*kala*, meaning to "loosen" or "set free"), and the *'ā'ama* crab (meaning to loose a hold or grip) (Handy and Pukui 1998:80). Other rites associated with purification or desacralization may have utilized *mahiki*, *kala*, and *'ā'ama*.

Exploitation of marine vertebrates and invertebrates was central to the subsistence as well as social and ritual lives of Kahikinui's late pre-Contact and early post-Contact inhabitants. The foregoing analysis demonstrates observable variations between ritual and domestic features and the marine-oriented subsistence activities associated with different social groups. Inter-assemblage variability may be explained in terms of a combination of ecological and social factors, including natural and human induced resource availability and food preference. By conceptualizing faunal materials as more than just food remains and understanding these assemblages as one of many residues of traditional Hawaiian lifeways, zooarchaeological interpretations are enriched.

Acknowledgements

The archaeological data described in this paper were collected between 1995 and 2003 during a series of field seasons under the overall direction of Patrick V. Kirch, with the support of several grants from the National Science Foundation (SBR-9600693, SBR-9805754, and BCS-0119819). Permission to work in Kahikinui was granted by the Department of Hawaiian Homes Lands, and we also thank Ka 'Ohana o Kahikinui for their support and assistance. Persons who assisted in collecting faunal data are too many to list here, but in particular we thank Cindy Van Gilder, Lisa Holm, and Sidsel Millerstrom. Monyka Salazar De Weaver and Shanna Boswell assisted S. J. with the measurements of the fish vertebrae, funded by a UAB-NSF ADVANCE award to S. J. We also thank Mike T. Carson for inviting us to contribute to this volume, and for his editorial comments. Finally, we acknowledge three anonymous reviewers whose comments helped to improve this paper.

References Cited

Armstrong, R. W. 1983. *Atlas of Hawaii Second Edition*. University of Hawai'i Press, Honolulu.

Buck, P. H. 1957. *Arts and Crafts of Hawaii*. Bishop Museum Special Publication 45. Bishop Museum Press, Honolulu.

Dixon, B., P. J. Conte, V. Nagahara, and W. K. Hodgins, 1999. Risk Minimization and the Traditional *ahupua'a* in Kahikinui, Island of Maui, Hawai'i. *Asian Perspectives* 38(2):229–254.

Dixon, B., P. J. Conte, V. Nagahara, and W. K. Hodgins, 2002. Settlement Patterns and Subsistence Strategies in Kahikinui, Maui. *Hawaiian Archaeology* 8:12–32.

Dye, T. 1996. Assemblage Definition, Analytic Methods, and Sources of Variability in the Interpretation of Marquesan Subsistence Change. *Asian Perspectives* 35:73–88.

Grayson, D. K. 1984. *Quantitative Zooarchaeology*. Academic Press, Orlando.

Handy, E. S. C., E. G. Handy, and M. K. Pukui. 1991 [1972]. *Native Planters in Old Hawaii: Their Life, Lore, and Environment. B. P. Bishop Museum Bullentin 233*. Bishop Museum Press, Honolulu.

Handy, E. S. C., and M. K. Pukui. 1998 [1958]. *The Polynesian Family System in Ka-'u, Hawai'i*. Mutual Publishing, Honolulu.

Kamakau, S. M. 1992 [1976]. *The Works of the People of Old; Na Hana a ka Po'e Kahiko*. Bishop Museum Press, Honolulu.

Kawaharada, Dennis (editor). 1992. *Hawaiian Fishing Traditions: Moke Manu and Others*. Kalamaku Press, Honolulu.

Kay, E. A. 1949. Some Edible Mollusks of Kauai, Hawaiian Islands. *Nautilus* 62:119–121.

Kay, E. A., and W. Magruder. 1977. The Biology of the *'Opihi*. Report prepared for the State of Hawai'i, Department of Planning and Economic Development, Honolulu.

Kirch, P. V. 1997. Kahikinui: An Introduction and the Cultural Landscape of Kipapa and Nakaohu ahupua'a: A Preliminary Report on an Intensive Archaeological Survey. In, *Nā Mea Kahiko o Kahikinui: Studies in the Archaeology of Kahikinui, Maui*, edited by P. V. Kirch, pp. 1–27. Special Publication No. 1. Oceanic Archaeology Laboratory, University of California Berkeley.

_____ 2004. Temple Sites in Kahikinui, Maui, Hawaiian Islands: Their Orientations Decoded. *Antiquity* 78:102–114.

Kirch, P. V., and S. J. O'Day. 2003. New Archaeological Insights into Food and Status: A Case Study from Pre-Contact Hawaii. *World Archaeology* 34:484–497.

Kirch, P. V., and W. D. Sharp. 2005. Coral^{230} Th Dating of the Imposition of Ritual Control Hierarchy in Precontact Hawai'i. *Science* 307:102–104.

Kirch, P. V., A. S. Hartshorn, O. A. Chadwick, P. M. Vitousek, D. R. Sherrod, J. Coil, L. Holm, and W. D. Sharp. 2004. Environment, Agriculture, and Settlement Patterns in a Marginal Polynesian Landscape. *Proceedings of the National Academy of Science of the United States of America* 101:9936–9941.

Kirch, P. V., and C. Van Gilder. 1996. Pre-Contact Early Historic Cultural Landscapes in Kahikinui District, Maui: A Progress Report. *Hawaiian Archaeology* 5:38–52.

Nagaoka, L. 1994. Differential Recovery of Pacific Island Fish Remains: Evidence from the Moturakau Rockshelter, Aitutaki, Cook Islands. *Asian Perspectives* 33:1–17.

O'Day, S. J. 2001. Excavations at the Kipapa Rockshelter, Kahikinui, Maui, Hawai'i. *Asian Perspectives* 40:279–304.

O'Day, S. J. 2004a. Marine Resource Exploitation and Diversity in Kahikinui, Maui, Hawaii: Bringing Together Multiple Lines of Evidence to Interpret the Past. *Archaeofauna* 13:97–108.

_____ 2004b. Past and Present Perspectives on Secular Ritual: Food and the Fisherwomen of the Lau Islands, Fiji. In, *Behaviour Behind Bones: The Zooarchaeology of Ritual, Religion, Status, and Identity,* edited by S. J. O'Day, W. Van Neer, and A. Ervynck, pp.153–161. Oxbow Books, Oxford.

Pukui, M. K. and S. H. Elbert. 1986. *Hawaiian Dictionary: Hawaiian-English English-Hawaiian: Revised and Enlarged Edition*. University of Hawai'i Press, Honolulu.

Reitz, E. J., and E. S. Wing. 1999. *Zooarchaeology*. Cambridge University Press, Cambridge.

Reitz, E. J., I. R. Quitmyer, H. S. Hale, S. J. Scudder, and E. S. Wing. 1987. Application of Allometry to Zooarchaeology. *American Antiquity* 52:304–317.

Sahlins, M. 1992. *Anahulu: The Anthropology of History in the Kingdom of Hawai'i Volume 1*. The University of Chicago Press, Chicago.

Sterling, E. P. 1998. *Sites of Maui*. Bishop Museum Press, Honolulu.

Tinker, S. W. 1978. *Fishes of Hawai'i: A Handbook of the Marine Fishes of Hawai'i and the Central Pacific Ocean*. Hawaiian Services Inc., Honolulu.

Titcomb, M. 1972 [1952]. *Native Use of Fish in Hawaii*. University of Hawai'i Press, Honolulu.

Titcomb, M. 1978. Native Use of Marine Invertebrates in Old Hawaii. *Pacific Science* 32:325–391.

Valeri, V. 1985. *Kingship and Sacrifice: Ritual and Society in Ancient Hawaii*. University of Chicago Press, Chicago.

Vitousek, P. M., T. N. Ladefoged, P. V. Kirch, A. S. Hartshorn, M. W. Graves, S. C. Hotchkiss, S. Tuljapurkar, and O. A. Chadwick. 2004. Soils, Agriculture, and Society in Precontact Hawai'i. *Science* 304:1665–1669.

Wing, E. S. 1998. The Sustainability of Resources used by Native Americans on five Caribbean Islands. Paper presented at the ICAZ meeting in Victoria, B.C., Canada, August 1998.

Barcoding Fish: Prospects for a Standardized DNA-Based Method of Species-level Identification for Archaeological Fish Remains

Shawn S. Barnes
Department of Anthropology,
University of Hawai'i at Mānoa

Introduction

The Universal Product Codes (UPC) or barcodes found on a wide range of purchase items are put there for the quick identification of each individual item brought to the register. The barcodes are printed and scanned in the same format, and a unique barcode exists for each specific type of product. For example, all cans of Diet Coke will have the same barcode, but a can of Cherry Coke or of Pepsi will have a different code. This system allows the rapid identification of each product (and thus, the pre-programmed price and inventory/sales records) by simply scanning an item over a laser without having so much as to look at it.

This kind of standardization has recently been applied to molecular taxonomy under the rubric of "DNA barcoding" (Herbert, Cywinska et al. 2003). DNA methodology has assisted in taxonomic identification for many years. However, this research has featured different genetic sequences used for different taxa in different laboratories around the world (Tautz et al. 2002). Barcoding seeks a standardized approach for animal identification by focusing on a 648 base pair sequence of the cytochrome *c* oxidase I (COI) gene found on the mitochondrial genome. This gene has become the standard measure for barcoding because: 1) it is easily retrieved and sequenced from modern specimens; 2) it can be aligned for sequence comparison; and 3) in general, the COI sequence differs significantly more among species than within them, allowing for accurate taxonomic identification. This last point is analogous to Coke and Pepsi cans. For most animal species studied thus far, the COI barcode sequence is generally uniform within one species but often measurably variable between even closely related species (Herbert et al. 2003; Herbert et al. 2004). Once comprehensive and accurate referencelibraries of COI sequence are established for comparison, barcoding offers the prospect of a standardized molecular route to animal species identification (for reviews, see Marshall 2005; Savolainen et al. 2005).

Barcoding has not been without controversy in biological circles (for reviews of major issues, see DeSalle et al. 2005; Mortiz and Cicero 2004; Rubinoff and Holland 2005). Most of this debate has focused on issues of species delimitation through DNA data and phylogenetic inferences based on COI sequence. However, these issues are usually not major concerns for the archaeologist whose faunal analysis focuses simply on taxonomic identification. The archaeologist will not likely be interested in the taxonomic lumping or splitting of fish species nor the phylogenetic history of fish in Hawai'i versus Tahiti. Therefore, by avoiding the most contentious pitfalls of the barcoding debate, the archaeologist may be in a position to utilize the advantages of the standardized, species-level identification of archaeofish offered by the barcoding approach.

Ancient DNA for the Archaeologist

The recovery of ancient DNA (aDNA) from archaeological material has contributed significantly to studies of the past (for a non-specialized review, see Meyer 2005). DNA may tend to conjure images of white coats and laboratories, but the analysis of ancient DNA begins with the archaeologist. Molecular techniques require viable DNA for analysis. For the archaeologist, the quality of DNA extracted, confidence in identification, and cost of any duplications necessitated by contamination will depend on the care of procedure taken during excavation and storage of remains.

Survival of viable aDNA in archaeological material is highly dependant on environment. In cold regions such as Siberia or the arctic, viable DNA has been recovered from material more than 100,000 years old (Nicholls 2005; Willerslev and Cooper 2005). In the Pacific, preservation conditions are much less favorable, but the limited time period of human occupation in East Polynesia has allowed for retrieval of viable aDNA throughout the human occupation period (Barnes et al. 2006; Nicholls et al. 2003; Robins et al. 2001). The high cost of aDNA analysis necessitates selection of those samples most likely to have viable DNA preserved. Generally, the colder the environment, the more likely DNA will survive. While a Siberia-like preservation environment cannot be hoped for in most of the tropical Pacific, the high peaks of Hawai'i Island offer a unique preservation opportunity for the region. However, most Hawaiian archaeofish deposits do not have this luxury, and sites for aDNA analysis should be chosen carefully. Moisture is a key factor in DNA degradation. Open sites exposed to the elements or water percolation are generally unfavorable to DNA survival. However, deeply buried material in beach dunes, while exposed to percolation, may also have some temperature regulation mediated by sand, and such sites have been known to produce viable aDNA. Barring the discovery of a large fish bone assemblage on Mauna Kea, the most likely environments for good DNA preservation are dry, protected areas such as rockshelters and cave sites (for reviews, see Mulligan 2006 and Robins et al. 2001).

Proper Excavation and Storage of Samples

Proper technique during excavation of samples that may be destined for DNA analysis is very important to minimize contamination. Contamination is the bane of aDNA research, and it is a particular issue in archaeological barcoding where universal primers can amplify human DNA just as easily as fish DNA. Human DNA contamination can manifest in the form of skin cells flaked from a non-gloved hand, an accidental sneeze, or a microscopic droplet of saliva (Paabo et al. 2004). In order to avoid contamination, the need for rigorous technique must begin at the archaeological site. Proper procedures for archaeological collection of samples for DNA processing has been outlined elsewhere (Mulligan 2006; Yang and Watt 2005), and they are briefly summarized here.

Selection of a minimal statistical sampling would be advisable given the high costs of aDNA analysis. If it is thought that DNA analysis may be performed on certain bone samples in the future, the following precautions are recommended during excavation and storage:

1) *Do not attempt to clean or wash samples.* Dirt or sand encrusting the bone may actually help protect against contamination entering the bone matrix. Cleaning will be performed in the DNA laboratory.

2) *Do not add preservatives to sample.* Preservative

chemicals can often inhibit the enzymes required in DNA extraction and analysis.

3) *Use fresh gloves when handling each prospective sample*. This measure will help avoid contamination from the archaeologist as well as cross-sample contamination.

4) *Store each prospective sample bagged individually*. Individual storage will help avoid cross-sample contamination.

5) *Make sure each sample is dry before storing in plastic bags*. This step will help avoid further degradation. Otherwise, a paper bag can be used to facilitate drying during short-term storage.

6) *Store samples in a cool, dry place*. Humidity and heat may degrade DNA and may also promote bacterial or fungal growth, adding possible sources of contamination.

7) *Great care should be taken when comparing archaeological samples to modern reference collection*. This last item is of the utmost importance. Modern reference specimens represent the most considerable source of DNA contamination. If prospective samples may be sent for DNA analysis, then they should not be removed from their plastic bag when being compared to a modern specimen.

Advantages of Molecular Identification

Identification of archaeological fish remains in the Pacific has traditionally relied mainly on cranial bone morphology, specifically the dentary, premaxilla, maxilla, quadrate, and articular bones (Leach 1986). However, these diagnostic bones can often be rare in assemblages, with postcranial elements dominating collections (Butler and Chatters 1994; Nicholls et al. 2003). Molecular techniques can be applied to traditionally non-diagnostic fish bone such as vertebrae or otoliths (Hutchinson et al. 1999). As long as viable DNA can be extracted, any piece of bone can be used for analysis. Sequence has been obtained from as little as 0.05 g of archaeological bone (Robins et al. 2001), however, such small amounts are only possible when preservation is exceptional. Several kilograms of bone sample can yield no DNA if preservation is particularly poor (R. Cann personal communication, 2006).

Identification of non-diagnostic bones to the species level may be valuable in accessing fishing strategies or evaluating prey choice and resource depression models (Allen 2002; Butler 2000, 2001). In an archaeological context, identification of non-diagnostic bones from pelagic fish such as *mahimahi* (*Coryphaena hippurus*) or *aku* (*Katsuwonus pelamis*) as opposed to inshore species such as fantail filefish (*Pervagor spilosoma*) may suggest open ocean hook-fishing behavior or inshore resource depletion.

Molecular identification can also be advantageous by avoiding the confounding issues of morphological differences between male/female or juvenile/adult. DNA sequence is constant throughout the life cycle, and it will yield the same signal from egg to adult, regardless of age.

Even when unambiguous diagnostic bones are present in an archaeological context, their morphological diversity can be greatly conserved among genera and species such that identification to only the family level is possible. The Pacific Islands represent a highly diverse marine environment with families often having multiple genera, species, and subspecies (Randall 2005). These intra-family taxa may inhabit quite different environments such as the *nenui* or rudderfish of Hawai'i in which some species are pelagic and others are found nearshore. Conventional morphologic identification may not allow identification of such closely related species.

The lack of resolution using traditional bone morphology prompted Allen (2002) to call for the further development of molecular-based identification methods to help resolve issues of changing habitat use, prey switches, and human impact on prehistoric Pacific Islands.

Barcoding Fish

Species identification by DNA-based technology has found considerable success in the Pacific. Previous research in the Pacific has been successful in species-level molecular identification of archaeological faunal remains such as rat (Matisoo-Smith and Allen 2001), pig (Allen et al. 2001), and New Zealand *moa* (Huynen 2003).

Reports of the molecular identification of archaeological fish remains have been limited thus far, but lately several papers have utilized various molecular techniques on fish remains from the Pacific and worldwide. The first successful application of DNA-based archaeofish identification was reported by Butler and Bowers (1998) who were able to identify archaeological salmon remains from the Pacific Northwest to the species level. This work on molecular salmon identification has been expanded to help understand social stratification and access to preferred species (Speller et al. 2005; Yang et al. 2004). Arndt et al. (2003) employed molecular identification to trace catfish species found at Mediterranean Roman sites to their source in the Nile, elucidating ancient trade networks. In a Pacific archaeofish context, Nicholls et al. (2003) used a DNA-based technique to identify inshore versus outer reef species of serranid remains from Aitutaki in the Southern Cooks, revealing an assemblage dominated by a small, inshore species. They found no evidence of prey switching throughout temporal sequence suggesting a pattern of mainly inshore fishing throughout occupation. Since diagnostic bone morphology is generally conserved across the serranid family, this identification of inshore habitat would not have been possible using conventional, morphology-based techniques (Allen 2002).

The pioneering studies mentioned above all used a non-barcoding approach, perhaps due to barcoding's relatively recent popularity or its inappropriateness for the specific research question being investigated. While leading the way for DNA-based identifications, these studies also focus on different sections of the mitochondrial genome in their identifications. Most required the time-consuming and laborious process of collecting and processing modern fish samples from the geographic area of interest in order to build a DNA reference library. Reference collections are the key to any taxonomic identification of archaeological fish (Leach 1986), and DNA-based taxonomic methodologies are no different. One must have an accurate and comprehensive database of DNA sequences for comparison in order to have confidence in molecular identifications. Just as morphological studies are only as accurate as one's bone reference collection, molecular identification is only as accurate as the DNA reference sequences compiled in the database (Herbert, Cywinska et al. 2003; Mulligan 2006).

The time and labor required to compile an accurate reference collection can often be a limiting factor in conventional taxonomic identification. However, the good news is that a comprehensive DNA reference database for the barcoding sequence region is already being compiled. The Consortium for the Barcoding of Life (www.barcodinglife.org) plans to sequence the COI barcoding region for all 1.7 million known animal species on Earth. Its subsidiary, the Fish Barcode of Life (www.fishbol.org) aims to barcode all marine fishes by 2010. The Bernice P. Bishop Museum currently is working with Fishbol in compiling a barcode reference library for Hawaiian fishes, and it expects to have a usable database within a few years (S. Jones, personal communication, 2006). The currently available Fishbol database is available online and updated weekly. It features taxonomic information and photographs for fish species already barcoded worldwide.

Practical Aspects of Fish Barcoding

Only in the past few years has molecular barcode identification begun to come into its own. The first report on successful barcode identification of modern fishes was recently published by Ward et al. (2005). The benefits of barcoding for marine biology in general have been extolled by Schander and Willassen (2005). In terms of ancient DNA, the first paper using a barcoding approach on archaeological remains has been published recently for New Zealand *moa* identification (Lambert et al. 2005). To date, the barcode approach has yet to be reported in the literature as an identification method for archaeological fish remains. However, as reference libraries continue to expand (www.fishbol.org), software advances (Steinke et al. 2005), and more studies on modern fish barcoding are published, archaeologists may be poised to utilize the barcoding approach in the near future.

Significant practical limitations of barcoding must be considered. While molecular identification techniques have the advantage of being reproducible in another aDNA laboratory, it is important to re-

member that DNA segments are not the essence of a species any more than bone morphology is. Molecular techniques are by no means definitive, and they are currently only as accurate as the traditional methods used to define taxa in the first place (Hebert and Gregory 2005).

Two significant technical problems also currently limit the application of barcoding to aDNA. First, the 648 base pair (bp) DNA fragment required for barcode identification (Herbert et al. 2003) is significantly larger than ~200 bp DNA fragments usually used in archaeological fish identification (Arndt et al. 2003; Butler and Bowers 1998; Nicholls et al. 2003; Speller et al. 2005; Yang et al. 2004). However, it may be possible to overcome this problem by using smaller portions of the 648 bp fragment or multiple overlapping amplifications to cover the whole region. The second technical issue is that the universal DNA primers used to chemically amplify the DNA of the barcoding region are particularly susceptible to modern contamination. This is a difficult issue but can be addressed most effectively by employing careful excavation and storage techniques as outlined above.

The cost of aDNA analysis is its major limiting factor in archaeology (Mulligan 2006). Costs for processing aDNA "in-house" (by an affiliate laboratory with no labor cost nor profit motive) can be about $70 per sample in consumables (Robins et al. 2001). Commercial laboratories (see www.ancientdna.com; www.tracegenetics.com; www.paleodna.com) can be considerably more expensive, starting around $400 per sample. Nonetheless, the cost of DNA analysis is consistently dropping as technology develops (Marshall 2005).

Conclusion

Molecular barcoding is a standardized approach to DNA species identification that is rapidly gaining popularity among field and molecular biologists (see Savolainen et al. 2005). The barcoding movement aims to establish a standard molecular taxonomic approach in the near future. Currently, incomplete reference databases and prohibitive costs restrict the widespread use of barcoding by archaeologists. However, as the molecular inventory of Pacific fishes nears completion (for weekly updates, see www.fishbol.org) and technological developments reduce processing costs, archaeologists may soon add barcoding to their toolbox for the identification of nondiagnostic fish bones. Proper excavation and storage of select samples for DNA analysis will aid archaeologists should such molecular techniques be employed in the future to investigate questions such as prey choice, resource depletion, human impact on Pacific marine fisheries, and other topics.

Acknowledgements

I thank Lisa Matisoo-Smith, Rebecca Cann, and Terry Hunt for their continued support and guidance. David Haymer and Arnold Suzumoto offered valuable advice. I am indebted to Mike Carson for his patience, encouragement, and meticulous assistance, which improved this paper immensely. Alex Morrison, Tim Rieth, and the *'au sole fia 'eli palapala* continue to provide many enjoyable hours of insightful discussion (*Alofa tele atu ia te 'oulua ma le tātou kalapu*).

References Cited

Allen, M. S. 2002. Resolving Long-term Change in Polynesian Marine Fisheries. *Asian Perspectives* 41:195–212.

Allen, M. S., E. Matisoo-Smith, and A. Horsburgh. 2001. Pacific Babes: Issues in the Origins and Dispersal of Pacific Pigs and the Potential of Mitochondrial DNA Analysis. *International Journal of Osteoarchaeology* 11:4–13.

Arndt, A., W. Van Neer, B. Hellemans, J. Robben, F. Volckaert, and M. Waelkens. 2003. Roman Trade Relationships at Sagalassos (Turkey) Elucidated by Ancient DNA of Fish Remains. *Journal of Archaeological Science* 30:1095–1105.

Barnes, S. S., E. Matisoo-Smith, and T. L. Hunt. 2006. Ancient DNA of the Pacific Rat (*Rattus exulans*) from Rapa Nui (Easter Island). *Journal of Archaeological Science* 33(11):1536–1540.

Butler, V. L., and N. Bower. 1998. Ancient DNA from Salmon Bone: A Preliminary Study. *Ancient Biomolecules* 2:17–26.

Butler, V. L., and J. C. Chatters. 1994. The Role of Bone Density in Structuring Prehistoric Salmon Bone Assemblages. *Journal of Archaeological Science* 21:413–424.

Butler, V. L. 2000. Resource Depression on the Northwest Coast of North America. *Antiquity* 74:-649–661.

———. 2001. Changing Fish Use on Mangaia, Southern Cook Islands: Resource Depression and the Prey Choice Model. *International Journal of Osteoarchaeology* 11:88–100.

DeSalle, R., M. G. Egan, and M. Siddall. 2005. The Unholy Trinity: Taxonomy, Species Delimitation, and DNA Barcoding. *Philosophical Transactions of the Royal Society B* 360:1905–1916.

Herbert, P. D. N., A. Cywinska, S. L. Ball, and J. R. DeWaard. 2003. Biological Identifications Through DNA Barcodes. *Protocols of the Royal Society B* 270: 313–321.

Hebert, P. D .N., and T. R. Gregory. 2005. The Promise of DNA Barcoding for Taxonomy. *Systematic Biology* 54:852–859.

Herbert, P. D. N., S. Ratnasingham, and J. R DeWaard. 2003. Barcoding Animal Life: Cytochrome C Oxidase Subunit 1 Divergences Among Closely Related Species. *Protocols of the Royal Society B* 270: S96–S99.

Herbert, P. D. N., M. Y. Stoekle, T. S. Zemlak, and C. M. Francis. 2004. Identification of Birds through DNA Barcodes. *PloS Biology* 2:1657–1663.

Hutchinson, W. F., G. R. Carvalho, and S. I. Rogers. 1999. A Nondestructive Technique for the Recovery of DNA from Dried Fish Otoliths. *Molecular Ecology* 8:893–894.

Huynen, I., C. D. Millar, R. P. Scofield, and D. M. Lambert. 2003. Nuclear DNA Sequences Detect Species Limits in Ancient Moa. *Nature* 425:175–178.

Lambert, D. M., A. Baker, L. Huynen, O. Haddrath, P. D. N. Hebert, and C. D. Millar. 2005. Is Large-Scale DNA Based Inventory of Ancient Life Possible? *Journal of Heredity* 96(3):1–6.

Leach, F. 1986. A Method for the Analysis of Pacific Island Fishbone Assemblages and an Associated Database Management System. *Journal of Archaeological Science* 13:147–59.

Marshall, E. 2005. Will DNA Barcodes Breathe Life into Classification? *Science* 307:1037.

Matisoo-Smith, E. and J. S. Allen. 2001. Name that Rat: Molecular and Morphological Markers in Pacific Rodent Remains. *International Journal of Osteoarchaeology* 11:34–42.

Meyer, A. 2005. *Hunting the Double Helix: How DNA is Solving Puzzles of the Past.* Allen and Unwin, Sydney.

Moritz, C., and C. Cicero. 2004. DNA Barcoding: Promises and Pitfalls. *PloS Biology* 2:1529–1531.

Mulligan, C. J. 2006. Anthropological Applications of Ancient DNA: Problems and Prospectives. *American Antiquity* 71:365–380.

Nicholls, H. 2005. Ancient DNA Comes of Age. *PloS Biology* 3:192–196.

Nicholls, A., E. Matisoo-Smith, and M. S. Allen. 2003. A Novel Application of Molecular Techniques to Pacific Archaeofish Remains. *Archaeometry* 45:133–147.

Paabo S., H. Poinar, D. Serre, V. Jaenicke-Despres, J. Hebler, N. Rohland, M. Kuch, J. Krause, L. Vigilant, and M. Hofreiter. 2004. Genetic Analysis from Ancient DNA. *Annual Review of Genetics* 38:645–79.

Randall, J.E. 2005. *Reef and Shore Fishes of the South Pacific.* University of Hawai'i Press, Honolulu.

Robins, J. H., E. Matisoo-Smith, and L. Furey. 2001. Hit or Miss? Factors Affecting DNA Preservation in Pacific Archaeological Material. *Research in Anthropology and Linguistics* 5:295–305.

Rubinoff, D., and B. S. Holland. 2005. Between Two Extremes: Mitochondrial DNA is Neither the Panacea nor the Nemesis of Phylogenetic and Taxonomic Inference. *Systematic Biology* 56:952–961.

Savolainen, V., R. S. Cowan, A. P. Vogler, G. K. Roderick, and R. Lane. 2005. Towards Writing the Encyclopaedia of Life: An Introduction to DNA Barcoding. *Philosophical Transactions of the Royal Society B* 360:1805–1811.

Schander, C., and E. Willassen. 2005. What Can Biological Barcoding Do for Marine Biology? *Marine Biology Research* 1:79–83.

Speller, C. F., D. Y. Yang, and B. Hayden. 2005. Ancient DNA Investigation of Prehistoric Salmon Resource Utilization at Keatley Creek, British Columbia, Canada. *Journal of Archaeological Science* 32:1378–1389.

Steinke, D., M. Vences, W. Salzburger, and A. Meyer. 2005. TaxI: A Software Tool for DNA Barcoding Using Distance Methods. *Philosophical Transactions of the Royal Society B* 360:1975–1980.

Tautz, D., P. Arctander, A. Minelli, R. H. Thomas, and A.P. Vogler. 2002. DNA Points the Way Ahead in Taxonomy. *Nature* 418:479.

Ward, R. D., T. S. Zemlak, B. H. Innes, P. R. Last, and P. D. N. Hebert. 2005. DNA Barcoding Australia's Fish Species. *Philosophical Transactions of the Royal Society B* 360:1847–1857.

Willerslev, E., and A. Cooper. 2005. Ancient DNA. *Proceedings of the Royal Society B* 272:3–16.

Yang, D. Y., A. Cannon, and S. R. Saunders. 2004. DNA Species Identification of Archaeological Salmon Bone from the Pacific Northwest Coast of North America. *Journal of Archaeological Science* 31:619–631.

Yang, D. Y., and K. Watt. 2005. Contamination Controls When Preparing Archaeological Remains for Ancient DNA Analysis. *Journal of Archaeological Science* 32:331–336.

An Analysis of Ground-Penetrating Radar's Ability to Discover and Map Buried Archaeological Sites in Hawai'i

Lawrence B. Conyers
Department of Anthropology,
University of Denver

Samuel Connell
Department of Anthropology
Foothill College

Introduction

The near-surface geophysical method called ground-penetrating radar (GPR) has to date seen limited use in Hawai'i for the discovery and mapping of buried archaeological sites. Its success in other areas of the world with similar ground conditions to Hawai'i, however, suggests that it could be utilized more extensively in the islands. Working with the Joint POW/MIA Accounting Command's Central Identification Laboratory (JPAC-CIL) to examine the effectiveness of GPR in Hawai'i, we studied the method's resolution and depth of investigation at a number of test sites on the islands of O'ahu and Hawai'i. The various sites had different ground conditions where varying environmental and moisture regimes and bedrock types affected the method's efficacy. The goal was to compare and contrast depth of GPR energy penetration and buried feature resolution in these various areas as a way to evaluate its potential effectiveness throughout the island chain. In this process, windward and leeward tests were made in both weathered and fresh basalt, deep clay soils, as well as coral bedrock and unconsolidated coral sand. The results of those tests, as well as an analysis of the ground conditions encountered, as they pertain to the effectiveness of GPR, are discussed here as a first step in building predictive models for the method's usefulness throughout Hawai'i.

The GPR Method

The GPR method functions by measuring the elapsed time between when pulses of radar energy are transmitted from a surface antenna, reflected from buried discontinuities, and then received back at another surface antenna (Conyers 2004).

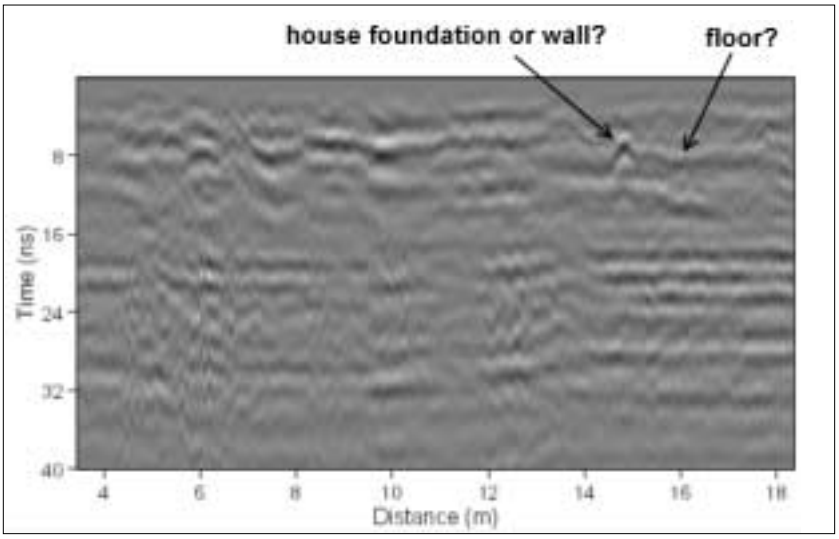


Figure 1. GPR reflection profile showing possible wall and floor of Queen Emma's house at Hickam Air Force Base, O'ahu.

When the paired antennas are moved along transects on the ground surface, two-dimensional profiles of buried stratigraphy can be produced by stacking many hundreds or thousands of reflections together to produce what are termed reflection profiles (Figure 1). Changes in the strength (measured as wave amplitudes) and the geometry of reflections in profiles can then be related to the distribution and orientation of subsurface units and features of interest. These changes might be stratigraphic layers, archaeological materials, or a variety of other objects or biogenic disturbances in the ground (Conyers 2006a). Many tens, or sometimes hundreds, of reflection profiles collected in a grid can then be analyzed within a three-dimensional "cube" of reflection data as a way to produce complex images of buried materials (Conyers 2004:148) in ways not possible using other near-surface geophysical methods (Johnson 2006).

Ground-penetrating radar is a geophysical technique that is most effective at buried sites where artifacts and features of interest are located within 2–3 meters of the surface, but it has occasionally been used for more deeply buried deposits (Conyers 2004:16). This depth of resolution and high degree of subsurface resolution makes it a geophysical method particularly applicable to Hawai'i, as deeply buried or complexly stratified archaeological deposits are much less common there than in other areas of the world.

A growing community of archaeologists has been incorporating GPR, as well as other near-surface geophysical methods, as a routine field procedure for many years (Conyers, 2004, 2006a; Gaffney and Gater 2003, Johnson 2006). When this is done, GPR maps and images become primary data that can be used to guide the placement of excavations, or to define sensitive areas containing cultural remains to avoid. For this reason, the method is particularly applicable to cultural resource management (CRM) projects where target areas need to be evaluated quickly and accurately in three-dimensions (Johnson 2006). Archaeological geophysicists have also used the GPR method as a way to place archaeological sites within a broader environmental context, test working hypotheses regarding past cultures, and to study human interaction with, and adaptation to, ancient landscapes (Conyers and Osburn 2006; Kvamme 2003).

The success of GPR surveys is to a great extent dependent on soil and sediment mineralogy, clay content, ground moisture, depth of burial, surface topography, and vegetation. It is not a geophysical method that can be immediately applied to any subsurface problem, although with thoughtful modifications in acquisition and data processing, GPR methods can be adapted to many differing site conditions. Our tests of GPR in a variety of Hawaiian sites produced successes at some, and failures at others, which are addressed here. Others who have worked with GPR in Hawai'i have documented similar results, with some suggesting that the technique is only marginally applicable to many Hawaiian soils because most are composed of wet clays (Doolittle 2006). Another supposition that has been used to explain equivocal GPR results in some areas of Hawai'i is that some Hawaiian soils and rocks have a high magnetite content, derived from the basalt parent material, which destroys radar energy in the ground (Olhoeft 1998). It is well known that both wet clay and magnetite are limiting factors in radar energy propagation (Doolittle 2006). However, in other basalt bedrock areas of the world published results appear to contradict these general assertions (Cassidy et al. 2004; Grant and Schultz 1994; Heggy et al. 2006; Miyamoto et al. 2005).

GPR Testing Methods In Hawai'i

Our goals were to test the GPR method's effectiveness in mapping buried archaeological sites and to prospect for modern and ancient human burials at a number of test areas on O'ahu and Hawai'i. These tests were carried out in December 2005 during a period of very dry ground conditions. In all these tests buried cultural materials and human remains were either known or suspected to exist in the tested areas, which could be used as targets. The acquired GPR reflection profiles were then processed into profiles and sometimes amplitude maps after the data were filtered and reflections were enhanced using standard GPR data processing techniques (Conyers 2004: 119). An analysis of the depth of penetration and feature resolution was then made and related to specific soil and other environmental conditions at each test site. While our selection of test areas was statistically biased, as sites were chosen mostly by ease of accessibility and informants with local knowledge and connections that allowed us access to the sites, a variety of ground conditions were encountered. At each site we evaluated the relative success qualitatively, based on what was known about the soils, sediments, and bedrock characteristics. As most archaeological surveys must be performed without having prior detailed knowledge of ground conditions, we chose to limit our research to data collection and analysis, and then determine after the fact what chemical or physical conditions of the ground might have been affecting the results by comparing them to published reports concerning soil and rock types in Hawai'i. Laboratory analysis and detailed stratigraphic testing was beyond the scope of this study, but is a method that would lend itself in the future to a much greater understanding of the complex factors related to GPR analysis in Hawai'i.

Factors That Affect GPR

Resolution of buried materials and the depth of investigation are the most important factors that must be taken into account at all archaeological sites where the GPR method is contemplated. These two variables are inversely related and an analysis of them is crucial when choosing the appropriate frequency antenna to use for data collection. Higher frequency antennas, above about 400 megahertz (MHz), are capable of better subsurface resolution, but transmit energy to shallower depths (Conyers 2004:39). For instance, a 400 MHz antenna can resolve objects and stratigraphic interfaces as small as about 20 cm in maximum dimension, but only rarely are effective below depths of 2–3 m. In contrast, lower frequency antennas (in the 100–200 MHz range) can theoretically transmit energy that penetrates 5 m or more, but are incapable of resolving objects or interfaces smaller than about 60 cm in dimension. In many soil conditions, especially those encountered in Hawai'i, our results indicate that depth of penetration is the most important factor in determining GPR effectiveness as some ground conditions in Hawai'i attenuate radar energy at quite shallow depths, no matter what the frequency of the transmitted energy.

Transmitted radar energy attenuation with depth is mostly a function of the electrical conductivity of surface soils, weathered bedrock, or sediment through which energy must pass (Doolittle and Collins 1995). High electrical conductivity material effectively destroys transmitted radar energy at shallow depths by removing the electrical component of the electromagnetic wave and propagation therefore ceases (Conyers 2004:49). Although there are some claims that lower frequency antennas are capable of greater depth penetration in even electrically conductive ground, our experience from a number of Hawaiian sites suggests that if the ground is highly electrically conductive, radar energy of any frequency will be attenuated at shallow depths. In some cases, Hawaiian soils attenuated GPR energy within the upper 30–40 cm and known features that were deeper in the ground were not visible. This depth constraint therefore limits the method's effectiveness in some areas, which was not predicable prior to collecting and analyzing the data. Other researchers have addressed the various soil factors that might limit radar energy penetration by computing what is termed GPR suitability indices (SI) based on information derived from published soil maps (Doolittle 2006). In this analysis, soil properties are categorized by their relative amounts of clay, mineralogy, the amount of dissolved salts or other electrically conductive materials in the ground, and the amount of

water retained. The SI maps of Hawai'i (Doolittle 2006) show most of the islands have moderate to low potential based on these suitability indices, with the exception of the more recent lava flow areas of east Maui and the island of Hawai'i. As these generalized maps do not give specific details about each of the soil units, or any analysis of buried feature resolution at various depths, the goal of the present study was instead to collect GPR data sets in these various ground conditions and then attempt to determine what it was about those conditions that allowed the method to be effective or not. As most of the test areas contained targets located in the upper 2–3 m (aside from the lava tube tests on Hawai'i), depth of investigation was considered to be the most important variable in evaluating the method's effectiveness. The idea was that if radar energy could be transmitted to those depths, either the 400 or 270 MHz antennas would be more than adequate for resolving the buried targets of interest.

Figure 2. The GSSI SIR-3000 system with survey wheel, 400 MHz antenna and control unit with flash memory chips for data storage and playback.

Radar energy loss, termed attenuation, always occurs as energy moves into the ground. This attenuation is a function of four general factors, each of which we attempted to account for in our test areas (Reynolds 1997; Heggy et al. 2006). Coupling losses occur when the radar antennas are not placed in direct contact with the ground, or when the ground surface is uneven, allowing radar energy to be scattered and lost before it effectively "couples" with the ground. This loss factor can be mostly overcome by making sure antennas are moved slowly and carefully along the ground surface. Another factor is geometric spreading that occurs as energy moves into the ground. This loss is a function of the conical shape of the transmitted radar pattern that spreads the energy out over a larger and larger surface area as it travels deeper in the ground (Conyers 2004:62). Spherical spreading with depth decreases the amount of energy that can be reflected back to the surface from any one buried object or interface below the surface, lowering the effective resolution of any reflections generated from it. This is a factor inherent in the method and cannot be adjusted for using standard GPR equipment. A third site-specific factor is energy scattering, which is caused as radar energy reflects in random directions from buried objects or discontinuities in the ground, redirecting some of it away from the surface receiving antenna so that it is not recorded. A similar site-specific factor, and the one that is most variable and important in determining the GPR method's effectiveness in Hawai'i, is electromagnetic attenuation. As radar energy is composed of both electrical and magnetic waves, which move in a cojoined fashion (Conyers 2004:24), the removal of either one or the other by electrically conductive or magnetically permeable ground effectively destroys the transmitted energy. In general, soils that are wet and have high clay content, especially clays of a certain mineralogy, will have high electrical conductivities as measured by their cation exchange capacity (CEC). In those clay soils, ions absorbed on some clay minerals will undergo exchange reactions with ions in the water, which increases the electrical conductivity of the ground (Doolittle and Collins 1995; Schultz 2005). While most studies of GPR effectiveness evaluate clay as a general constituent, clay mineral types vary considerably with respect to their electrical properties (Grim 1968; Saarenketo 1998). For instance, kaolinite clay has a very low CEC, and therefore readily allows the transmission of radar energy, while montmorillionite clay is very conductive (high CEC) and most radar energy is lost at very shallow depths in ground in this constituent (McDonald et al. 2005). In Hawai'i these and other clays are common, and are geographically distributed based on

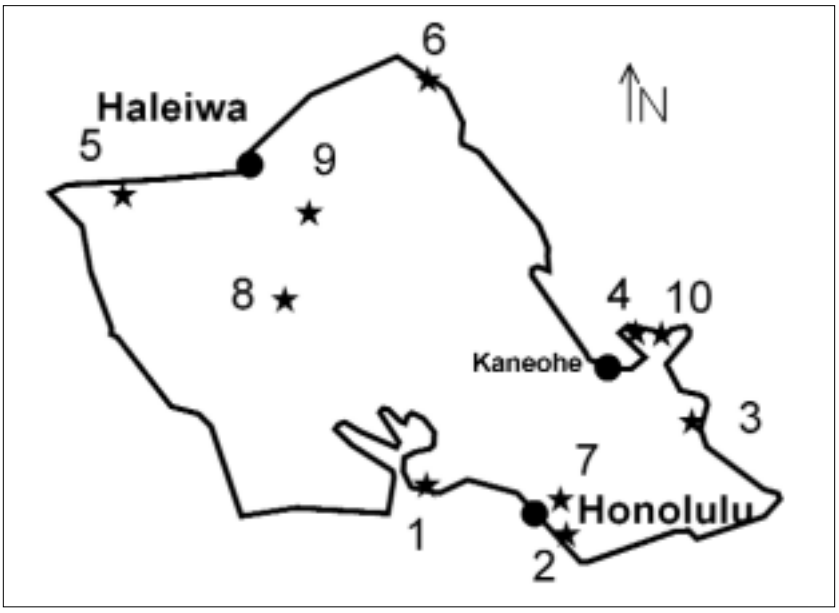


Figure 3. Base map of the O'ahu GPR tests.
1. Queen Emma's house and Battery Hazbrouk: Hickam Air Force Base, 2. Waikiki Kona District, 3. Bellows Air Force Base, 4. Clipper Golf Course, Marine Corps Base Hawaii, 5. Dillingham Air Field, 6. Laie, 7. Punchbowl Cemetery, 8. Schofield Barracks cemetery, 9. Opaeula Fire Base, 10. Cinder Cone at Kāne'ohe Marine Base.

bedrock types and the amount of moisture and weathering time (Foote at al. 1972; Vehara 2005). The size, surface area, cation-exchange capacity, and water holding capacity of clay minerals therefore can vary greatly in Hawai'i. In general, highly weathered soils can often contain mostly kaolinitic, gibbsitic, and halloysitic soils, which have a low cation-exchange capacity and therefore better radar energy penetration (Grim 1968). We encountered no soils in Hawai'i with these properties, although kaolinite clays are known to exist on Kauai (Foote et al. 1972; Macdonald et al. 1983) and perhaps some very weathered windward areas of O'ahu.

Hawaiian Tests

In all tests the Geophysical Survey Systems, Inc. (GSSI) Subsurface Interface Radar System model 3000 (SIR-3000) was used to collect GPR data. The unit was mounted on a cart system, with a survey wheel used to place reflections in space along survey transects (Figure 2). Both 270 and 400 MHz antennas were used depending on the depth of the known buried features (with the 400 MHz most widely used, as the critical depth of burial at most test sites was in the upper two meters). Reflection data were transferred to a laptop computer and processed using software that is publicly available (Conyers 2005). This software allowed reflection profiles to be viewed and analyzed for effective depth penetration, and at some sites grids of many closely spaced profiles were used to produce amplitude maps of buried features of interest.

A total of 10 locations were studied, sometimes with numerous tests and grids of data at each (Figure 3). Each test location will be discussed below and categorized by the types of soils, sediments, or rock types encountered.

Weathered Coral Soils

A number of data grids were collected at Hickam Air Force Base in Honolulu (Figure 3) on ground that is composed of a very thin surface soil underlain by weathered coral bedrock with admixtures of coral and shell sand. This weathered bedrock is mostly fill, originally dredged from nearby Pearl Harbor. Its composition mimics the type of carbonate ground that would be found in uplifted coral or lithified beach-rock units along some portions of the Hawaiian coastline (Macdonald et al. 1983). The tests were performed to assess the resolvability of buried bones and objects placed in the ground to mimic human remains and also to search for the possible remains of the country retreat of Queen Emma (1836–1885) who lived here until her death. The structure was last mapped in 1897 at the site of Fort Kamehameha, purchased from the estate of Queen Emma in 1907 by the U.S. Government and eventually renamed Hickam Air Force Base (Anderson et. al 1998; Putzi and Dye 2005). The 400 MHz antennas were used with data collected in a 40 nanosecond (ns) time-window (Conyers 2004:39), which corresponds to a depth of about 2.6 m in the ground (calculated using an average of 7.5 cm/ns velocity of radar energy). These calculations of velocity were made at all test sites by fitting the hyperbolic shaped reflections generated from rocks and other "point source" reflections in the ground to hyperbolas of a known geometry, using a program called *Fieldview* (Lucius

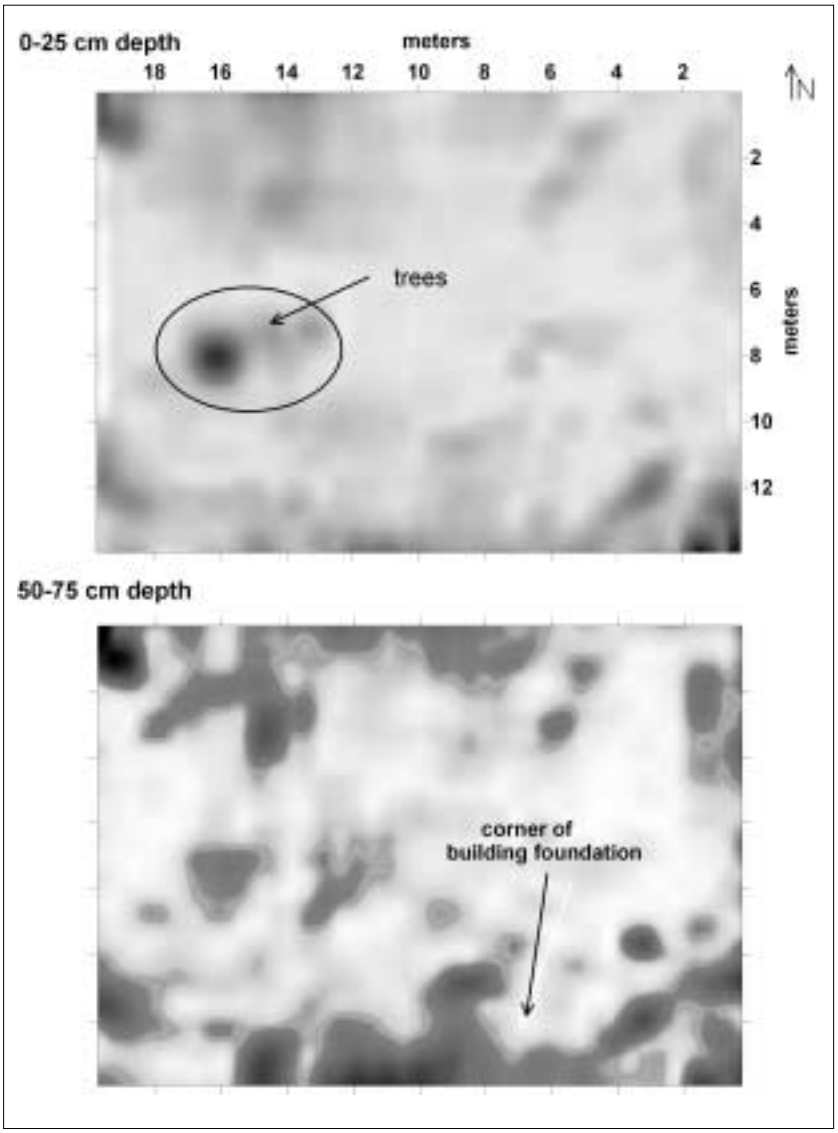


Figure 4. Amplitude slice-maps of the Hickam Air Force Base grid showing the possible corner of Queen Emma's house. Darker shades of gray designate the location of high amplitude reflections while white show areas of little or no radar reflection.

and Powers 2002; Conyers and Lucius 1996). As reflection hyperbola geometry is a function of the velocity of the material in the ground, this program can produce very accurate estimates of this important conversion factor, which is necessary to correct all radar travel times to approximate depth in the ground (Conyers 2004:117).

Good reflections were recorded throughout the recording window in this area (Figure 1). Some energy attenuation was noticeable below about 1 m or so, but coherent reflections were still visible to the maximum depth recorded (Conyers 2004:91). Amplitude analysis was performed on reflections recorded in a 14 x 20 m grid of profiles collected at 50 cm intervals. In this data processing step, the amplitudes of all recorded reflections are displayed in horizontal slices of a given thickness. These amplitudes represent the relative differences of adjacent buried materials, which are extracted from the profiles and viewed as horizontal maps. In this way, amplitude maps are analogous to analyzing soil changes in arbitrary excavation levels in standard archaeological field excavations (Conyers 2004:148). When this mapping step was performed, the square corner of what appears to be the foundation of Queen Emma's house became visible in the general area indicated by the historic maps (Figure 4).

As most coral bedrock and coral sand in Hawai'i are found along the coast, the proximity of this type of ground to salty or brackish water is a factor that must be considered with GPR, as the dissolved salts in this ground water will act as a conductor and attenuate radar energy at a very shallow depth (Doolittle 2006). Most of our tests in the Hickam area were located 100 meters or more inland from the bay, and good GPR reflection data indicated that ground water in this area was mostly fresh. There was little energy attenuation within the time window that data were collected, with good reflections recorded to at least 2 m depth. Most radar reflections recorded from within the coral bedrock were weak, but still discernable, suggesting there was some energy attenuation with depth. This is probably due to the somewhat electrically conductive constituents of carbonates, which are known to attenuate radar energy (Doolittle 2006). This energy loss was partially overcome by increasing the gains during data processing, which is a method of artificially enhancing reflection amplitudes recorded from deeper in the ground so they may become visible (Conyers 2004: 91). In these types of Hawaiian environments, the GPR method should therefore be considered reliable and effective, at least for mapping features to about 2 m depth.

To test how close to the bay the antennas could get and still collect good data, we placed the radar antennas directly on the beach in the salt water at the

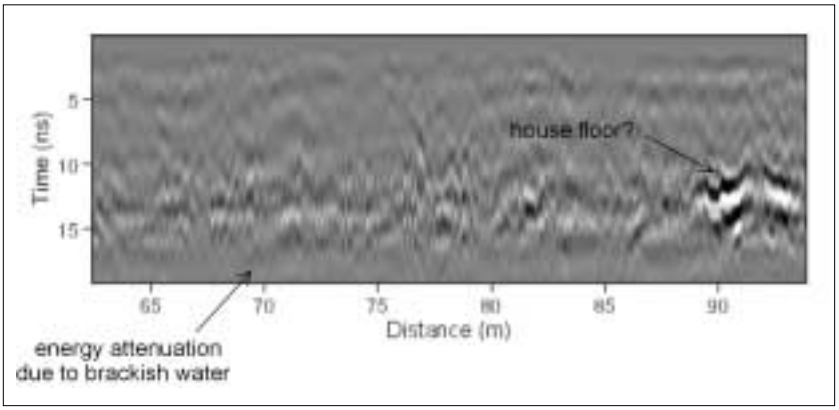


Figure 5. GPR reflection profile from Waikiki's Kona District showing energy attenuation at the base due to brackish water, but a highly reflective possible house floor above.

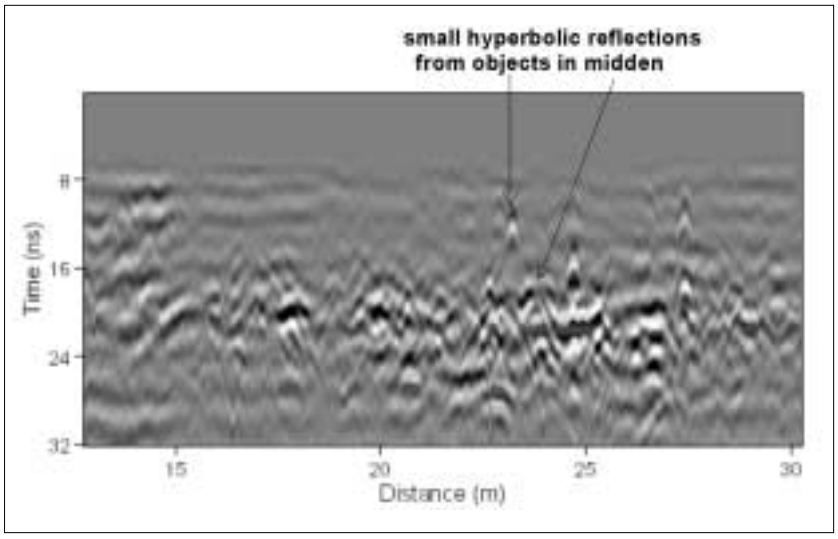


Figure 6. GPR reflection profile showing small hyperbolic reflections from objects in an ancient midden, Bellows Air Force Base, O'ahu.

beginning of a profile, and then collected a line up the beach face on top of stabilized sand dunes at the Battery Hasbrouck area of Hickam Air Force Base (Figure 3). Energy attenuation along this line was noticeable only within about 4 m of the salt water, with good reflections recorded to about 1.5–2 m depth farther inland. This test indicates that GPR is a very effective tool to about 2 m depth along the coast in coral-carbonate areas within just a few meters of the salt water. That would not be the case where there is saltwater intrusion into the shallow near-shore aquifers.

In a similar near-shore carbonate setting, a test was conducted in a vacant lot in the Waikiki Kona District that was slated for construction (Figure 3). This area contains coral beachrock bounded by historic fishponds. Engineering drill tests indicate that brackish groundwater is located about 1.5–2 m below ground surface (Hammatt 2005). The GPR reflection profiles in this location showed good radar reflections in profile, discovering a possible house floor or other historic feature at about 1 m depth, which is about 12 ns in two-way radar travel time (Figure 5). Below that level the brackish groundwater appears to have attenuated all radar energy.

Carbonate dunes

The numerous coral and shell fragments that make up dunes in low-lying areas of the coast, as well as most of the modern Hawaiian beaches (Macdonald et al. 1983), were also tested to determine resolution and depth penetration. A 20 x 30 m grid of GPR reflection data was collected using the 400 MHz antennas with 50 cm profile spacing at Bellows Air Force Base on O'ahu's windward side (Figure 3). This test, about 250 meters inland from the beach, was in an area where human burials had been discovered by archaeological excavations, with indications of habitation structures and middens nearby (Kam 1986; Putzi and Dye 2005). In this data set, excellent reflections were recorded to about 2 m depth and a number of buried features were imaged including the midden that had previously been tested and a second previously-unknown midden in a different part of the grid (Figure 6). Reflection profiles also recorded a metal water line running through the grid and Hawaiian burials that had been uncovered nearby and then re-buried many years ago (Figure 7).

All reflection profiles from the Bellows grid were processed into amplitude slices, each approximately 25 cm thick (Figure 8). These maps clearly show the two known re-burials, one previously known midden of fire cracked rock and bone and shell tools (the one to the south of the water pipe), and a much larger midden to the north. Resolution was so good in this grid that individual objects that are probably the fire cracked rocks or other midden debris can be seen as high amplitude reflections (Figure 8). This test at Bellows shows the excellent results that GPR

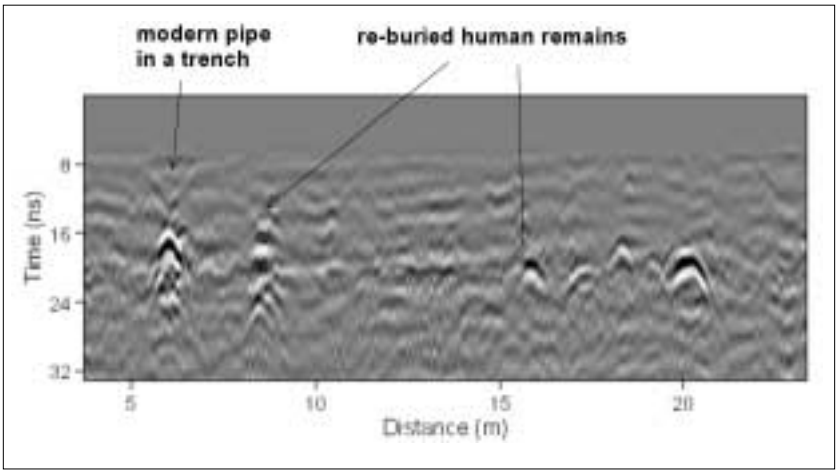


Figure 7. GPR reflection profile showing re-buried human remains and a modern water pipe, Bellows Air Force Base, O'ahu.

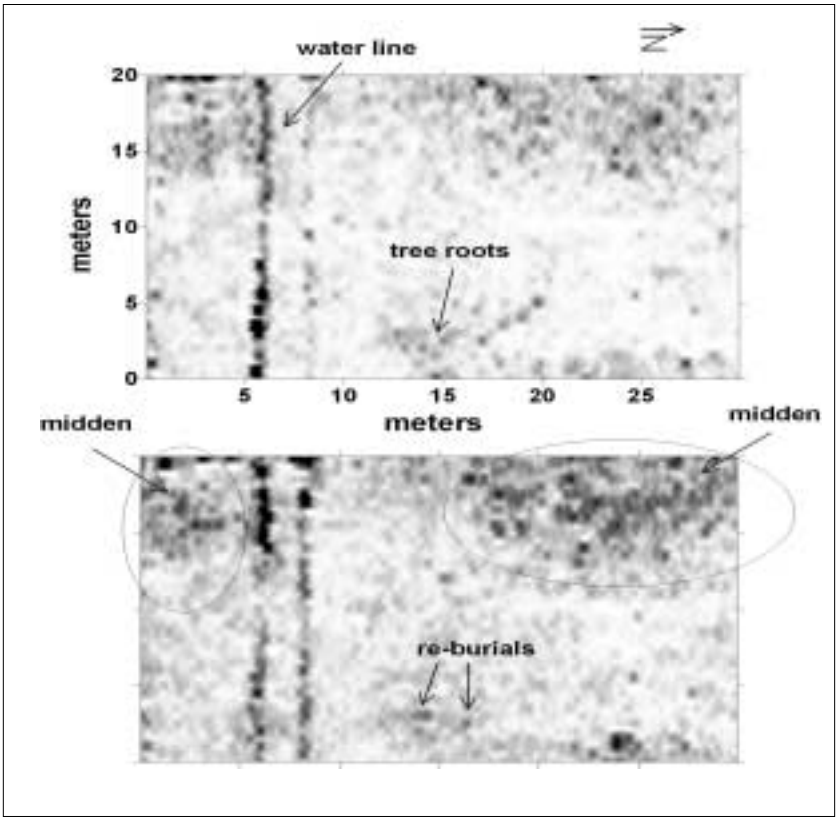


Figure 8. Amplitude slice-maps of the features mapped at Bellows Air Force Base, O'ahu including two ancient middens, re-buried human remains and a modern water pipe.

can provide in carbonate sand, in this case with good resolution to at least 2 m depth.

As active carbonate dunes can often contain archaeological materials along the coast, test profiles were collected along the modern beach at Marine Corps Base Hawaii (MCBH), also on the windward side of O'ahu, just west of the Kāne'ohe Clipper Golf Course (Figure 3). Although the stratigraphy there is quite complex, reflections from a number of buried features are visible in reflection profiles. These include probable cross-beds within dunes and buried surfaces of inter-dune compacted surfaces that were later covered by the advancing dunes (Figure 9). Good reflections were recorded at this test site to about 2 m using the 400 MHz antennas. If the archaeological targets of interest were artifacts or features on or within ancient living surfaces (perhaps inter-dune habitation surfaces), which were later covered by the dunes, the GPR method would be an excellent tool for accurate mapping.

Ancient Hawaiian burials were often placed in sand dunes both along the coast and in dune deposits farther inland. Just south of the runway at Dillingham Air Field on O'ahu's northwest coast (Figure 3), one such burial ground was tested in carbonate sand where both historic and ancient burials were known to be present. Some of this area had been disturbed by earth moving equipment in the past, and it was unknown if or where intact burials might still be present. Using the 400 MHz antennas, good reflections were recorded to between 2 and 2.5 m (30 ns) and a number of possible burials were discovered (Figure 10). Although these were not confirmed by intrusive testing methods, they are very similar to burial features seen elsewhere (Conyers 2006b). They are also located in an area where Thomas Shirai, a descendant of the Hawaiian family that once lived here, remembers his grandfather pointing out graves, which date from at least the 1860s and possibly much earlier. Also recognizable at this site is disturbance by earth moving equipment, visible as areas of little or no radar reflection, where sand was removed, homogenized, and then later used as backfill, creating a zone in the GPR profiles where there is no significant radar reflection (Figure 10).

A vacant lot slated for construction in Lā'ie, on O'ahu's North Shore (Figure 3) was used as a test lo-

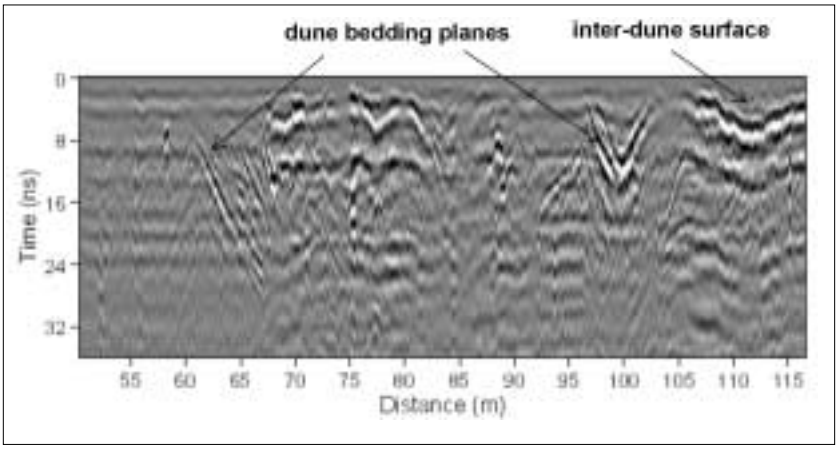


Figure 9. GPR reflection profile collected in active carbonate dunes along the Kāne'ohe Marine Reserve beach, O'ahu.

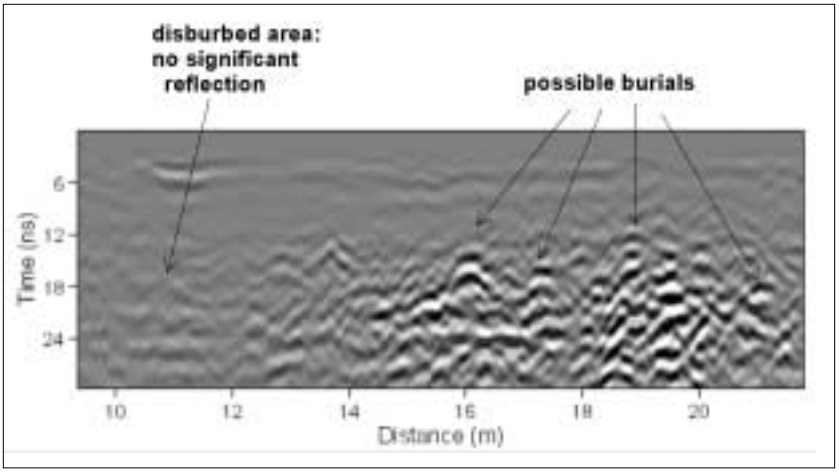


Figure 10. GPR reflection profile from Dillingham Air Field showing possible burials and disturbed area in carbonate sand dunes.

cation to try the GPR method's utility for a common CRM task, cultural resource evaluation. In this area, what appeared to be highly disturbed carbonate sands just landward of a rock breakwater were tested for the presence of burials and also to determine if house floors, middens, or possible hearth features were preserved in the sand. Good reflections were recorded to about 2 m (40 ns) using the 400 MHz antennas and reflection profiles showed a very complex stratigraphy consisting of numerous cut and fill features as well as individual reflections produced from large objects in the ground (Figure 11). The cut and fill features were interpreted as recent ground disturbances, with objects within them interpreted to be recent trash. Other areas outside of these disturbed zones were noted as containing possible intact cultural features. All areas of interest were noted on maps and rated as to their importance and possible origin. Excavation was allotted only one day by the client, so only representative features seen in the GPR maps and profiles were tested in order to confirm their origin. Excavations by Garcia and Associates personnel in February, 2006 consisted of both shovel tests and 1 x 1 m excavations, which confirmed the interpretation that this area had been heavily disturbed by recent excavations. The objects imaged by GPR within the cut and fill areas were found to be recent metal, wood, and glass debris, with the inclusion of some human and animal bones. While it is likely that human burials were once located in this area, the GPR analysis suggests they had been destroyed by excavation activity. The areas in the GPR profiles with little or no reflection were confirmed to be sterile sand. GPR mapping at this site proved to be an excellent method to quickly evaluate the archaeological potential of an area, and allowed targeting of excavations in specific areas of interest. Unfortunately, at this location the GPR evaluation showed that almost all of the area had been so disturbed by recent activity that little or no potential exists for intact cultural remains.

In general, the carbonate dune areas of Hawai'i provide an excellent medium for GPR analysis. As long as the sand is well above the brackish water table, good radar reflections can be collected to at least 2–2.5 m in most settings. As this type of ground contains a variety of archaeological sites, GPR can be used as a very fast and accurate way to test fairly large areas and to delineate features that can be tested with excavations, if necessary.

Compacted carbonate beachrock or other carbonate material overlain by thin soils have more limited energy penetration than the dunes. This is probably because they have undergone weathering that has transformed some of the carbonate minerals into clay, which appears to somewhat attenuate radar energy. Even in these cases, good reflections were still recorded to about 1–2 m when the ground water was fresh. Where brackish ground water was encountered, radar energy attenuation occurred at a much shallower depth.

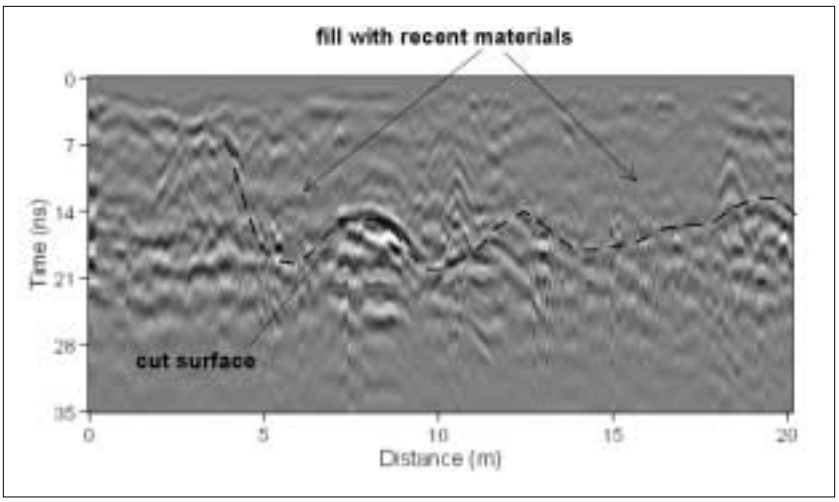


Figure 11. GPR reflection profile in carbonate beach sands, Laie, North Shore, O'ahu. Significant cut and fill features from recent disturbance are visible, which were confirmed by excavations.

Weathered Basaltic Soils

As most of the Hawaiian island chain's bedrock is composed of basalt, it is important to understand GPR energy penetration in soils that have formed on this material, as well as energy propagation within the volcanic rock. An understanding of the electrical properties of the weathering products formed from basalt, which can produce the thick reddish-brown clay soils visible throughout the islands, is therefore crucial. Hawaiian basalt is composed of silica, plagioclase feldspar (sodium and calcium aluminum silicates), and iron-magnesium minerals such as magnetite, pyroxene and olivine (Macdonald et al. 1983). The silica in the basalts is mostly stable over time, and its chemical composition affects radar energy very little (Doolittle 2006). The feldspar minerals in basalt, however, will readily weather to a variety of clay minerals depending on environmental conditions, with kaolinite clays formed in the more humid windward areas and allophane, spectite, and montmorillonite clays in the drier leeward areas (Macdonald et al. 1983). The iron and magnesium-rich minerals in the basalt weather to the hydrated iron oxides hematite and limonite, which give many Hawaiian soils their distinctive reddish-brown to yellowish color. In some very wet windward areas, Hawaiian soils containing kaolinite can further weather to bauxite (gibbsite and goethite clays) when the soils are heavily altered by the leaching action of intense rainfall (Macdonald et al. 1983). In some of the drier leeward areas, calcium carbonate can be an additional basalt weathering product, which produces variegated whitish-red soils. Each of these soil constituents produced on basalt bedrock, in various combinations, will produce surface materials of varying electrical conductivity and magnetic permeability, which can affect the depth to which radar energy will penetrate. When these various materials become water saturated, cations will become mobilized, conducting an electrical current. This chemical property causes these soils to conduct the electrical portion of the electromagnetic wave away, destroying the propagating radar waves.

The most common way to measure the electrical conductivity of soils is by measuring CEC, a common measurement used in determining soil fertility for agriculture (McDonald et al. 2005). The higher the CEC, the greater the electrical conductivity, as measured in units of centimeters of cation change per kilogram. Kaolinite has the lowest CEC of common Hawaiian soils, in the range of 2 to 15 cm/kg, while montmorillonite has the highest (ranging from 80 to 150 cm/kg). The calcium carbonate found in soils in leeward areas will also increase the electrical conductivity when wet, as this mineral constituent can mobilize cations. Therefore, in a basic way, the clay soils formed on basalt in leeward locations will have poorer radar energy propagation, as these electrically conductive soils will destroy most radar energy readily in the ground. As the soils become progressively more weathered because of greater rainfall toward the windward areas, radar energy depth penetration will improve.

As a test of basalt soils on the leeward side of the island, GPR reflection profiles were collected at the National Memorial Cemetery of the Pacific, also called Punchbowl Cemetery (Figure 3), where metal caskets were known to be located at standard depths in the ground. The soil in this area is composed of weathered basalt, with additions of some weathered coral rubble that was imported to level the ground. The ground has been heavily irrigated and fertilized (until a few years ago with iron-rich liquid fertilizer). A number of reflection profiles were collected using the 400 and 270 MHz antennas over known graves. Radar energy was severely attenuated below about

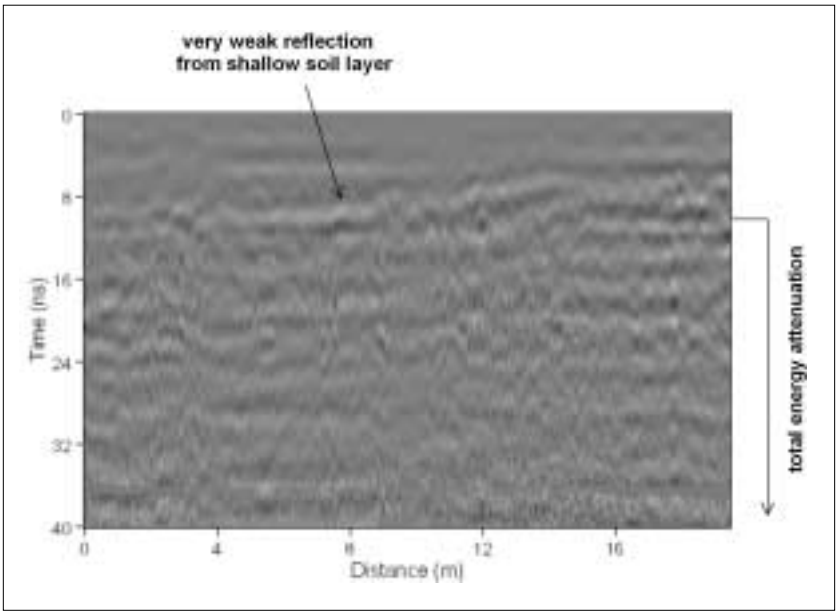


Figure 12. GPR reflection profile from Punchbowl Cemetery, O'ahu. Almost total radar energy attenuation occurred below about 15 nanoseconds (about 40 centimeters in the ground).

10 ns, which is approximately 40 cm in the ground (Figure 12). No coherent reflections were obtained below 20 ns (80 cm) in any of the profiles, and none of the caskets, whose tops were about 120–150 cm below ground surface, were visible. These tests confirm those performed by Sabrina Buck (2003), who reported similar results. Shallow energy attenuation at this location is probably the result of highly conductive clays in the soil, but could also partially result from some magnetic attenuation due to long-term application of iron-rich fertilizer. This high iron content, perhaps from magnetite that had not completely weathered to ferrous oxide minerals in the basaltic fill and possibly from the fertilizer, could have caused the attenuation. Of all the GPR data collected as part of this study, that at Punchbowl showed the most severe attenuation with depth.

While magnetite in Hawaiian soils has generally been considered a limiting GPR factor (Olhoeft 1998), tests in the laboratory suggest that elevated electrical conductivity may play a more important role in tropical soils (Robinson et al. 1994). In these tests, the magnetite by itself did not cause energy attenuation, but when it was crushed and put in a water solution, higher radar attenuation resulted. This suggests that magnetic permeability might play a very minor role in radar energy attenuation within most Hawaiian rocks, compared to electrical conductivity. It is more likely that the clays in these soils, which consist of higher amounts of montmorillionite with higher electrical conductivity, are producing the high energy attenuation close to the surface.

Tests were conducted in soils formed on basalt parent material at the Schofield Barracks Post Cemetery (Figure 3). This site is in a more windward location than Punchbowl and is in a soil classified as Kunia silty-clay (Foote et al. 1972; Soil Survey Staff 1999). This soil type is composed of dark reddish-brown silty clay with some manganese concretions. While no chemical analysis has been published on the material from Schofield, similar soils in weathered basalts nearby have cation exchange capacities of between 20 and 30 cm/kg, which suggests they contain both kaolinite and montmorillonite clays. Montmorillonite clays are much more electrically conductive than the kaolinitic constituents, and we predicted these soils would produce only moderate radar energy attenuation.

Reflection profiles from the cemetery showed good reflections to about 35 ns, which is about 1.5 m below ground surface after correcting for velocity (Figure 13). Reflection hyperbolas generated from the tops of caskets located at about this depth were visible, with some deeper reflections from other soil discontinuities to depths of about 2 m.

Amplitude slice-maps of a portion of the cemetery where child burials were located (at various depths) were constructed in order to map individual graves and other buried features (Figure 14). Tree roots and sprinkler lines are visible in the shallow slices, while the various deeper slices show the location of the burials as high amplitude reflections. The Schofield Barracks GPR data show that in moderately weathered soils produced on basaltic parent material, good radar energy can penetrate to about 1.5–2 m and good resolution of buried features is possible.

Within the old sugar cane fields just above Hale'iwa, on land owned by the Bishop Estate, a grid of radar data was recorded at the Opaeula Fire Base (Figure 3) where concrete bunkers were built just after the

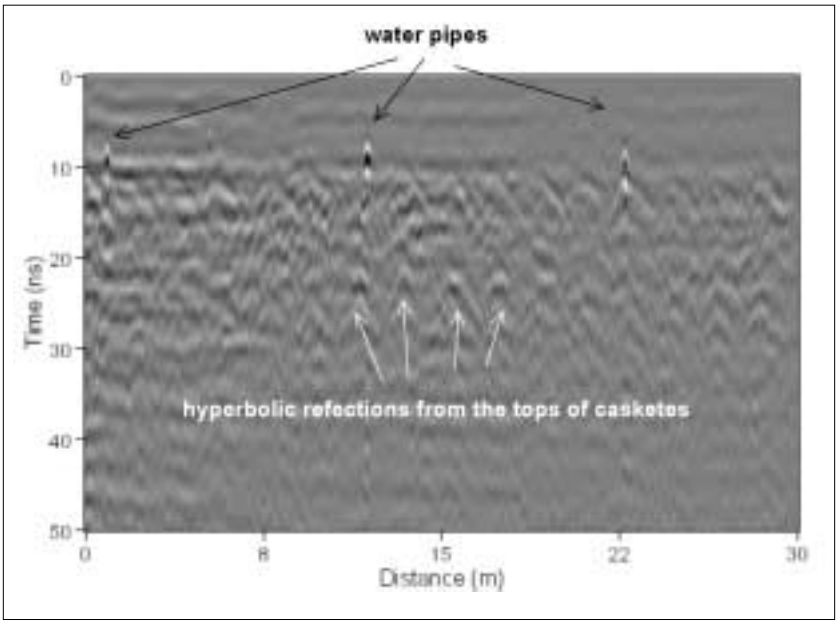


Figure 13. GPR reflection profile from Schofield Barracks Base Cemetery. Good resolution to about 2 meters allowed caskets to be readily identified (only a few are annotated on this figure).

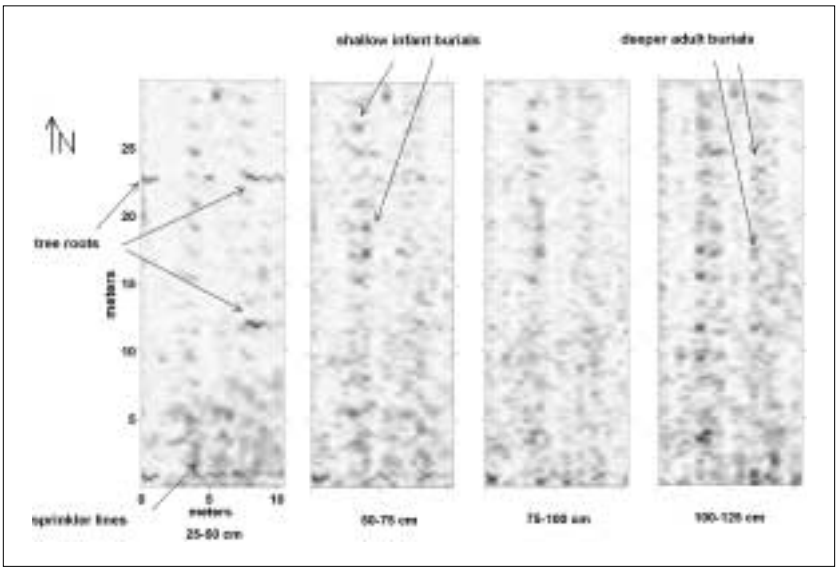


Figure 14. Amplitude slice-maps of graves at various depths, Schofield Barracks, O'ahu.

Pearl Harbor bombings of 1941 (Bennett 1994). In this area there are deeply weathered dark reddish-brown soils similar to those encountered at Schofield Barracks. Both the 400 and 270 MHz antennas were used in this area, and good reflections were recorded to about 40 ns, which is about 2 m in the ground. Energy from both antennas was attenuated below that depth. In this area, the features of interest were located more than 2 m below the ground surface, and the GPR method was not capable of penetrating to that depth. Both frequency antennas transmitted energy that penetrated to about the same depth, indicating that 2 m is about the limit of GPR mapping in these types of soils.

Basalt Rock and Rubble

On the flanks of a cinder cone at MCBH on the northeast shore of O'ahu (Figure 3), an attempt was made to map ancient Hawaiian burials that had been encountered during construction of the Pond Road housing project. In this area, about 70 cm of basalt rubble from the nearby cinder cone was deposited on top of a dark brown clay layer of unknown origin and thickness. This layer was visible in a backhoe trench to a depth of 1.3 m. The burials were discovered in the clay layer at about 1 meter depth. A recently buried six-inch diameter plastic pipe (80 cm below surface) was used as a target to test radar penetration in this type of basalt rubble. Both 400 and 270 MHz antennas were used, and the plastic pipe was not visible. Buried objects such as the pipe should be visible in reflection profiles as distinct hyperbolic reflections (Conyers 2004:54).

This test suggests that there is something about recently erupted basaltic cinders that is highly attenuating to radar energy at a very shallow depth. Similar GPR tests conducted in recently erupted basaltic lavas at Craters of the Moon in Idaho indicates that high amounts of titanium and iron in some basaltic ejecta of this sort increases radar attenuation, but only when low frequency antennas below 100 MHz are used (Heggy et al. 2006). That study showed that for most antennas used for archaeological purposes (200 MHz or higher), losses of radar energy with depth was a product of inhomogenieties in the basalt that produced energy scattering, caused by individual cinders, air vugs, or stratigraphic layering. The higher frequency antennas that employ shorter

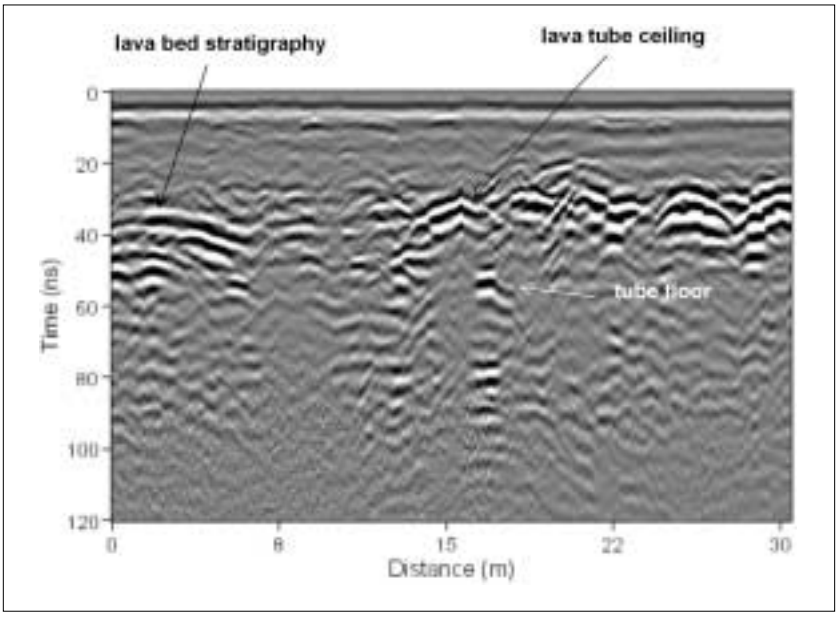


Figure 15. GPR reflection profile of the ceiling and floor of a lava tube, with adjacent lava stratigraphy, Island of Hawai'i.

wavelength radar energy would therefore be more likely scattered by the buried cinders in the ground, and therefore not recorded back at the surface antenna. This might be what caused poor energy penetration at the Kāne'ohe cinder cone, as the ground was composed of cinders about 5 cm in diameter. However, laboratory measurements of basaltic lavas from Idaho showed that the magnetic permeability of tephra is higher than that of flow rocks because of its higher concentration of magnetite (Heggy et al. 2006). While this mineralogical variable has been noticed in Hawai'i (Olhoeft 1998), it is possible that in cinder cone areas the higher magnetite content of the lava could be playing a significant role in energy attenuation by destroying the magnetic portion of the electromagnetic waves. Other studies question this supposition (Saarenketo 1998), and tend to support the laboratory data of Robinson et al. (1994), suggesting that electrical conductivity variables caused by water and certain clay types are the more important factor in the depth of radar energy penetration.

In tests using the 270 MHz antennas in 5,000-year old basalt flows on the Island of Hawai'i, excellent energy penetration occurred to at least 4 m or more. At O'oma Phupua'a lava tube, just northwest of the Kona airport, the top and floor of a lava tube were recorded in reflection profiles. The top of the tube is quite visible at 40 ns (Figure 15), which is 2.8 m below ground surface. Volcanic stratigraphy along the margins of the tube is well defined to a depth of about 5 m (60 ns). In this leeward area of Hawai'i, the basalt is mostly unweathered and appears to transmit energy readily to at least 5 or 6 m. The tests performed there are similar to those done by Olhoeft et al. (2000) at Volcanoes National Park on the southern coast of Hawai'i and mimic those from Craters of the Moon, Idaho (Heggy et al. 2006) and Iceland (Cassidy et al. 2004). It is apparent in these tests that fairly fresh lava is a good transmitter of radar energy, and in this case the magnetite and other ferromagnesian minerals do not appear to cause significant radar energy attenuation.

Conclusions

Coral sand and carbonate areas of Hawai'i along the coasts are a good medium for ground-penetrating radar mapping of buried archaeological materials and associated stratigraphy. Excellent resolution of buried features, using antennas in the 400 MHz frequency range, occurred to depths of between 1 and 2.5 m in this type of ground. Soils formed on basalt parent material in leeward areas, and in ejecta of recent cinder cones, was a poor medium for GPR due to the scattering effects of the cinders, and possibly the attenuating properties of magnetite in the tephra. In the other more typical reddish brown clay-rich soils found in Hawai'i, energy penetration to about 1.5–2 m was common. Penetration depths were much shallower in these soils in leeward areas, likely due to the electrically conductive clay types found in those environmental conditions. Penetration depth appears to increase in more windward locations where the higher conductivity clays in the soils have undergone alteration to less conductive clay minerals. This depth of radar energy penetration was the case at all tests except the recent cinder cone on the windward side where radar energy penetration was severely limited due to the dispersive nature of the cinders. In general, depth penetration to greater than about 2 m is not expected in weathered clay soils anywhere on O'ahu. This depth, how-

ever, is more than deep enough for the mapping of most archaeological sites found in this region of Hawai'i. Relatively recent basalt flows on the island of Hawai'i allowed energy penetration to at least 5–6 m, which is a depth suitable for mapping near-surface lava tubes.

Acknowledgements

The authors would like to thank the Joint POW-MIA Accounting Command (JPAC), the Central Identification Laboratory (CIL), and the ORISE program for graciously hosting the senior author and supplying the equipment needed to carry out the surveys. These groups also funded many other elements of this study. At JPAC-CIL we were generously provided a forum to discuss the latest techniques of GPR research. At the CIL Thomas Holland, John Byrd, and Sabrina Buck were invaluable contributors to this study. Our study was helped by a large cast of characters from around the Hawaiian Islands, including Valerie Curtis the Hickam Staff Archaeologist, Karen Desilets a NAVFAC Pacific archaeologist, Jen Robins and John Peterson of Garcia and Associates, Hal Hammatt and Matt McDermott of Cultural Surveys Hawaii, Laura Gilda, a Cultural Resources Specialist at Schofield Barracks, Bob Rechtman of Rechtman Consulting, Floyd McCoy from Windward Community College, Rick Rogers from Opaeula Fire Base, the staff of the National Memorial Cemetery of the Pacific, Thomas Shirai of O'ahu and especially Mike Desilets of Garcia and Associates.

References Cited

Bennett, J. D. 1994. Site Survey: Battery Carroll C. Riggs, Opaeula Ranch, O'ahu. In *Batteries Brodie & Opaeula (8-Inch 55 Caliber MKIX Naval Mounts) Saratoga Gun Group, North Shore, Oahu, T.H.* Compiled for the Coast Defense Study Group (CSSG) and the Council of America's Military Past (CAMP) by J.D. Bennett and Scarp Associates.

Buck, S. C. 2003, Searching for Graves Using Geophysical Technology: Field Tests with Ground-penetrating Radar, Magnetometry and Electrical Resistivity. *Journal of Forensic Science* 48 (1):1–7.

Cassidy, N. J., Russell, A. J., Pringle, J. K. and J. L. Carrivick. 2004. GPR derived architecture of large scale Icelandic Jokulhlaup deposits, Northeast Iceland. In *Proceedings of the 10th International Conference on Ground-penetrating Radar*, Delft The Netherlands June 31–24, edited by Evert Slob, Alex Yarovoy and Jan Rhebergen, Delft University of Technology, pp. 581–584.

Conyers, L. B. 2004. *Ground-penetrating Radar for Archaeology*. Altamira Press, Walnut Creek, California.

Conyers L. B. 2005. GPR Software Programs: http://www.du.edu/~lconyers/SERDP/software_downloads.htm.

Conyers, L. B. 2006a. Ground-penetrating Radar. In *Remote Sensing in Archaeology*, edited by Jay K. Johnson, The University of Alabama Press, Tuscaloosa, Alabama, pp. 131–160.

Conyers, L. B. 2006b. Ground-penetrating radar techniques to discover and map historic graves, *Historical Archaeology*, v 40, n. 3, pp. 64–73.

Conyers, L. B. and J. E. Lucius. 1996. Velocity analysis in archaeological ground-penetrating radar studies. *Archaeological Prospection*, v. 3, pp. 312–333.

Conyers, L. B. and T. Osburn. 2006. GPR Mapping to Test Anthropological Hypotheses: A Study from Comb Wash, Utah, American Southwest. In *Proceedings of the 11th International Conference on Ground-penetrating Radar*, Columbus Ohio, June 19–21, 2006, edited by Jeffrey J. Daniel, pp. 1–8.

Doolittle, J. A. 2006. Ground-Penetrating Radar Soil Suitability Maps of the Conterminous United States. U.S. Department of Agriculture Natural Resources Conservation Service, http://soils.usda.gov/survey/geography/maps/GPR/index.html.

Doolittle, J. A. and M. E. Collins. 1995. Use of soil information to determine application of ground-penetrating radar. *Journal of Applied Geophysics*, 33:101–108.

Foote, D. E., Hill, E., Nakamura, S. and F. Stevens. 1972. Soil Survey of the Islands of Kauai, O'ahu, Maui, Molokai and Lanai, State of Hawai'i. U.S. Department of Agriculture Soil Conservation Service. In cooperation with the University of Hawaii Agricultural Experiment Station, Honolulu, Hawaii.

Gaffney, C. and J. Gater. 2003. *Revealing the Buried Past: Geophysics for Archaeologists.* Tempus Publishing, Stroud, Gloucestershire, England.

Grant, J. A. and P. H. Schultz. 1994. Erosion of ejecta at Meteor Crater: Constraints from ground penetrating radar. 789–803 pp. In: *Proceedings Fifth International Conference on Ground-Penetrating Radar.* Waterloo Centre for Groundwater Research and the Canadian Geotechnical Society. June 12–14, 1994, Kitchner, Ontario, Canada.

Grim, R. E. 1968. *Clay Mineralogy, 2nd Edition.* McGraw-Hill, New York.

Hammatt, H. H. 2005. *Archaeological Literature Review and Field Inspection of the Proposed Kaioo Drive Multi-Family Development in Waikiki, Kona District, Island of Oahu.* Draft copy prepared for Kusao & Kurahashi, Inc. by Cultural Surveys Hawaii, Inc., Kailua, Hawaii.

Heggy, E., Clifford, S. M., Grimm, R. E., Dinwiddie, C. L., Wyrick, D. Y. and B. E. Hill. 2006. Ground-penetrating radar sounding in mafic lava: Assessing attenuation and scattering losses in Mars-analog volcanic terrains. *Journal of Geophysical Research*, Volume III E06S04: pp. 1–16.

Johnson, J. K. 2006. A comparative guide to applications. In *Remote Sensing in Archaeology*, edited by Jay K. Johnson, The University of Alabama Press, Tuscaloosa, Alabama, pp. 305–320.

Kam, W. 1986. *Memorandum: Investigation of Discovery of Human Skeletal Remains Bellows AFS, Koolaupoko, Oahu.* Prepared by the State of Hawaii, Department of Land and Natural Resources, Honolulu, Hawaii.

Kvamme, K. L. 2003. Geophysical surveys as landscape archaeology. *American Antiquity*, v. 63, n. 3, pp. 435–457.

Lucius, J. E. and M. H. Powers. 2002. GPR data processing computer software for the P.C. U.S.G.S. Open File Report 02-116. U.S. Department of the Interior, U.S. Geological Survey, Denver, Colorado, USA.

Macdonald, A., Abbott, A. T., and F. L. Peterson. 1983. *Volcanoes in the Sea: The Geology of Hawaii.* University of Hawaii Press, Honolulu

McDonald, L. M., Evangelou, V. P. and M. A. Chappel. 2005. Cation exchange, in *Encyclopedia of Soils in the Environment*, edited by Daniel Hillel. Elsevier Academic Press, Amsterdam, vol. 1, pp. 180–188.

Miyamoto, H., Haruyama, J., Kobayashi, T., Suzuki, K., Okada, Y., Hishibori, T., Showman, A., Adam, P., Lorenz, R., Mogi, K., Crown, D. A., Rodriguez, J. A. P., Rokugawa, S., Tokunaga, T., and K. Masumoto. 2005. Mapping the structure and depth of lava tubes using ground penetrating radar. *Geophysical Research Letters*, v. 32, L21316, pp. 1–5.

Olhoeft, G. R. 1998. Electrical, magnetic and geometric properties that determine ground penetrating radar performance. In *Proceedings of GPR 98, 7th International Conference on Ground Penetrating Radar*, edited by D.A. Noon, G. F. Stickley and D. Longstaff. SPIE International Society of Optical Engineering, 4084. pp. 482–487.

Olhoeft, G. R., Sinex, D. B., Sander, K. A., Lagmanson, M. M., Stillman, D. E., Lewis, S., Clark, B. T., Wallin, E. L. Kauahikaua, J. P. 2000. Hot and cold lava tube characterization with ground penetrating radar. In. *Proceedings of SPIE, Eighth International Conference on Ground Penetrating Radar*, edited by David A. Noon, Glen F. Stickley and Dennis Longstaff, v. 4084, pp. 482–487.

Putzi, J. L. and T. S. Dye. 2005. *Archaeological Monitoring Report for Replace Military Family Housing Projects Phase I at Hickam Air Force Base and Bellows Air Force Station, Hawai'i*. Prepared for Rim Architects by T. S. Dye & Colleagues, Archaeologists, Inc., Honolulu, Hawaii.

Reynolds, J. M. 1998. *An Introduction to Applied and Environmental Geophysics*. Wiley, New York.

Robinson, D. A., Bell, J. P. and C. H. Batchelor. 1994. Influence of Iron Minerals on the determination of soil water content using dielectric techniques. *Journal of Hydrology*, v. 161, pp. 169–180.

Saarenketo, T. 1998. Electrical properties of water in clay and silty soils. *Journal of Applied Geophysics*, v. 40, pp. 73–88.

Schulze, D. G. 2005. Clay minerals. In *Encyclopedia of Soils in the Environment*, edited by Daniel Hillel. Elsevier Academic Press, Amsterdam, v. 1, pp. 246–254.

Soil Survey Staff. 1999. Soil Taxonomy, *A Basic System of Soil Classification for Making and Interpreting Soil Surveys 2nd Edition.* US Department of Agriculture—Natural Resources Conservation Service, Agriculture Handbook No. 436, US Government Printing Office, Washington, DC.

Vehara, G. 2005. Volcanic Soils. In *Encyclopedia of Soils in the Environment*, edited by Daniel Hillel. Elsevier Academic Press, Amsterdam, v. 4, pp. 225–232.

Rights, Rites, and Riots: Values of Resources and Research in Hawaiian Archaeology

Mike T. Carson
International Archaeological Research Institute, Inc.
2081 Young Street
Honolulu, Hawai'i 96826

Introduction

As in many regions, Hawaiian archaeological resources are becoming increasingly recognized as valuable by a variety of stake-holders, yet the perceived value of archaeological research is somehow out-ranked by other potential values of the same resources. Artifacts, sites, and other resources are accepted as important for cultural meaning, general appreciation, and responsible management. Potential scientific value is generally recognized, but it is not always understood to be significant. Meanwhile, the practice of archaeology is viewed as a costly nuisance, an unwanted intrusion into the past, and a self-serving trivial hobby. Clearly, archaeologists need to improve the perceived value of their research as a significant and desirable contribution.

In the strictest sense, the archaeological value of a resource equals its potential to generate research data, but other stake-holders have different opinions about this largely misunderstood value relative to other considerations. Archaeological research constitutes only one of many possible values of any given resource (Carver 1996; Darvill 1995; Mathers et al. 2004). An abandoned site (for example, a set of mounds in the Kona Field System) may be viewed as less valuable than an intended housing complex, roadway, airport, industrial factory, agricultural field, or other development. A museum collection (such as the Forbes Cave assemblage), ancient monument (such as Pu'u o Mahuka Heiau), a geographically or culturally defined landscape (such as Waimea Valley of O'ahu Island), or other resource may be seen as important for traditional cultural practitioners or for members of a community-based group, but the role of archaeologists in learning new information is often disregarded. Nonetheless, these examples are potentially valuable sources of

archaeological data, and moreover the research results are likely to increase other kinds of resource values.

In the awkward position of deciding what is best for the resources, government agencies and sometimes special-interest groups act on their behalf. However, archaeological significance rarely plays more than a perfunctory role, because true significance is rampantly misunderstood (Butler 1987; Hardesty and Little 2000). Also, serious questions arise when one person or group attempts to out-rank the perspectives and concerns of others, effectively over-riding their rights to equal representation.

The present work discusses the general role of resource management, considers perspectives of various stake-holders, and compares relative values of these perspectives. The presentation is in general terms for broad applicability, but some aspects are particular to Hawaiian archaeology.

Resource Management

Archaeological resource management is in some ways part of a larger framework designed to encourage responsible decision-making prior to potential adverse impacts on natural and cultural resources (King 2000, 2002, 2003). The primary concern is for the best long-term treatment of whatever resource is being considered. This concept of responsibility is welcomed in most cultural contexts and in nearly every recognized legal system in the world.

For resources that are finite and irreplaceable, the default management position tends to be for preservation when practical and when not out-ranked by other concerns. Preservation of critical natural habitats and endangered species can be accepted as generally beneficial, and this fundamental concern in most cases out-ranks potential interests of property owners, business opportunists, and others. In contrast, preservation of archaeological resources is difficult to uphold relative to other interests.

Preservation of an archaeological resource, when it occurs, is almost always in recognition of values for education, general appreciation, tourism, cultural identity, or other factors extraneous to research. Only very rarely is preservation enacted as a means to allow ongoing research, such as at the Māhāʻulepū Caves and Sinkhole in Kauaʻi (Burney et al. 2001). However, the Māhāʻulepū research includes archaeology as only one peripheral component of a larger interdisciplinary program. At least in Hawaiʻi, significant archaeological research is an extreme rarity for preserved sites, museum collections, and other resources.

In many cases, baseline archaeological data (concerning site location, form, function, and chronology) may be used toward making the case to preserve a site or to claim that research potential has been exhausted, but this scope of work plainly does not constitute significant research (see Butler 1987). Baseline site-specific documentation is the first step in building archaeological knowledge (Carson 2005:118–119). Beyond this initial step, significant research is an entirely different operation, wherein "the uniqueness of a given set of data needs to be recognized for how it can contribute to new knowledge" (Carson 2005:122).

Labeling an investigation as data recovery, mitigation, or academic research emphatically does not mean that significant research has been conducted. As has been stated in a recent review of this problem (Carson 2005:122):

> Simply calling attention to a previously unknown or little-known topic does not automatically generate interest, and often it suggests that the topic is actually trivial or frivolous. Also, following a current trend or fad in academia does not ensure that the work is meaningful.

Ironically, archaeologists are often charged with the task of developing the same preservation plans, mitigation plans, and academic research designs that exclude the possibility of significant archaeological research. Routinely, minimal and superficial archaeological data are mistaken for significant research value. Mapping a site and perhaps conducting one or two very small test excavations constitutes only minimal data collection. The data content can be preserved in perpetuity, but this procedure does not guarantee that significant research can be conducted. In effect, this approach de-values archaeological research by creating a false impression of what is required for a significant research contribution.

As Carver (1996) describes in Britain, heritage management preserves what is already known (or thought

to be known under possibly false pretenses) about particular sites and about generalized history or prehistory, yet this stance is contrary to archaeological research aiming to solve mysteries of the unknown and to contribute new (i.e., previously unknown) information of significance. In Hawai'i and other parts of the United States, the international field of "heritage management" is named "historic preservation" in recognition of its goal to preserve historical sites and their data content.

Historic preservation and archaeological research of course can cooperate productively, but a perverse understanding of preservation has somehow out-ranked an increasingly rare interest in new research at least in Hawai'i. As a result, archaeological exercises tend to reinforce what is already known or presumed to be important for historic preservation, and the potential for significant research is neglected. Such does not need to be case, and productive research contributions will be possible only with a drastic change on the part of practicing archaeologists.

The historic preservation process in Hawai'i repeatedly reinforces pre-conceived notions about what makes archaeological resources significant. Field surveys rely on minimal description of surface-visible stonework ruins, interpreted in a framework suggested by government land records and available ethnohistoric traditions. Surface features are interpreted as the remains of residences, cultivation fields, and other activity areas attested in land records and consistent with traditional community configurations and boundaries. This approach certainly bears merits, but other possibilities still need to be acknowledged.

Hawaiian archaeology has become a tool to verify that sites and other resources represent the material vestiges of an ethnohistorically envisioned model of traditional Hawaiian settlement systems. The model assumes that spatial patterns and chronological trends of land use are already well known, so new survey findings serve only to embolden the pre-existing model. Moreover, the generalized patterns and trends are assumed to be largely definable from government land records (especially Land Commission documents of the middle 19th century) and the ethnohistorically defined *ahupua'a* system (literally "pig altars," referring to individual communities giving tribute to a paramount chief). When archaeological features are encountered in a field survey, they are interpreted as evidence of habitations, temples, or other parts of the given *ahupua'a* of that particular survey area. When the age of a site component is known or estimated, it is interpreted in a simplified chronology of the evolution of the *ahupua'a* system in general.

The status quo approach is relevant for much of the Hawaiian archaeological record, and it does not necessarily preclude other possible approaches that "think outside the box." Nonetheless, the "box" imposes definite limits, and it virtually ensures that nothing new is learned. Rather than contribute new knowledge, the same "box" is defined repeatedly.

By contributing little if any new substantive or theoretical knowledge, the status quo of Hawaiian archaeology does not constitute a convincing value for preservation (or for science). In other words, a site is unlikely to be preserved as a means to allow new investigation, because little if anything of importance is expected to be learned. Archaeological value invariably is mentioned as a reason for preservation, but the goal is to preserve a site rather than to learn something new about it. In practice, Hawaiian archaeological sites are preserved not because of their potential to contribute new data but rather for their embodiment of what is already known or assumed about those sites.

In nearly all presently known cases, preserved sites are strictly off-limits except for recognized cultural practitioners and perhaps certain community-based groups. In some cases, members of the general public are permitted to approach within a certain distance of a site, museum collection, or other resource for remote visual appreciation. As members of the general public, archaeologists do not possess any special right to conduct research at a preserved site or with a curated museum collection.

At least in principle, much can be accomplished with re-analysis of "preserved" pre-existing data from prior work and museum collections, but at least two practical problems are evident. First, the success of any re-analysis depends on having important information already recorded in a useful manner. Second, this approach does not always generate significant new results. The nature of re-analysis tends to focus on theoretical contribution, because presumably the

substantive contribution has been completed in the original documentation of the primary data, except in cases where major advances in technique and method enable entirely new kinds of analysis.

The avoidance of archaeological research is in most cases unjustified, because research results could only increase accuracy and precision of knowledge, as well as improve other kinds of values of a resource (Darvill 1995). This situation is especially applicable for sites with subsurface components not visible from surface observation, for rare museum collections requiring special curation conditions, for skeletal materials not permitted to be on display, and for the incredible volumes of discarded ancient material rubbish typically not suitable for museum exhibition.

A distinction may be noted between productive and exclusionary forms of resource management. The productive form encourages responsible research to enhance interpretive and general appreciation values. In contrast, the exclusionary approach disallows any kind of activity perceived as intrusive or destructive. In extreme cases, archaeological research is discouraged as an uninvited intrusion into the past or into a realm where cultural rights and privileges out-rank all other interests, yet these opinions are almost never challenged by those interested in archaeological research.

Extremist positions about archaeological resource management beg the question of who has the right to make these kinds of decisions. Property ownership, traditional cultural practice, community responsibility, and archaeological research are all legitimate value systems in relation to a given resource. What gives one person or group the right to exclude the interests of others and to claim the sole ability to act on behalf of a site or other resource? Truthfully, the various stake-holders simply voice their opinions about resource value, relative to their own perspectives in the present. Consultation among various stake-holders can accommodate diverse opinions and perspectives, whereas unbalanced exclusion of some but not all value systems clearly violates the general principle of responsible resource management.

Resource Stake-Holders

For those considering land development in places containing archaeological resources, the value of those resources often manifests itself negatively, in the form of a cost paid toward professional archaeologists to provide unexpected or unwanted services. Much more costly, though, are delays in intended land use, due to prolonged consultation and review process with government agencies and other entities. Moreover, site preservation areas prevent maximum land use efficiency by occupying space intended for some other profitable use. Quite understandably, most property owners strive to minimize or avoid these kinds of negative values, and other potential uses of their properties are regarded as much more valuable in a positive sense.

For traditional cultural practitioners, archaeological resources potentially represent physical links with the past and perhaps with ancestors. In some cases, these resources are important for some groups to exercise their legal rights and cultural expectations for freedom of personal and religious expression. These cases generally are uncontested when burial sites or obvious religious places are involved, but they tend to be negotiable when concerning other kinds of sites or resources.

Community-based groups continue to form in increasing frequency, dedicated to care for natural and cultural resources in places of interest, where their members have personal or familial connections. These places often contain archaeological sites, so these sites become part of a group's general concern or responsibility for resource management.

The research value of an archaeological resource is too often unjustified or grossly misunderstood. Archaeologists tend to exacerbate this problem by being exceptionally poor at specifying how a particular set of data may be significant even just within the esoteric field of archaeology (Butler 1987). As has been stated previously (Carson 2005:117): "Archaeological information in itself is not inherently interesting or meaningful, but rather it needs to be coordinated with a significant research program." The "invisible" nature of archaeological research value is easily overrun by other interests, namely property rights and cultural rights. When archaeological research is not

valued by other stake-holders, and especially when it destroys portions of resources but preserves only their abstract data content, then resource managers are reluctant to permit these activities.

As inanimate objects, archaeological resources themselves cannot be stake-holders representing their own interests. Nonetheless, they were created by human beings now deceased, and in some cases they include the physical remains of the deceased. The dead have no legal rights, but a basic level of respect for fellow humankind is always applicable. For example, laws prohibit grave-robbing, sale of human remains, sale of antiquities, vandalism of sites, looting, and unlicensed alteration of archaeological resources. Moreover, the State of Hawai'i has adopted particularly restrictive laws and guidelines concerning the treatment of human remains, especially in burial site contexts.

Relative Values

Albeit contrary to purported resource management goals, in practice cultural values and property ownership values out-rank archaeological values. Under the premise that all value systems have equal rights to representation, the rights of legitimate stake-holders are to be considered as a whole for resource management. Through consultation, some values may be found more important than others on a case by case basis. Archaeologists, however, are not perceived as having rights to conduct research, but rather their research is viewed as a privilege. The potential contribution of archaeological research to other value systems is generally discounted or misunderstood.

By mistaking minimal and superficial data for significant research, the overall value of true archaeological research is diminished. Basic resource identification and documentation are routinely mistaken for research value, but this scope of work is only the beginning of a four-step process in building archaeological knowledge (Carson 2005:118–124). By ending the knowledge-building process at its most rudimentary stage, significant archaeological research is virtually guaranteed to be impossible.

Poor understanding of science and of research significance is unfortunately common among archaeologists, further fueling the perception of a marginal value for archaeology in general. By claiming that tentative or untested models comprise definitive or conclusive evidence, some researchers call undue attention to their work as pseudo-science, with the effect of mislabeling (and by extension de-valuing) the work of more diligent colleagues as similarly superficial (at best) in regards to understanding even the most basic principles of science. Equally embarrassing are claims that important information has been discovered when in fact the results are extremely esoteric.

Apparent reversals of conclusions reflect inability to provide reliable scientific data and implicate archaeology as a flawed discipline, but this dysfunction can be completely avoided with proper attention to scientific interpretation. Sampling small portions of the larger archaeological universe, researchers must interpret limited facts, and representative sampling poses a serious problem for most interpretations. For instance, a single anomalously early date in Hanalei Valley on the north shore of Kaua'i was misinterpreted as evidence for irrigated agriculture in the first millennium A.D. (Schilt 1980), but later work overwhelmingly documented irrigated field contexts in the same site post-dating A.D. 1400 (Athens 1983). Moreover, a recent synthesis of radiocarbon dates from the region exposed the single early date as an extreme anomaly that probably should be disregarded (Carson 2006).

Another diminishment of archaeological value is due to chronic under-bidding by private contractors and universally low salaries in all branches of the profession. This problem is more serious than most are willing to admit. Meanwhile, the minimization of monetary value helps to marginalize archaeology as a value system in general, so the situation benefits those interested in de-valuing archaeology. In fact, the salary of any archaeologist is but a fraction of that of almost any other highly specialized professional with advanced academic degrees and training.

Archaeology is viewed by many as an esoteric interest of little real value, exacerbated by poor understanding of science, frequent failures to identify true research significance, general inability to articulate research findings with other value systems, and embarrassingly low salaries. Even the smallest cost toward its operation sometimes is considered a nuisance. In extreme cases, traditional cultural practitioners and community-

based groups either are unaware of the potential contribution of archaeological research or are strongly opposed to it as a perceived offense of a site, museum collection, or other resource.

Concluding Statement

The foregoing review stresses a need to improve the perceived value of archaeology. Most helpful would be to find ways to make archaeological research not only acceptable but also desirable, particularly in relation to other value systems. Indeed, research results can enhance various potential values of sites, museum collections, and other resources. In Hawai'i as in many places, potential for resource value-enhancement is almost entirely unexplored in terms of creative arts, education, tourism, symbolic representation, cultural identity, book sales, and other possibilities (Darvill 1995:43–48). Most crucial is to promote truly significant research and to publicize results in a way more easily perceived as valuable.

Acknowledgements

Much of this work is based on personal musings and conversations with a number of individuals, including J. Stephen Athens, Michael F. Dega, Christophe Descantes, B. Keola Lindsey, John A. Peterson, Timothy M. Rieth, and H. David Tuggle. Their input has helped shape some of my thoughts on the subject of value systems in Hawaiian archaeology, but they are not to be burdened with responsibility for the opinions expressed here.

References Cited

Athens, J. S. 1983. Prehistoric Pondfield Agriculture in Hawai'i: Archaeological Investigations at the Hanalei National Wildlife Refuge, Kaua'i. Report prepared for United States Fish and Wildlife Service. Department of Anthropology, Bernice P. Bishop Museum, Honolulu.

Burney, D. A., H. F. James, L. P. Burney, S. L. Olson, W. Kikuchi, W. L. Wagner, M. Burney, D. McCloskey, D. Kikuchi, F. V. Grady, R. Gage III, and R. Nishek. 2001. Fossil Evidence for a Diverse Biota from Kaua'i and Its Transformation since Human Arrival. *Ecological Monographs* 71:615–641.

Butler, W. 1987. Significance and Other Frustrations in the CRM Process. *American Antiquity* 54:820–829.

Carson, M. T. 2005. Science, Sanctimony, and Salvation: Considering a Unified Organizational Structure for Hawaiian Archaeology. *Hawaiian Archaeology* 10:115–129.

———. 2006. Timing of Colonisation, Land Use Chronology, and Implications for Palaeodemography in Kaua'i, Hawaiian Islands. *Journal of The Polynesian Society* 115:in press.

Carver, M. 1996. On Archaeological Value. *Antiquity* 70:45–56.

Darvill, T. 1995. Value Systems in Archaeology. In *Managing Archaeology*, edited by M. A. Cooper, A. Firth, J. Carman, and D. Wheatley, pp.40–50. Theoretical Archaeology Group. Routledge Press, London.

Hardesty, D. L., and B. J. Little. 2000. *Assessing Site Significance: A Guide for Archaeologists and Historians.* AltaMira Press, Lanham.

King, T. 2000. *Federal Planning and Historic Places: The Section 106 Process.* AltaMira Press, Lanham.

———. 2002. *Thinking about Cultural Resource Management: Essays from the Edge.* AltaMira Press, Lanham.

———. 2003. *Places that Count: Traditional Cultural Properties in Cultural Resource Management.* AltaMira Press, Lanham.

Mathers, C., T. Darvill, and B. J. Little (editors). 2004. *Heritage of Value, Archaeology of Renown: Reshaping Archaeological Assessment and Significance.* University Press of Florida, Gainesville.

Schilt, R. A. 1980. Archaeological Investigations in Specified Areas of the Hanalei Wildlife Refuge, Hanalei Valley, Kaua'i. Report prepared for United States Fish and Wildlife Service. Department of Anthropology, Bernice P. Bishop Museum, Honolulu.

Up In Smoke: Assumptions of Survey Visibility and Site Identification

Lisa Holm and Patrick V. Kirch
Department of Anthropology
University of California Berkeley

Introduction

Pedestrian surface survey, or the discovery and documentation of visibly detectable prehistoric and historic remains in the modern landscape, has been a critical part of archaeological field research for more than half a century. Despite increasingly accessible technologies such as satellite imaging, aerial photography, and geophysical testing, surface survey remains the primary means through which archaeologists obtain regional-scale data; it is widely employed both as a precursor to subsurface investigation and as an end in itself. Its ubiquity may in part be explained by the fact that: 1) it is both non-invasive and non-destructive, and therefore more in tune with the concerns of many native and local stakeholders; 2) it is less costly and time consuming than excavation, particularly when issues of material analyses, curation, and archiving are taken into consideration; and 3) it can provide a broad regional perspective on past human activities within either a culturally meaningful or arbitrarily defined area. State and Federal mandates, which dictate that potential impacts to cultural resources be investigated in advance of land modification, further ensure the continued pervasiveness of pedestrian surface survey, as its presumed reliability and cost-effectiveness make it a mainstay among cultural resource management agencies.

Despite the prevalence of pedestrian survey in archaeological field research, critical assumptions underlying its use often go overlooked or unscrutinized. While the current literature emphasizes the theory-ladenness of archaeological data and the interpretations that take place "on the trowel's edge" (Hodder 1999:92), few recent studies have revisited some of the fundamental methodological difficulties that continue to pervade the discipline. A good deal of archaeological literature was

devoted to surface survey and other field methodologies in the 1970s and 1980s, but such topics have received comparatively little attention within the last decade. Much of that earlier literature treated archaeological survey in conjunction with research design and sampling strategies (Ammerman 1981; Plog et al. 1978; Schiffer et al. 1978), subsurface or shovel testing (Krakker et al. 1983; Lightfoot 1986, 1989; Nance and Ball 1986, 1989; Shott 1989), site versus non-site approaches (Dunnell and Dancey 1983), and the correlation or stochasticity between surface and subsurface findings (Lewarch and O'Brien 1981; Wandsnider and Camilli 1992). Few studies attempted explicitly to examine the effects of surface conditions upon site discovery and data recording (Terrenato and Ammerman 1996; Thoms 1979). The tension between imperfect surface visibility and the need to rely upon data collected at the regional level has led to an increasing reliance on so-called "intensive" or "full coverage" pedestrian surveys. The implicit assumption is that the more intensive the survey, the greater the likelihood that all cultural features within a given region will be detected and recorded. The question remains, however, is such optimism justly founded?

Archaeologists who conduct pedestrian surveys are well aware that not all areas of a landscape offer the same opportunities for site or artifact discovery; the effects of cultural and natural processes as well as the nature of the archaeological remains themselves all play a seminal role. For instance, in surveying heavily forested regions, lands under intense cultivation, or areas affected by development or landscape modification, expectations may be low for finding sites or artifact scatters through surface survey alone. Geomorphological and pedological processes also may impede visibility, as in the case of areas affected by alluvial or aeolian inflation. Finally, at the most fundamental level, many cultural remains will not be visibly (or at least readily) apparent upon the ground surface. Though this has long been acknowledged in the American Northeast and in Europe where shovel testing and remote sensing are typically incorporated within survey programs, many archaeologists in the American Southwest and in the Pacific continue to operate under the assumption that a site will include some surface manifestation. The range and relative importance of the factors influencing site discovery will vary from one locale to another, and they are also likely to vary within a single locale at different points in time.

Although archaeologists have long been aware of surface survey limitations and constraints, few explicit attempts have been made to monitor or measure the extent of the problem. This avoidance may stem from the difficulties inherent in quantifying site recovery or from the desire to preserve a sense of optimism about surface survey. Most regional-scale studies presuppose that surface survey will provide a full or at least representative view of the extant cultural remains in a given area. To learn that such data are incomplete or suspect would call into question many of the interpretations that have been generated through the results of survey work conducted within the last several decades. Albert Ammerman (1981: 79) gave voice to this dilemma:

> We have been distracted by the technical and more formal questions arising about sampling from asking the basic question: how well are we doing at recovering the sites that were once occupied in those areas that we cover? For most surveys, no clear answer to this question can be given. We tend to be optimistic and assume that all or most of the sites in an area can be detected during a single coverage. However, due to factors beyond our own control such as ground cover or geomorphology, many of the sites in an area may go undetected. . . . It would be useful if some of the energy spent on questions of sampling were redirected to the issue of the quality of site recovery.

It would seem that the key to addressing questions about the quality of site recovery lies in examining case studies that allow for the quantification of what is missed and what is discovered during the course of a typical pedestrian survey. A chance event in 2003—a brush fire that laid bare a large portion of the Kahikinui District—provided the ideal setting for just such a case study.

The present work seeks to test some of the long-held assumptions about the comprehensiveness of "intensive" pedestrian survey by exploring and quantifying the relationships between surface visibility, site obtrusiveness, natural topography, and site identification. The results provide a cautionary tale about the ability of intensive survey to reveal all surface ar-

chaeological features under the common conditions of relatively heavy vegetation cover, variable topography, and poor site visibility. Given that archaeologists in Hawai'i and elsewhere typically conduct pedestrian surveys under such constraints, the case study results bear implications for the reliability of survey data generated within and beyond the Hawaiian archipelago.

The Environmental Mosaic of Kahikinui

The Kahikinui District occupies the southern flanks of East Maui on the leeward side of Haleakalā (Figure 1). The dominant land surface in the western and central portions of the district is composed of largely undissected Hāna Volcanic Series flow slopes originating from the southwest rift zone, and it is characterized by sporadic pyroclastic vents (Macdonald et al. 1983; Stearns 1985). Geologically, the Hāna Series flows are quite youthful (<100,000 yr), evidenced by a marked lack of weathering, minimal stream dissection, and relatively little soil development. These flow slopes contrast starkly against the eastern sector of the district, which is characterized by the more mature and deeply weathered Kula Volcanic Series (>226,000 yr) flows.

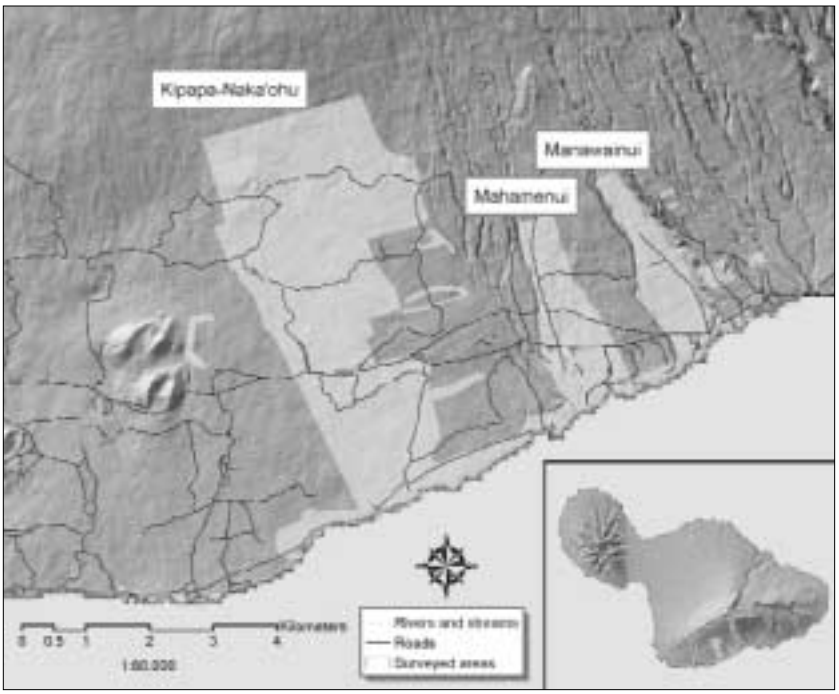


Figure 1.
Location of study area in Kahikinui, Maui.

Contrasts between western and eastern Kahikinui are also apparent with respect to hydrography. A few intermittent stream channels, ranging in width about 2 to 8 m, occur in the western half of the district; waterworn gravels indicate that these channels are sporadically active, though none flow regularly today (Stock et al. 2003). In the eastern half of the district, the topography is marked by more deeply incised channels; the most notable of these is Manawainui Gulch, which reaches vertical depths of over 100 m for much of its length. There is a steep rainfall gradient between the forested uplands of Kahikinui and the coast. The upland zones (about 300 to 2,000 masl) receive an average of 750 to 1,000 mm of rainfall per year, while the immediate coastal zone receives an average of <500 mm (Giambelluca and Schroeder 1998). Very likely, the effects of deforestation and animal depredation in the upper reaches of the district drastically curtailed the amount of surface water available, though it now seems likely that subsurface recharge through fog drip may have been the more critical source of moisture for the ancient Hawaiian population of Kahikinui (Stock et al. 2003).

Based upon observations of ecological variability and the distribution of archaeological features recorded to date, three environmental and habitation "zones" appear to cross-cut the Kahikinui District. The first is a coastal zone, which stretches from the rocky unprotected cliffs of the immediate coastline to an elevation of about 50 masl (about 0 to 200 m from the shore). Within this zone, vegetation is sparse, rainfall is minimal, and solar radiation is pronounced; the majority of cultural features recorded within this area seem to be related to the procurement of marine resources. A second so-called "barren zone" has been noted, beginning just inland of the coastal zone and extending to an elevation of about 175 masl (about 200 to 800 m from the shore). This zone is characterized by low but occasionally dense introduced grasses and lantana (*Lantana camara*) with very few cultural features; the explanation for this pattern likely has much to do with the limited amount of surface or groundwater available throughout the area, as well as a lack of soil development or soil nutrients (Vitousek et al. 2004). The third zone consists of a densely vegetated upland expanse that lies between the elevations of about 175 to 600 masl (about 800 to 2,500 m from the shore). This area is characterized by the densest distribution

of ancient Hawaiian cultural remains (including habitation sites, agricultural features, and ritual *heiau*), and it also exhibits the densest and most diverse array of vegetation communities. It has been hypothesized that this third zone was a "sweet spot" in which the cultivation of dryland crops such as *ʻuala* (sweet potato or *Ipomoea batatas*) would have been most successful due to the congruence of adequate moisture and high soil fertility (Kirch et al. 2004). It is this upland zone with which the present study is concerned.

History of Archaeological Survey in Kahikinui

The first survey of Kahikinui took place in 1929 when Winslow Walker briefly passed through the region on horseback, selectively recording *heiau* sites that were indicated by his Hawaiian guide (Walker n.d.; Sterling 1998:viii). It was not until 1966 that a more intensive program of archaeological survey was initiated in the Kīpapa and Nakaʻohu *ahupuaʻa* by Peter Chapman, a graduate student from Stanford University working under the auspices of the Bishop Museum (Van Gilder and Kirch 1997:46). Building upon Chapman's unfinished work from 1966 and 1967, Kirch recommenced archaeological investigations in Kīpapa and Nakaʻohu in 1995, and he has regularly conducted survey and excavation work there since that time (Kirch and Van Gilder 1996; Kirch 1997a, 1997b). In addition to the on-going work undertaken by Kirch and his associates at the University of California at Berkeley, the district also has been the subject of several other projects. In 1996, many of the ritual structures of Kahikinui were re-identified and excavated by Michael Kolb and students from Northern Illinois University (Kolb and Radewagen 1997). Between 1995 and 1997, the Hawaiʻi State Historic Preservation Division (SHPD) surveyed 645 ha in the upper elevations of Kīpapa, Nakaʻohu, and Nakaʻaha in areas awaiting resettlement under the Department of Hawaiian Homelands (DHHL) Kuleana Homestead project (Dixon et al. 1997). The SHPD also conducted a further study in February through June of 1998 and July of 1999, surveying 175 ha along the immediate coastal strip between Alena and Manawainui at the behest of the DHHL (Nagahara et al. 2000). Most recently, Kahikinui has served as one of two settings for a study of biocomplexity (Kirch et al. 2004; Vituousek et al. 2004). As a result of these combined efforts, Kahikinui has become one of the most intensively studied archaeological landscapes within the Hawaiian archipelago.

Archaeological Survey in Manawainui and Mahemenui, 2001 to 2002

The Mahamenui-Manawainui Archaeological Project (MMAP) was conceived in 1999 as the basis of Holm's dissertation research (Holm 2006). Though extensive fieldwork had been conducted by that time in the "core" of Kahikinui, little was known about the eastern "frontier" or "periphery" of the district—those areas comprising the territories of Mahamenui and Manawainui that bordered the neighboring polity of Kaupō. It was postulated that geographic and geologic dissimilarities between the central and eastern portions of the district would have inspired marked differences in daily practice, settlement patterning, and inter-polity interaction. The comparative body of data amassed through years of research in Kīpapa and Nakaʻohu coupled with research undertaken in Mahamenui and Manawainui has enabled a fuller exploration of the variability that existed between *ahupuaʻa* situated within the same socio-political district (see Figure 1).

Vegetation Conditions in Manawainui and Mahamenui

Prior to European contact and the introduction of exotic vegetation, the Kahikinui District was characterized by a series of native vegetation communities, ranging from coastal dry grasslands, through lowland dry shrublands and dry forests, into a montane dry forest on the higher slopes of Haleakalā, and finally subalpine shrublands (Medeiros et al. 1986). These vegetation communities and the effects that Native Hawaiian cultivators had on them have been investigated and partially reconstructed through charcoal analysis by Coil (2004). Today, only remnants of these original vegetation communities exist, represented in the Manawainui and Mahamenui areas by scattered *wiliwili* (*Erythrina sandwicensis*), *ʻakia* (*Wikstroemia monticola*), and *ʻulei* (*Osteomeles anthyllidifolia*).

The modern vegetation with which field crews had to contend in the 2001 and 2002 surveys was dominated by a variety of exotic, invasive species, most of which will be familiar to archaeologists working in Hawaiian lowland field conditions. The coastal and "barren" zones up to about 175 masl are characterized by several species of introduced grasses, which do not greatly impede surface visibility. Above this elevation, however, vegetation cover increases markedly in density and height, with the dominants becoming a mix of lantana (*Lantana camara*) and *koa haole* (*Leucaena glauca*), along with other exotic taxa such as Sodom's apple (*Solanum linnaeanum*), wild passionfruit (*Passiflora foetida*), and various other shrubs and grasses. In recent years, the vine *Glycine wightii*, originally introduced to Maui as pasture fodder, has increased dramatically across the Kahikinui landscape and when growing in combination with *Lantana* and *Leucaena* forms a particularly dense vegetation mat that is difficult to penetrate physically or visually. Throughout much of the survey area, exotic vegetation covered the landscape up to heights of 1 to 1.5 m, largely obscuring surface visibility. Such vegetation typifies the field conditions faced by archaeologists throughout much of the Hawaiian Islands.

Field Survey Methods

In May of 2001, field investigations began in the Manawainui *Ahupua'a*. A week of reconnaissance was undertaken to define the project extents and to assess the feasibility of accessing various areas, which was followed by a period of intensive pedestrian survey. Between May 28 and June 26, Holm and three to four field assistants systematically surveyed the western half of the Manawainui *Ahupua'a* between Palaha Gulch to the west and Manawainui Gulch to the east (223 ha). This intensive survey was accomplished by walking in northeast-southwest contiguous transects, roughly following the natural topographic contours. Survey intensity, given by the distance between crew members, ranged from about 5 to 10 m, a distance that varied based upon a subjective assessment of surface visibility and terrain. Whenever possible, adjacent crew members were advised to maintain visual contact to ensure that transects were consistent and that as few cultural features as possible were missed. Given the vegetation conditions discussed above, however, it was acknowledged that some features might be impossible to detect regardless of the survey intensity used.

Previous work in the Kīpapa and Naka'ohu *ahupua'a* indicated that the average dimensions of surface architectural features were about 7.5 m in length, 4.2 m in width, and 0.5 m in exterior height. Following Krakker et al. (1983) and Lightfoot (1986), a simple formula for calculating the probability of encountering a site of a given size using a particular survey intensity is $p = \pi r^2/i^2$. Though this formula originally was used to assess appropriate intervals for subsurface testing, it was found to be equally suitable for calculating survey intensity in settings with standing architecture and heavy vegetation. Calculations showed that a survey intensity of 5 m theoretically had a 100% chance of revealing features with a 2.82 m radius or greater, whereas a survey intensity of 10 m theoretically offered a 100% chance of locating features with a 5.65 m radius or greater. Based upon the average site dimensions noted above for Kīpapa and Naka'ohu, the radius of a "typical" site was calculated as $\sqrt{(7.5*4.2)/2} = 2.8$ m. Given the expected averages, the chosen survey intensity in Manawainui seemed an appropriate balance between potential site recovery and the cost requirements of conducting fieldwork.

Our efforts in Manawainui, though intensive, could not truly be called an example of "siteless" or "offsite" survey (Dunnell and Dancey 1983). Though isolated finds were collected and spatially recorded with a global positioning system (GPS) receiver as they were encountered, the basic focus of our investigations remained the "site" or "feature," which invariably consisted of unmortared dry-stone architecture. No effort was made during this initial phase of field research to explore the seemingly "empty" spaces between standing structures through shovel testing, augering, or test excavation.

All cultural remains encountered during survey were recorded using a standardized protocol. Following Weisler and Kirch (1985:131–132), that protocol included rejecting the term "site" in favor of one of four hierarchical descriptors: 1) "single architectural components", which comprised isolated walls, terraces, mounds, or upright stones spatially unassociated with any other component; 2) "features", which

consisted of structures containing two or more components such as shelters or enclosures with two to four walls; 3) "compound structures" that included more elaborately built features with more than four components such as complex *heiau*; and 4) "site complexes", which encompassed groups of spatially associated components assumed to be contemporaneous, such as series of close-set agricultural terraces.

Once a "site" had been given one of these four descriptors, it was assigned a unique identifier and then recorded on a standardized form patterned after those used in Kīpapa and Nakaʻohu. These forms included: 1) a tape and compass map drawn to scale (typically 1:50 or 1:100); 2) a series of attributes with coded values that could be rapidly recorded to characterize the feature's context, morphology, and construction; and 3.) free text descriptions of the feature's location, surface visibility, view planes, estimated age, perceived function, and relation to other cultural or natural features. All features noted during the 2001 field season were also spatially referenced with one or more sets of coordinates collected with a GPS receiver.

In June 2002, the second phase of MMAP was begun in the territory of Mahamenui. Following the same survey protocol as that employed the previous summer, 245 ha were surveyed within an area bounded on the east by Kepuni Gulch and on the west by a prominent ridgeline that bisected the *ahupuaʻa*. By incorporating the previously recorded SHPD survey data for the immediate coastal strip of the Mahamenui study area, an additional 20 ha of survey data were added for a final total of 265 ha.

As of 2002, intensive survey in Mahamenui had revealed a total of 491 single components, features, compound structures, or site complexes, and another 359 were recorded in Manawainui (Holm 2006). Forms included isolated upright stones, shelters and enclosures, single terraces or terrace complexes, and long low stone alignments believed to be remnant field systems or boundary markers (*kuaīwi*). Ultimately, the average length, width, and height of the sites recorded in Mahamenui and Manawainui corresponded fairly closely to expectations, with a slightly higher mean length in Manawainui due to the presence of several north-south trending field or boundary alignments that were notably absent in Kīpapa and Nakaʻohu (Table 1).

Table 1. Average feature size in the areas under intensive survey.

Area	Average Length (m)	Average Width (m)	Average Height (m)
Kīpapa-Nakaʻohu	7.5	4.1	0.5
Mahamenui	8.8	4.2	0.6
Manawainui	10.6	4.8	0.4

Statistically speaking, the survey intensity employed during the 2001 and 2002 field seasons should have been sufficient to reveal all cultural features of "average" dimensions arrayed throughout the landscape, as well as many others that fell below the mean. While the vegetation throughout Mahamenui and Manawainui proved to be extremely dense if not impenetrable in some areas, confidence was high that the survey results had yielded a fairly comprehensive look at the ancient Hawaiian landscape. The question that could not be definitively answered at that time, however, was how successful or accurate were the surveys in terms of site identification?

The 2003 Re-Survey Project

On July 6, 2003 a brush fire began along the Highway 31 corridor that winds its way from Kula to Hāna. Its point of origin was within the Mahamenui *Ahupuaʻa*, but later attempts to control the blaze through "back-firing" resulted in further devastation to the Manawainui *Ahupuaʻa* as well. Fanned by 48 kph winds, the fire rapidly spread westward, consuming over 5,000 acres before it could be contained and extinguished. The DHHL Kuleana homesteads, which lay within the Kīpapa and Nakaʻohu *ahupuaʻa*, fortunately remained untouched, though the diverse vegetation communities that populated the eastern half of the district were largely destroyed (Figure 2).

In October of 2003, just three months after the fire, Kirch and two field assistants visited the area during the course of an unrelated project being conducted in the neighboring district of Kaupō. A brief recon-

Figure 2. Survey area before (left) and after (right) brush fire.

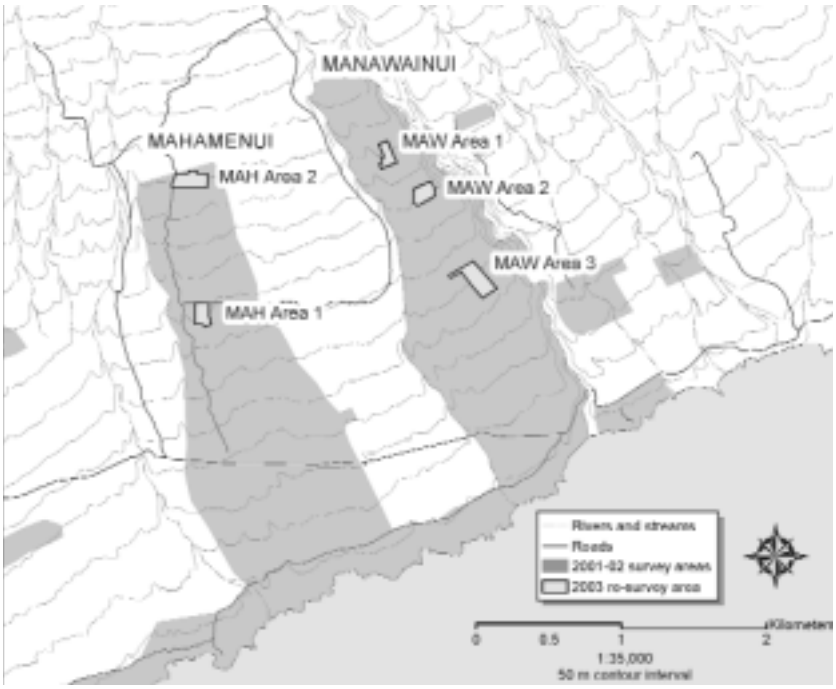


Figure 3. Survey sample areas in Kahikinui.

naissance revealed that the fire had created exceptional conditions of surface visibility throughout the eastern half of the district. Virtually all vegetation had been burned away, and an absence of rain had yet to stimulate significant regrowth. Given this unique opportunity, Kirch devoted two days to the re-survey of five sample areas that had been covered by the surveys conducted in Mahamenui and Manawainui in 2001 and 2002 (Figure 3).

Because time and personnel were limited, Kirch's team adopted a different survey strategy than that employed by Holm. The 2003 crew members did not use standardized field forms, nor did they attempt to re-identify sites that had been previously recorded. Instead, they began anew by recording all cultural features encountered within the chosen sample areas, assigning a unique identifier to each. Free text notes and sketch drawings were made, and feature extents were mapped with a GPS receiver; the raw GPS data were later corrected and imported into a geographic information system. In all, 6 ha were re-surveyed in three distinct areas of Manawainui, and 4 ha were re-recorded in two discrete portions of Mahamenui (Table 2). After evaluating the re-survey data, the Mahamenui sample areas were excluded from any formal attempts to quantify site recovery. One area was subject to less intensive investigation due to the presence of on-site visitors, while the other was found to extend slightly beyond the area of the original 2002 survey. Despite these limitations, the results from the re-survey of the Manawainui sample areas proved revealing.

2003 Re-survey Results

Tables 3 through 5 summarize the 2003 project results for the three areas re-surveyed within Manawainui *Ahupua'a.* They list the unique identifiers assigned during 2003: the length, width, and relative height (in stone courses) of each feature; a brief morphological description; and the identifier they received in 2001 if previously recorded.

Of the nine components or features that were observed within Sample Area 1 in 2003 (Table 3), five (55%) were not detected during the 2001 survey (Figure 4). Four of the components missed were modified outcrops or stone mounds, approximately 2 m or less in diameter, which had roughly a 13 to 50% chance of being detected. One feature not originally noted however was a 11.8 x 7.5 m enclosure with heavily collapsed west and south walls, situated on the western edge of a gully. This was surprising, given that its dimensions should have assured its recovery through the intensive survey strategy employed

Table 2. The surveyed and re-surveyed sample areas of Mahamenui and Manawainui.

Survey Area	Survey Dates	Avg. Surface Visibility	No. Field Personnel	Total Area Surveyed, km²	Total Area Surveyed, ha
Mahamenui					
W. Mahamenui	06/01/02–06/30/02	Poor	4–7	2.65	265.41
Fire Survey Area 1	10/18/03	Excellent	3	0.02	1.5
Fire Survey Area 2	10/18/03	Excellent	3	0.02	2.32
Manawainui					
W. Manawainui	05/28/01–06/26/01	Poor	4–5	2.23	222.92
Fire Survey Area 1	10/19/03	Excellent	3	0.01	1.31
Fire Survey Area 2	10/19/03	Excellent	3	0.02	1.69
Fire Survey Area 3	10/19/03	Excellent	3	0.03	2.93

in 2001; the fact that it was overlooked likely reflects the obscuring effects of dense exotic vegetation. Although all three re-survey areas in Manawainui lay in the upper and most heavily vegetated zone of Kahikinui, precipitation (and hence of ground cover density) were found to increase with elevation. As the uppermost area to be re-surveyed, Sample Area 1 would have been characterized by the poorest surface visibility, and thus it should include the greatest proportion of features missed during the original survey.

The results from Sample Area 2 (see Table 4) proved somewhat more heartening. Of the 17 components and features recorded during the re-survey, only four (23%) had not been identified in 2001 (Figure 5). Two consisted of low one- to two-course terraces, while a third was a slightly more prominent three- to four-course terrace. The fourth structure to go unrecorded, a low one- to two-course semi-circular mound, could easily have been overlooked amidst heavy vegetation or mistaken for natural rock outcrop.

Sample Area 3 was characterized by the greatest site density of all those re-surveyed (see Table 5). Thirty-five components or features were recorded in 2003 within this 2.9 ha area, 23 of which (66%) were not detected in 2001 (Figure 6). That statistic is alarming when taken by itself, until the nature of the newly detected features is considered. One feature

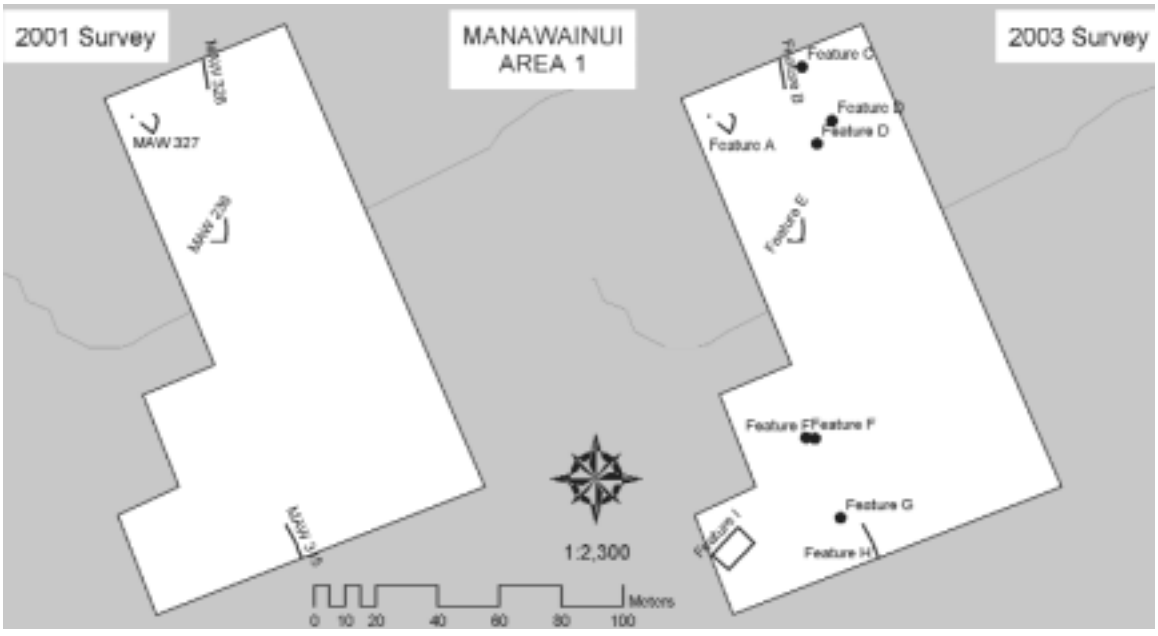


Figure 4. Surface features identified in Manawainui Area 1 during 2001 (left) and 2003 (right) surveys.

Table 3. Features discovered through the re-survey of Manawainui Area 1.

2003 Survey Designation	2001 Survey Designation	Description	Length (m)	Width (m)	Courses (height)	Vegetation Class*	Slope Class**
Feature A	MAW 327	Wall/Shelter Adjoining Terrace	5.16	3.7	2–3	M	1
Feature B	MAW 328	Free-standing Wall	4.4	1.5	2–3	L	2
Feature C	—	Stone Mound	1.7	1.5	2–3	L	2
Feature D	—	Modified Outcrop	2	1.5	1–2	M	1
Feature E	MAW 236	Wall/Shelter Adjoining Terrace	7.2	5.48	1–2	M	3
Feature F	—	Modified Outcrop	1.5	1	2–3	M	2
Feature G	—	Stone Mound	2.25	2	1–2	L	2
Feature H	MAW 315	Free-standing Wall	3.71	—	1–2	L	3
Feature I	—	Enclosure	11.8	7.5	2–3	D	4

* Vegetation Class: L=light; M=medium; D=dense

** Slope Class: 1=5–10°; 2=10–15°; 3=15–20°; 4=20–25°+

was described as a "cleared area" in which surface rubble was notable by its absence; two features were midden or lithic scatters, both described as being "very light"; and eleven components were either low isolated terraces or stone alignments, typically one to two stones in height (0.15 to 0.25 m). Given the small size or low, collapsed nature of many terraces and alignments in Kahikinui, it is not surprising that so many features were missed within a relatively confined area. More disturbing was that two rectangular enclosures, measuring 4 x 3 m and 5 x 3 m respectively, were also missed in 2001; statistically they had a 37% and 47% probability of being detected using a survey transect interval of 10 m and a 100% probability of being detected with an interval of 5 m.

An important point must be noted about the methodology employed in the original survey of 2001 versus that used in the re-survey of 2003. During the original Manawainui survey, features that were found to be contiguous or construed as components within a larger "site complex" were generally given a single designation. Multiple terrace complexes for example were typically composed of 6 to 12 discrete terraces distributed within a confined area; because they were clearly part of a larger whole, however, they were given the same unique identifier. During the 2003 survey, single architectural components or features were frequently given separate designations

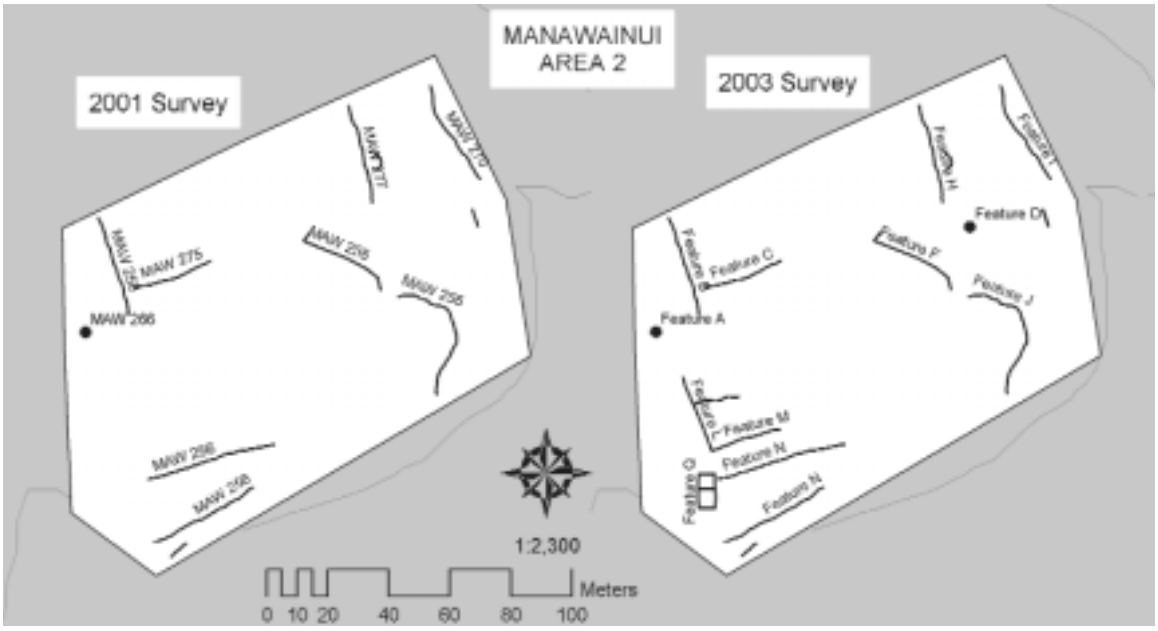


Figure 5. Surface features identified in Manawainui Area 2 during 2001 (left) and 2003 (right) surveys.

Table 4. Features discovered through the re-survey of Manawainui Area 2.

2003 Survey Designation	2001 Survey Designation	Description	Length (m)	Width (m)	Courses (height)	Vegetation Class*	Slope Class**
Feature A	MAW 266	Stone alignment	5.46	1.2	1–2	D	3
Feature B	MAW 258	Stone alignment	—	—	1–2	M	3
Feature C	MAW 275	Stone alignment	22.80	—	2–3	M	2
Feature D	—	Stone Mound	2.50	1.5	1–2	D	2
Feature E	MAW 255	Free-standing Wall	6.85	1.5	2–3	D	4
Feature F-J	MAW 255	Stone alignment	—	—	1–2	M	1
Feature G	MAW 277	Shelter	5.76	1.3	2–4	M–D	3
Feature H	MAW 277	Shelter	—	—	2–3	M–D	3
Feature I	MAW 270	Stone alignment	—	—	1–2	M–D	3
Feature J-F	MAW 255	Free-standing Wall	—	—	2–3	M	1
Feature K-L-M	—	Terrace	—	—	3–4	D	3
Feature L-K-M	—	Terrace	—	—	1–2	D	3
Feature M-K-L	—	Terrace	—	—	1–2	D	2
Feature N-P	MAW 256	Terrace	—	—	1–2	D	2
Feature O	MAW 258	Terrace	—	—	2	D	3
Feature P-N	MAW 256	Terrace	—	—	1–2	D	4
Feature Q	MAW 257	Enclosure	—	—	2–4	M–D	2

* Vegetation Class: L=light; M=medium; D=dense

** Slope Class: 1=5–10°; 2=10–15°; 3=15–20°; 4=20–25°+

even if they were clearly an associated part of a larger site complex, which serves to inflate the total number of components and features missed during the 2001 survey. Taking these methodological differences into account, the percentages of components or features that were missed may be slightly modified. Based on the 2001 survey criteria of feature-grouping, the relative percentage of identification for Sample Area 1 remains the same at 55%; in Sample Area 2, only 2 out of 13 (15%) components or features would not have been detected; and in Sample Area 3, 20 out of 30 (66%) would have remained undiscovered.

Quantifying Recovery

Approximately 52% of the extant surface features recorded in 2003 were not recorded during the original 2001 field season, which highlights just how much may be missed during the careful and intensive pedestrian survey of an archaeological landscape. While the ability to assess the overall success or failure of intensive survey in Manawainui was useful, further measures were required to understand the causes underlying those results. It has long been assumed by many archaeologists that ground cover is the single most critical factor affecting surface visibility and hence site recovery, and certainly the defining difference between field conditions in 2001 and 2003 was the presence of often dense vegetation in the first instance and its virtual absence in the second. To assess and isolate the effects that ground cover may have had upon the original pedestrian survey in Manawainui, several steps were taken.

A series of false-color infrared aerial photographs, covering the central and eastern portions of Kahikinui, was orthorectified by Holm using ERDAS Imagine 8.7 and a series of ground control points collected by GPS receiver. The three areas comprising the 2003 re-survey were closely examined using these orthorectified images to distinguish types of ground cover. Using a supervised classification, four categories were constructed for areas of light (L), medium (M), medium to dense (M–D), and dense (D) vegetation, thus simplifying the original continuous infrared coverage. The GPS maps of features detected during 2003 were overlaid against this ground cover classification, and the ordinal categories into which they fell were noted in the project database. Because the aerial photographs used in this project dated from the early 1990s, there was some concern that ground cover might have changed substantially between their collection date and the time of the 2001 survey. As a precautionary measure, results from the supervised classification were cross-

Table 5. Features discovered through the re-survey of Manawainui Area 3.

2003 Survey Designation	2001 Survey Designation	Description	Length (m)	Width (m)	Courses (height)	Vegetation Class*	Slope Class**
Feature A-B	MAW 296	Enclosure	8.5	6.1	2–4	M	4
Feature B-A	MAW 296	Shelter	—	—	2–4	M	3
Feature C	MAW 295	Shelter	8.1	4.5	2–4	D	2
Feature D	—	Terrace	—	—	2	M–D	5
Feature E	—	Stone Mound	5	—	1–2	D	2
Feature F	Historic Road	Other	—	—	0	L–M	2
Feature G	—	Stone Mound	—	—	1–2	D	2
Feature H	—	Stone Alignment	12	—	1–2	D	1
Feature I	—	Enclosure	4	3	3–4	D	2
Feature J	MAW 92	Enclosure	7	6	2–4	D	1
Feature K	Mauka-makai Wall	Stone Alignment	—	—	1–2	D	2
Feature L-N	—	Shelter	—	—	2–4	D	1
Feature M	—	Stone Mound	1.5	—	1–2	M	2
Feature N-L	—	Terrace	—	—	1–2	D	2
Feature O	MAW 93	Enclosure	—	—	1–2	D	1
Feature P	—	Stone Mound	1.5	1.5	1–2	M–D	2
Feature Q	Mauka-makai Wall	Stone Alignment	28	—	1	M–D	3
Feature R	—	Enclosure	5	3	2–4	D	2
Feature S	—	Stone Mound	1.5	1.5	1–2	M	3
Feature T	—	Terrace	2.5	—	1–3	M	2
Feature U	—	Terrace	6	3	1–3	M	2
Feature V	MAW 90	Terrace	4	2.5	3–4	M	3
Feature W	—	Stone Alignment	—	—	1–2	M	3
Feature X-Y	—	Stone Alignment	—	—	1–2	M–D	3
Feature Y-X	—	Stone Alignment	—	—	1–2	M–D	3
Feature Z	Mauka-makai Wall	Stone Alignment	—	—	1–2	L	3
Feature AA	—	Cleared Area	—	—	0	M	3
Feature AB	—	Midden and/or Lithic Scatter	6.9	5.5	0	L	3
Feature AC-AD	MAW 52	Shelter	4.9	2.2	2–4	M	2
Feature AD-AC	MAW 52	Shelter	5.7	1.4	2–4	M	1
Feature AE-AF	—	Terrace	4.7	2.9	1–2	M–D	1
Feature AF-AE	—	Terrace	7.1	3.7	1–2	M–D	2
Feature AG	—	Midden and/or Lithic Scatter	—	—	0	L	2
Feature AH	—	Terrace	2.5	—	1–2	M	2
Feature AI	—	Shelter	2.6	1.7	2–4	L	2

* Vegetation Class: L=light; M=medium; D=dense

** Slope Class: 1=5–10°; 2=10–15°; 3=15–20°; 4=20–25°+

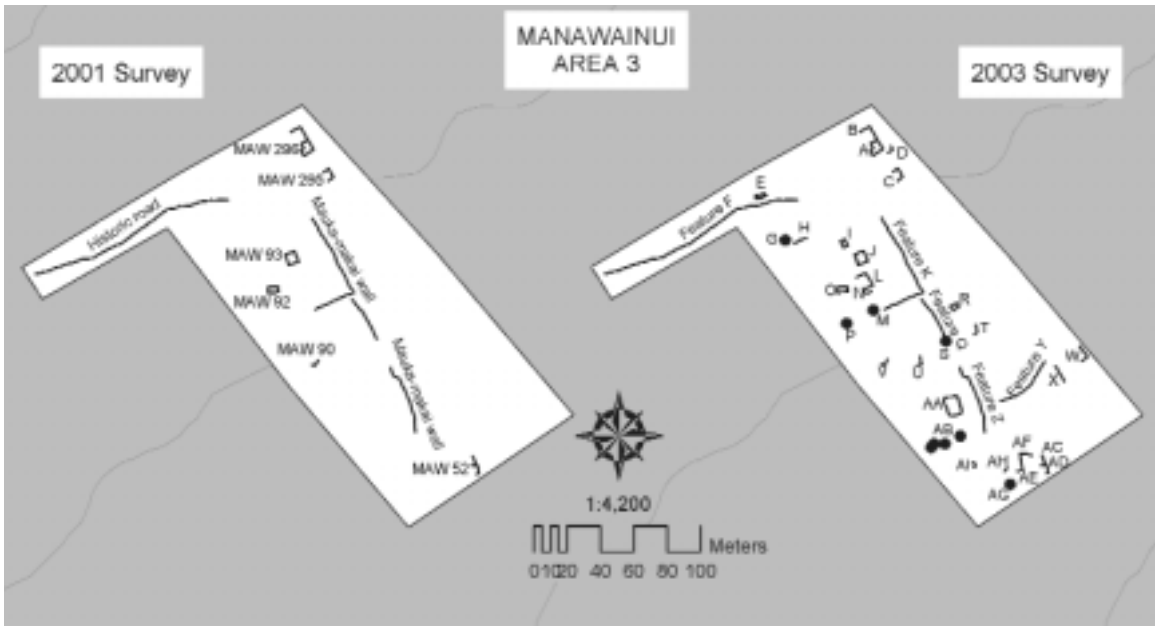
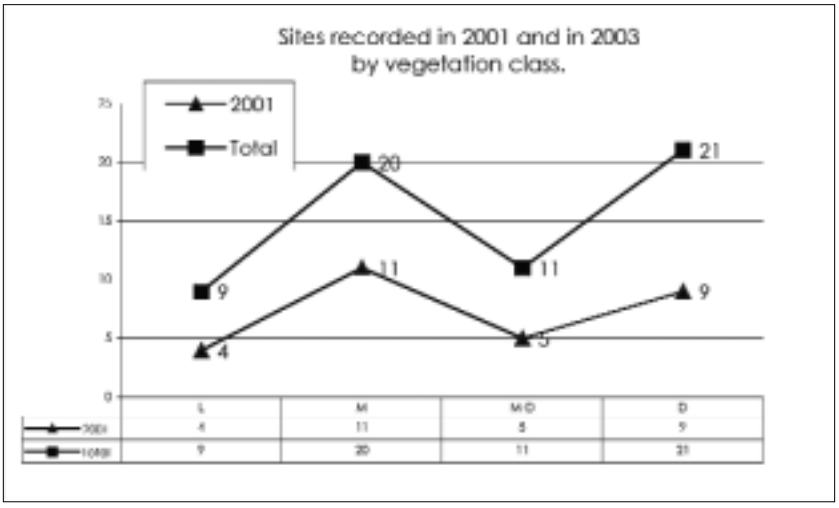


Figure 6. Surface features identified in Manawainui Area 3 during 2001 (left) and 2003 (right) surveys.

checked against the free text descriptions of vegetation and surface visibility that had been recorded for each feature during the 2001 survey; the initial classification was found to be reliable, and so it was used without further refinement.

A simple univariate plot was generated to highlight any obvious differences between site recovery in 2001 and 2003 with respect to ground cover (Figure 7). As anticipated, the greatest proportion of features to go unnoted in 2001 fell into the densest (D) vegetation class, where only nine out of 21 features (43%) had been observed. What was *not* anticipated, however, was that the other vegetation classes would display very similar patterns. Approximately 44% of all features under light (L) vegetation were detected during the original survey, followed by 46% under medium to dense (M–D) vegetation, and 55% under medium (M) vegetation. Though more than half of all features extant within the Manawainui re-survey areas were overlooked during initial survey, it seemed that a representative proportion had nevertheless been discovered within each vegetation class, and that the results obtained in 2001 could *not* be attributed to ground cover density as originally supposed.

Figure 7. Univariate plot contrasting the sites recorded in 2001 and 2003 with respect to vegetation density or ground cover.



After reviewing the types of features that remained unrecorded in 2001, it was hypothesized that site discovery may have been most severely limited not by ground cover but rather by the nature of the features themselves. As was noted earlier, the mean feature size in Kīpapa and Nakaʻohu was about 7.5 by 4.1 x 0.5 m, which yielded an average "radius" of 2.9 m (see Table 1). Given those expected values, the survey intensity in Manawainui was tailored accordingly. What such numbers obscure, however, is that many features within Kahikinui are far from "average"; many are irregularly shaped, are indistinguishable from the surrounding topography, or run parallel to survey transects, thus minimizing their likelihood of detection. For instance, a stone-faced

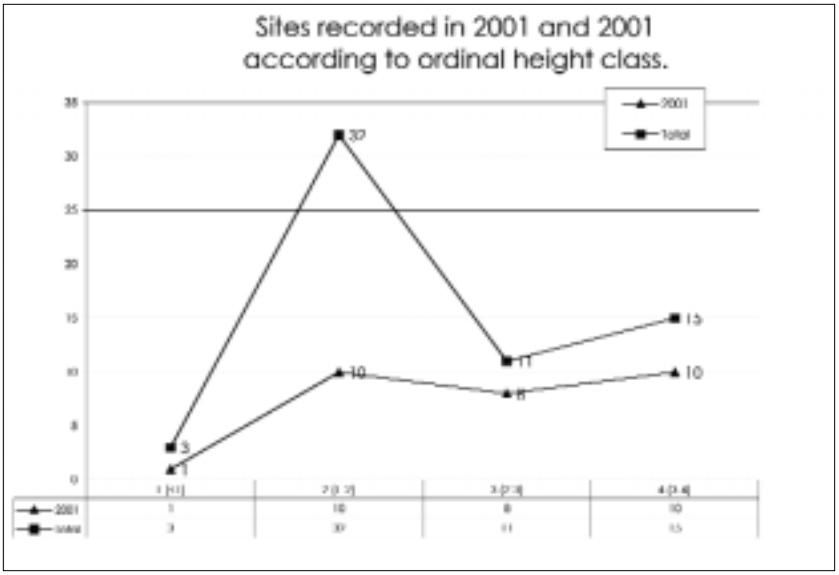


Figure 8. A univariate plot contrasting the sites recorded in 2001 and 2003 with respect to feature height.

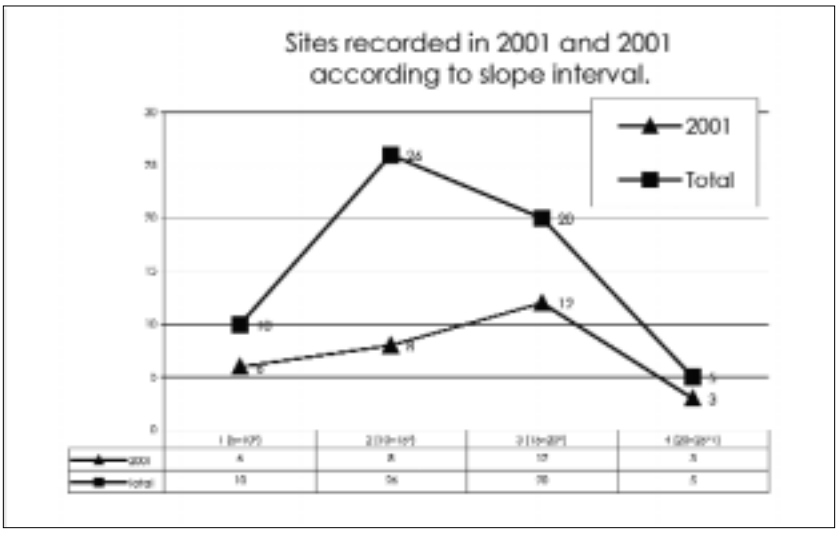


Figure 9. A univariate plot contrasting the sites recorded in 2001 and 2003 with respect to slope interval.

earth-filled terrace may measure 10 x 2 m, but if it consists of only one to two stacked courses, if it blends with the physical terrain, or if it is oriented parallel to the slope, then it may prove difficult to detect under typical field conditions. In retrospect, it was conjectured that the most important spatial characteristic affecting recovery was not overall site size but rather site obtrusiveness or height above the ground surface.

To explore this idea, each feature recorded in 2003 was classified according to an ordinal measure of wall height based upon the number of stacked stone courses used in its construction. Those features that lacked surface architecture such as artifact scatters were grouped as "1," those possessing an average of one to two stone courses were grouped as "2," and so on culminating in a total of four height classes. A ratio scale measure was not used because while absolute feature height was recorded during the original survey, it was seldom noted during the re-survey. As with ground cover, a simple univariate plot was generated for the number of features that fell into each height class to highlight any general trends. Interestingly, 53% of all features noted during the 2003 re-survey were constructed with just one to two stone courses, only 31% of which were recorded in 2001 (Figure 8). Certainly there seemed to be a "case to answer" with respect to feature height and site recovery (Orton 1980), but before attempting any formal analysis, one further variable was examined.

In addition to low feature height, it was conjectured that the ruggedness of the physical terrain itself may have played a direct or indirect role in site recovery. Ideally, in a pedestrian survey using transect intervals of 5 to 10 m, all crew members would be equally spaced at all times. In practice, this is almost never achieved. The physical topography of most regions precludes the ability to survey in a perfectly regular pattern. This is particularly true in Kahikinui, where some areas are characterized by rough unweathered lavas, others are incised with steep river gulches, and many are blanketed by impassable vegetation. It was hypothesized that the surveyors' ability to "stay on transect" would co-vary with the ruggedness of the surface terrain, thereby influencing site recovery. During the 2003 re-survey, this would not have been an issue; because conditions of surface visibility were so ideal, the re-survey was less a matter of maintaining a particular survey intensity or interval and more a matter of simply recording what was so clearly arrayed across the landscape.

Using slope as a proxy measure for topographic variability, each feature recorded in 2003 was placed in one of four classes that were divided into 5° intervals. Once again, a univariate plot of the differences between the 2001 and 2003 surveys was generated (Figure 9), but the results were unexpected. The initial

assumption was that sites would be most readily identified in areas of minimal slope. Under such conditions, transects are easier to maintain, allowing surveyors to concentrate upon observation rather than on the navigability of the terrain. In comparing the relative percentages of features found within each slope class during 2001 and 2003, however, this does not appear to have been the case. The majority of sites were situated upon gentle slopes of 10 to 15°, which also proved to be the class in which the greatest percentage (69%) of sites went unrecorded in 2001. In each other slope class, only 40% of extant sites remained unobserved during the initial survey, so it would seem that the variability of the physical terrain did not affect site discovery in the manner predicted.

Though simple descriptive statistics were informative in identifying general trends in the data, a more thorough exploration of the impacts of ground cover, feature height, and local topography on site recovery was attempted with the aid of logistic regression analysis. Logistic regression is a statistical procedure that can be used to probe the varying strengths of association between a dependent variable and a mixture of nominal, ordinal, interval, or ratio-scale independent variables. It can accommodate tabulated data with more than one subject per case or data in which each case is a discrete subject. One of the key characteristics of logistic regression is that the dependent variable is dichotomous or polytomous, which means that it may be classified in two or more mutually exclusive and exhaustive categories; the number of categories encompassed by the dependent variable dictates whether binomial or multivariate logistic regression is used, though the procedures are essentially the same. The final outcome yields a prediction of the presence or absence of a characteristic or event based on the values of a set of predictor variables.

Within archaeology, binary logistic regression has been widely used in conjunction with site predictive modeling. In such applications, environmental and cultural variables that are found to correlate with the presence or absence of sites are used to explore unsurveyed territories to assess the likelihood that they contain cultural remains (Kohler 1986; Kvamme 1983; Warren 1990a; Westcott and Brandon 2000). The dependent variable in these studies is typically the "land parcel," which is divided into the mutually exclusive categories of "site" or "non-site." In the present study, the dependent variable is not the land parcel but rather the archaeological feature itself, which may fall into the mutually exclusive categories of "recorded" or "not recorded" in 2001; the independent variables comprise each class of ground cover, feature height, and slope. Using the attribute information collected in 2001 and 2003, each feature was categorized according to these independent variables and then incorporated within a forward stepwise binary logistic regression model using SPSS 14.0. The forward stepwise procedure is often used as an exploratory measure; it selects the strongest variables, or those that prove most effective in correctly predicting the values of the dependent variable, until no further significant predictors are available.

The standard formula for logistic regression is:

$$p(B)= \frac{\exp(\alpha + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots \beta_n X_{ni})}{1 + \exp(\alpha + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots \beta_n X_{ni}}$$

In this formula, p(B) is the probability that case *i* is a member of Group β; exp is a function that raises the number exponentially to a parenthetical value *e* (Euler's number). A Y-intercept constant is expressed as α, β_1 is a regression coefficient for variables $X_1 \ldots X_n$ and $X_1 \ldots X_n$ are values of variables $1 \ldots n$ for the *i*th case. Excellent treatments of logistic regression formulas and procedures are available in Warren (1990b) and in Hosmer and Lemeshow (1989).

Applying the model to the present case study, only two variables emerged as powerful predictors of whether or not a site would be recorded during pedestrian survey under typical field conditions. In congruence with the univariate plots, those variables were the second slope class (10 to 15°) and the second height class (one to two stone courses). Interestingly, *none* of the vegetation classes proved to be significant predictors of whether or not a site would be recorded. In evaluating the model's efficiency, it was found to attain an optimum performance at a cut point probability of 0.50. At that cut point, it correctly classified 69% of the sites not recorded in 2001 and 59% of the sites recorded in 2001 with an overall effectiveness of 64%. In other words, based

upon two classes for slope and height, the model correctly predicted whether a site would or would not be found in 39 of 61 cases. Unfortunately, these results did not represent a significant improvement over chance classification.

When conducting a logistic regression analysis, a sample of cases is typically withheld during the model's development, then used to cross-validate the results. Because the number of available cases in this analysis was so limited, the model was originally constructed using all 61 features recorded within the three re-survey areas. In secondary iterations, however, random selections of 21 cases were withheld for testing, and the model was reconstructed using only 40 features. The percentages of correctly classified sites were surprisingly similar, so it seemed unlikely that the forward stepwise procedure was merely recording "noise" in the data; instead the results seemed to reflect actual trends.

While the effectiveness of the logistic regression model was somewhat disappointing, the general trends that it revealed did help to explain why and how certain features may have been missed during the 2001 survey. That feature height was more important than ground cover density in predicting site discovery was initially unexpected, though it has been observed that even "light" vegetation may obscure unobtrusive structures such as one to two course stone terraces, walls, or mounds. Logically, features with no standing architecture should be even harder to locate during pedestrian survey, though the height class "courses <1" was not selected as a strong predictor within the logistic regression model. This was probably because only three such sites were recorded in 2003; two were light artifact scatters, and the third was a historic road or trail that was detected in 2001 through changes in vegetation. Thus the absence of architecture, which should have been a strong predictor, was likely excluded from the model by a single anomalous feature.

It was initially conjectured that low feature height would impede site discovery, and that supposition was supported by the descriptive statistics and the logistic regression model. What was surprising, however was that the 10 to 15° slope class also proved to be a *negative* predictor of feature identification. It was hypothesized that areas of highly variable terrain or extreme slope would hamper survey efforts and lead to a lower incidence of site discovery, though the opposite seemed to be the case. It is possible, though not provable, that this pattern had little to do with the local topography at all and was instead a reflection of the survey interval used.

Along transects with rugged terrain, a narrower survey interval was usually adopted with the expectation that sites would be harder to find and that vegetation would be denser (as was typical in drainages and swales). In areas of low relief, however,surface visibility often was assumed to be sufficient to permit a wider survey interval, and so transects in such areas were often spaced 8–10 m rather than 5 m apart. Thus, while sites characterized by more than two stone courses were observed, lower ones featuring fewer courses were typically missed unless the surveyors literally stumbled across them. The fluid nature of the survey interval may also explain why vegetation density apparently had so little impact on site recovery. In areas of extremely dense ground coverage, transects were deliberately tightened to compensate for poor visibility, and so less was ultimately overlooked. In areas of sparser or lower vegetation, transects were loosened, and so a greater number of unobtrusive sites went unrecorded. Unfortunately, these conclusions cannot be absolutely confirmed, though they do offer feasible explanations of why certain site types were missed in specific areas.

Discussion

This study has explored the relationships between surface visibility (as a function of vegetation cover), site obtrusiveness, topography, and site recovery. Archaeologists have long relied upon "intensive" survey to provide a comprehensive view of the range of cultural features contained within a given region, but findings indicate that any blanket claims to comprehensiveness must be treated with some skepticism. Exceptional circumstances allowed for the comparison of two surveys in a single area under typical conditions versus conditions of exceptional surface visibility. Rather than relying on hypothetical or statistically anticipated results, those sites that had been recorded could be contrasted against those that might have been recorded under ideal field condi-

tions. Though the circumstances underlying this effort are not likely to arise again in the near future, there is clearly a need for further case studies that explore the limitations of one of archaeology's most pervasive methodologies. Because each archaeological project is unique, context-dependent, and affected to a greater or lesser extent by a number of factors, no single case study can provide a definitive index of potential effects upon site identification; the greater the amount of data at our disposal, however, the more informed our strategies may be.

While there remains no simple means of "correcting" for vegetation cover, low site visibility, or topographic variability, a heightened awareness of the biases introduced by such factors may lead to further attempts to monitor or quantify the problem, and to more sophisticated interpretations about the data that are recovered. Initially, dense ground cover was assumed to be the greatest impediment to site discovery, and survey efforts were adjusted accordingly. A sense of optimism about visibility in other areas was found to be unjustified, however, and many unobtrusive sites remained undiscovered as a consequence. Armed with a heightened awareness of these limitations, future survey efforts in Kahikinui may be altered, and initial conclusions about settlement distribution and density may be modified in light of the types and numbers of sites that were overlooked. For instance, low one- to two-course earth-filled terraces, small stone mounds, and modified rock outcrops were common, but because they were extremely difficult to detect, they were the most likely site types to go unrecorded. Within Kahikinui, such sites are typically associated with dryland cultivation, and so any early suppositions about agricultural activity or intensification must be questioned.

Though the findings in this study were somewhat unexpected, there is little reason to suppose that they would be atypical of other inventory surveys conducted under like conditions. The question remains, what might be done to heighten the effectiveness or mitigate the failings of pedestrian survey? Many projects are already timed to take advantage of seasonal differences in ground cover, which is a positive step towards enhancing site recovery. Additional measures may also be taken, however, such as selectively re-surveying sample areas using a very narrow survey interval of 5 m or less. Conducting sample re-surveys using a different transect orientation might also be constructive, particularly in those areas marked by rugged terrain or dense vegetation. Details regarding local impacts upon site identification might be also be made more explicit in archaeological survey reports, so that those who depend upon the results (researchers, agency officials, planners, developers, etc.) may be fully apprised that what was detected is not necessarily all that is present. Finally, in the course of reporting survey results, it would be informative to note the region-specific types of features that are most likely to go undiscovered. Making such anticipated shortcomings as unambiguous as possible should allow for a more informed approach to planning, monitoring, and interpretation. Ultimately, it must be acknowledged that even "intensive" archaeological surveys will recover only a fraction of what once existed in the distant past and what remains within the modern landscape.

Acknowledgements

Permission to carry out archaeological research in Kahikinui was provided by the Department of Hawaiian Home Lands. Financial support for work in Manawainui was provided by the George Franklin Dales Memorial Scholarship, the Stahl Endowment of the U.C. Berkeley Archaeological Research Facility, the Lowie-Olsen Fund of the Department of Anthropology, U.C. Berkeley; and National Science Foundation Grant BCS-0119819. We thank the undergraduate and graduate students who assisted with the fieldwork undertaken in 2001–02, John Holson and James Coil who assisted during the 2003 re-survey, and David Purdy of the U. C. Berkeley Department of Statistics for his advice regarding the logistic regression procedures used in this paper. A heartfelt *mahalo nui loa* is extended to Ka 'Ohana o Kahikinui for their friendship, support, and *kokua*. Finally, we are indebted to Mike Carson and two anonymous reviewers for providing constructive critiques on an earlier draft of this paper.

References Cited

Ammerman, A. J. 1981. Surveys and Archaeological Research. *Annual Review of Anthropology* 10:63–88.

Coil, J. 2004. "The Beauty that Was": Archaeological Investigations of Ancient Hawaiian Agriculture and Environmental Change in Kahikinui, Maui, Hawaiian Islands. Ph.D. Dissertation, University of California, Berkeley.

Dixon, B., P. J. Conte, V. Nagahara, and W. K. Hodgins 1997. Upland Forest Periphery Subsistence and Settlement in the *Ahupua'a* of Kipapa, Nakaohu, and Nahaaha: A Preliminary Assessment. In *Na Mea Kahiko O Kahikinui: Studies in the Archaeology of Kahikinui, Maui*, edited by P. V. Kirch, pp. 28–44. Oceanic Archaeology Laboratory, Special Publication No. 1. Archaeological Research Facility, University of California, Berkeley.

Dunnell, R. C., and W. S. Dancey. 1983. The Siteless Survey: A Regional Scale Data Collection Strategy. In *Advances in Archaeological Method and Theory, Volume 6*, edited by M. Schiffer, pp. 267–287. Academic Press, New York.

Giambelluca, T. and T. Schroeder. 1998. Climate. In *Atlas of Hawai'i*, edited by S. Juvik and J. Juvik, pp. 49–59. Third edition. University of Hawai'i Press, Honolulu.

Holm, L. 2006. The *'Āina* and the Archaeology of Mahamenui and Manawainui, Kahikinui, Maui Island. Ph.D. Dissertation, University of California, Berkeley.

Hosmer, D., and S. Lemeshow. 1989. *Applied Logistic Regression.* Wiley and Sons, New York.

Kirch, P., A. Hartshorn, O. Chadwick, P. Vitousek, D. Sherrod, J. Coil, L. Holm, and W. Sharp. 2004. Environment, Agriculture, and Settlement Patterns in a Marginal Polynesian Landscape. *Proceedings of the National Academy of Sciences* 101:9936–9941.

Kirch, P. V. 1997a. The Cultural Landscape of Kipapa and Nakaohu *Ahupua'a*: A Preliminary Report on an Intensive Archaeological Survey. In *Na Mea Kahiko O Kahikinui: Studies in the Archaeology of Kahikinui, Maui*, edited by P. V. Kirch, pp. 12–27. Oceanic Archaeology Laboratory, Special Publication No. 1. Archaeological Research Facility, University of California, Berkeley.

Kirch, P. V. 1997b. Kahikinui: Introduction. In *Na Mea Kahiko O Kahikinui: Studies in the Archaeology of Kahikinui, Maui*, edited by P. V. Kirch, pp. 1–11. Oceanic Archaeology Laboratory, Special Publication No. 1. Archaeological Research Facility, University of California, Berkeley.

Kirch, P. V., and C. Van Gilder. 1996. Pre-contact and Early Historic Cultural Landscapes in Kahikinui District, Maui: A Progress Report. *Hawaiian Archaeology* 5:38–52.

Kohler, T. A., and S. C. Parker. 1986. Predictive Models for Archaeological Resource Location. In *Advances in Archaeological Method and Theory, Volume 9*, edited by M. B. Schiffer, pp. 397–451. Academic Press, New York.

Kolb, M. J., and E. C. Radewagen. 1997. Na Heiau o Kahikinui: The Temples of Kahikinui. In *Na Mea Kahiko O Kahikinui: Studies in the Archaeology of Kahikinui, Maui*, edited by P. V. Kirch, pp. 61–77. Oceanic Archaeology Laboratory, Special Publication No. 1. Archaeological Research Facility, University of California, Berkeley.

Krakker, J. J., M. J. Shott, and P. D. Welch. 1983. Design and Evaluation of Shovel-Test Sampling in Regional Archaeological Survey. *Journal of Field Archaeology* 10:469–480.

Kvamme, K. L. 1983. *A Manual for Predicting Site Location Models: Examples from the Grand Junction District, Colorado.* Report submitted to the Bureau of Land Management.

Lewarch, D. E., and M. J. O'Brien. 1981. The Expanding Role of Surface Assemblages in Archaeological Research. *Advances in Archaeological Method and Theory, Volume 4*, edited BY M. B. Schiffer, pp. 297–342. Academic Press, NewYork.

Lightfoot, K. G. 1986. Regional Surveys in the Eastern United States: The Strengths and Weaknesses of Implementing Subsurface Testing Programs. *American Antiquity* 51:484–504.

———. 1989. A Defense of Shovel-Test Sampling: A Reply to Shott. *American Antiquity* 54:413–416.

Macdonald, G. A., A. T. Abbott, and F. L. Peterson. 1983. *Volcanoes in the Sea: The Geology of Hawaii*. Second edition. University of Hawai'i Press, Honolulu.

Nagahara, V., W. K. Hodgins, and P. J. Conte. 2000. *Appendix A: Kahikinui Makai: Archaeological Inventory Survey of a Portion of the Kahikinui Coastline, Island of Maui*. Department of Hawaiian Homelands, Honolulu.

Nance, J. D., and B. F. Ball. 1986. No Surprises? The Reliability and Validity of Test Pit Sampling. *American Antiquity* 51:457–483.

———. 1989. A Shot in the Dark: Shott's Comments on Nance and Ball. *American Antiquity* 54:405–412.

Orton, C. 1980. *Mathematics in Archaeology*. Cambridge University Press, Cambridge.

Plog, S., F. Plog, and W. Wait. 1978. Decision Making in Modern Surveys. In *Advances in Archaeological Method and Theory, Volume 1*,edited by M. B. Schiffer, pp. 383–421. Academic Press, New York.

Schiffer, M. B., A. P. Sullivan, and T. C. Klinger. 1978. The Design of Archaeological Surveys. *World Archaeology* 10:1–28.

Shott, M. J. 1989. Shovel-Test Sampling in Archaeological Survey: Comments on Nance and Ball, and Lightfoot. *American Antiquity* 54:396–404.

Stearns, H. T. 1985. *Geology of the State of Hawaii*. Second edition. Pacific Books, Palo Alto.

Sterling, E. P. 1998. *Sites of Maui*. Bishop Museum Press, Honolulu.

Stock, J., J. Coil, and P. Kirch. 2003. Paleohydrology of Arid Southeastern Maui, Hawaiian Islands, and Its Implications for Prehistoric Human Settlement. *Quarternary Research* 59:12–24.

Terrenato, N., and A. J. Ammerman. 1996. Visibility and Site Recovery in the Cecina Valley, Survey, Italy. *Journal of Field Archaeology* 23:91–109.

Thoms, A. V. 1979. Survey Error: A Result of Intensive Archaeological Surveys. In *Scholars as Contractors*, edited by W. J. Mayer-Oakes and A. W. Portnoy, pp. 95–105. U.S. Department of the Interior, Heritage Conservation and Recreation Service, Interagency Archaeological Services Division, Washington D.C.

Van Gilder, C. V., and P. V. Kirch. 1997. Household Archaeology in Kipapa and Nakaohu, Kahikinui. In *Na Mea Kahiko O Kahikinui: Studies in the Archaeology of Kahikinui, Maui*, edited by P. V. Kirch, pp. 45–60. Oceanic Archaeology Laboratory, Special Publication No. 1. Archaeological Research Facility, University of California, Berkeley.

Vituousek, P., T. Ladefoged, P. Kirch, A. Hartshorn, M. Graves, S. Hotchkiss, S. Tuljapurkar, and O. Chadwick. 2004. Soils, Agriculture, and Society in Precontact Hawai'i. *Science* 304:1665–1669.

Walker, W. n.d. Archaeology of Maui. Unpublished manuscript on file. Department of Anthropology, Bernice P. Bishop Museum, Honolulu.

Wandsnider, L., and E. Camilli. 1992. The Character of Surface Archaeological Deposits and Its Influence on Survey Accuracy. *Journal of Field Archaeology* 19:169–188.

Warren, R. E. 1990a. Predictive Modelling of Archaeological Site Location: A Case Study in the Midwest. In *Interpreting Space: GIS and Archaeology*, edited by K. M. S. Allen, S. W. Green, and E. B. W. Zubrow, pp. 201–215. Taylor and Francis, London.

Warren, R. E. 1990b. Predictive Modelling in Archaeology: A Primer. In *Interpreting Space: GIS and Archaeology*, edited by K. M. S. Allen, S. W. Green, and E. B. W. Zubrow, pp. 90–111. Taylor and Francis, London.

Weisler, M. and P. V. Kirch. 1985. The Structure of Settlement Space in a Polynesian Chiefdom: Kawela, Moloka'i. *New Zealand Journal of Archaeology* 7:129–158.

Wescott, K. L,. and R. J. Brandon (editors). 2000. *Practical Applications of GIS for Archaeologists: A Predictive Modeling Toolkit*. Taylor and Francis, Philadelphia.

Book Review

Lilley, Ian (editor). 2006. *Archaeology of Oceania: Australia and the Pacific Islands.* Blackwell Studies in Global Archaeology. Blackwell Publishing, Oxford.

Review by Mike T. Carson

At nearly 400 pages, *Archaeology of Oceania* presents 18 dense chapters focusing on modern archaeological theories and politics in the Pacific region. The self-stated goal is to introduce readers "to the diversity of current approaches to the intellectual challenges of archaeology in Australia and the Pacific Islands," with five overlapping themes: 1) colonization; 2) interaction; 3) cultural diversification; 4) environmental change; and 5) contemporary politics.

This ambitious volume's editor, Ian Lilley, provides an introduction that is respectable for its academic accuracy and thoughtfulness yet also accessible to a wide range of readers. The book's goals are clearly set, drawing attention to Australia as a sometimes under-appreciated part of the large and diverse Pacific region in terms of archaeological discourse. As the editor acknowledges in the introduction, the large geographic scope necessitates omissions when compiling chapters that focus only on specific localities.

Following the introduction, this volume is structured in three main parts: 1) Australia; 2) the Pacific; and 3) politics. The balance includes five chapters for Australia, nine for the Pacific, and three for politics. Sadly, the editor offers no further printed contribution beyond his introduction, and no conclusion is available.

The Australian contributions, along with sections of the introductory chapter, comprise a strong baseline education about Australian archaeology today. Fundamental issues of chronology and site contents are addressed adequately, and readers are equipped with information and references to learn more about spatial distribution, functional variation, and other substantive issues. These chapters also contribute toward modern understanding of ontology, social identity, and other intellectual notions.

The Pacific contributions offer updated studies from a sample of locations. Several other chapters would be needed for a full representation of current archaeological work in the Pacific, but the given sample constitutes a fair overview survey. Some of these chapters may appear so narrowly focused as to be of little interest to those working outside that particular area, but in fact the topics and approaches are applicable in a variety of situations. In this regard, probably of most impact will be chapters concerning early agriculture in the New Guinea highlands, an alternative perspective on the Lapita cultural complex, and a model of territory formation in the Hawaiian Islands.

The three contributions in the "politics" section differ greatly from one another, as is typical of politics in almost any arena. The first chapter remarks on the role of archaeology in the history of politics in New Caledonia. The second offers an example of colonial powers and ideology commandeering heritage management in Fiji. The last chapter offers revealing perspectives from three indigenous people in the Pacific involved in archaeology in their home regions.

Curiously, this book does not include a conclusion that could have revisited and assessed the self-stated goal and five overlapping themes noted in the introduction. Instead, the three indigenous archaeologists' perspectives are highlighted as the "last words" of the volume.

Regarding one of the primary goals of the "Blackwell Studies in Global Archaeology" series to provide material accessible to a wide readership yet without sacrificing theoretical sophistication, the present volume achieves uneven success. A supplementary text (or set of texts) would be necessary for students to learn fundamental baseline archaeological information about Australia and the Pacific, or else the more intellectual pursuits would wander without substantive basis. In some cases, actual data could argue against the models and interpretations proposed by some of the authors, but such cases are open for debate.

As a compilation of both Australian and Pacific chapters, this volume achieves mediocre success. For those working primarily in the Pacific, the Australian chapters are a useful beginning toward understanding and appreciating archaeological knowledge in Australia and how it relates to the Pacific. For those working primarily in Australia, the Pacific chapters probably are of little interest, and they represent only a very small sample of current archaeological investigations in the region. In both cases, caution is advised to appreciate the noteworthy contributions but meanwhile to avoid temptation of accepting the contributions as complete.

This book is somewhat disappointing in regards to its five overlapping themes of 1) colonization, 2) interaction, 3) cultural diversification, 4) environmental change, and 5) contemporary politics. When compiling chapters from multiple authors, naturally not all topics will be addressed thoroughly. The manner in which each chapter contributes toward one or another theme is unclear, despite the noble efforts in the editor's introductory chapter. Most readers probably will not learn much about any of these themes in depth.

For students learning about archaeology in Oceania, this book is useful to highlight contemporary topics. However, students will need to look elsewhere to learn basic archaeological data of the region. Sadly, publication of primary data has been increasingly difficult in deference to theoretical and cognitive pursuits, but ample substantive data can yet be found.

For professional archaeologists already working in Oceania, this book offers the convenience of a range of chapters roughly equivalent to what could be assembled from various regional journal volumes. By including contributions from such a vast region, this book exposes some readers to information and ideas that they otherwise would be unlikely to encounter.

Editorial and subscription notices

Hawaiian Archaeology, founded in 1984, is published by the Society for Hawaiian Archaeology, a registered tax-exempt organization.

Address

Hawaiian Archaeology, Society for Hawaiian Archaeology, P. O. Box 23292, Honolulu, Hawai'i 96823-3292 is the address for all matters relating to the Society and to *Hawaiian Archaeology*.

Current subscriptions

Hawaiian Archaeology is published annually and distributed to members of the Society for Hawaiian Archaeology. Current dues are:

Institutional/Family—$35
Regular—$30
Student—$15
Lifetime—$500

Membership applications are available from the Corresponding Secretary of the Society for Hawaiian Archaeology.

Notes for contributors

Articles on Hawaiian prehistory or archaeology, or that contribute to the advance of method and theory as these apply to Hawai'i, are considered for publication in *Hawaiian Archaeology*. Submissions are preferred in electronic form accompanied by illustrations in Tagged Image File Format (TIFF) or Encapsulated PostScript (EPS). Detailed submission guidelines are posted on the Society's website. Preferred style is as you find it in this number, and generally follows *The Chicago Manual of Style*, 15th Edition, for scientific and technical publications using the short (B) form for bibliographic citations.

Conventions for radiocarbon dates

In citing radiocarbon dates, *Hawaiian Archaeology* uses the following conventions: B.P. (before 1950); CRA (conventional radiocarbon age) indicates a radiocarbon age that (i) uses 5568 as the ^{14}C half-life, (ii) was measured against the NBS oxalic acid standard, (iii) uses 1950 as the zero date for radiocarbon time, (iv) is normalized for $\partial^{13}C$, and (v) has not been corrected for reservoir effects; B.C./A.D. indicates a measurement that has been calibrated to calendar years.

Cover Image

An Offering Before Captain Cook, in the Sandwich Islands, 1779. Engraving by John Hall (figures) and Samuel Middiman (landscape) after a drawing by John Webber. Courtesy of Barbara Pope.