

# *Environmental Change and Prehistoric Polynesian Settlement in Hawai'i*



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IT HAS NOW BEEN A LITTLE MORE than a decade since Patrick Kirch (1982a) summarized the available and rather uneven evidence for environmental change in Hawai'i, compiling information from both archaeological and natural history sources. The actual data, which from today's perspective were quite limited, concerned various aspects of the native flora and fauna of Hawai'i in addition to aspects of geomorphological alteration of the Hawaiian landscape. Taken together, these data suggested to Kirch that the prehistoric Polynesian colonizers of Hawai'i had (Kirch 1982a:1) "a far greater impact on the Hawaiian ecosystem than has heretofore been realized." According to Kirch's thesis, the use of fire, primarily for agricultural clearing, was a major factor in the Polynesian transformation of the Hawaiian environment. This view contrasted with the then-prevalent notion that it was only after Western contact that massive environmental degradation occurred. The causes included the introduction of hoofed mammals for ranching, plantation agriculture, and the proliferation of introduced plant and animal species that often had no competitors and flourished at the expense of the local biota.

Although Kirch's article paved the way for establishing a productive domain of research relating to an understanding of Polynesian adaptations to their island environment in Hawai'i, until recently there have been few in-depth or focused studies. Investigations that go beyond simple generalizations based on limited or uneven data and anecdotal accounts or programs of intensive field and laboratory research followed by quantifiable and replicable presentations of the data are rare. Of course, there are several notable exceptions, especially the work of the avian paleontologists Storrs Olson and Helen James (James and Olson 1991; Olson and James 1982, 1984, 1991). During the past decade, largely as a result of their investigations, 35 fossil species have been formally added (a number of others are pending) to the historically known 40 (lumping) to 55 (splitting) endemic bird species identified for the Hawaiian Islands (James and Olson 1991:82). As James and Olson (1991:82) observed,

... the chronological data linking rapid disappearance of a major portion of the Hawaiian avifauna with prehistoric human settlement is convincing. Factors that

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probably played a role in avian extinctions are habitat destruction, particularly of lowland forests, predation by humans and introduced mammals, and possibly unidentified introduced diseases ([citing] Olson and James 1982, 1984, 1991).

Another exception is the work of Christensen and Kirch (1986) concerning terrestrial gastropods, and there also have been several smaller or more limited studies.

During the past two years, we have begun a determined effort to clarify several issues or aspects of prehistoric environmental change in Hawai'i that concern vegetation change and lowland infilling and coastal progradation. Although the meaning of vegetation change is obvious, the implications of lowland infilling and coastal progradation may be less so. Here we are referring to the notion that inland expansion of Polynesian settlement and agriculture from the coastal areas in Hawai'i, presumably a result of population growth, led to vegetation removal and destabilization of the soils. The soils in turn were transported downslope through erosional processes and deposited at the mouths of valleys, eventually forming alluvial fans and/or filling low-lying areas and prograding the coastline (see Spriggs 1985, 1986). The logical extension of this perspective is that rather than degrading their habitat, the ancient Hawaiians actually *enhanced* it by causing the expansion of the land area suitable for large-scale intensive pondfield agriculture for taro, the main staple of the Hawaiian diet (see Cuddihy and Stone 1990:26; Kirch 1982a:1 citing Kelly 1975; Spriggs 1985:424-425).

In terms of an interpretive perspective, there are currently two primary points of view regarding prehistoric environmental change in the Pacific. The first is that it is either entirely or mostly a response to Polynesian impacts, directly or indirectly, to the fragile island ecosystems that had evolved entirely in the absence of humans. Kirch's (1982a) article concerning environmental change in Hawai'i falls most clearly into this framework. The other view is that environmental change has relatively little to do with prehistoric Islanders and represents on-going processes in the natural environment as presented in the work of Nunn (1991). The data we have collected in Hawai'i regarding vegetation and geomorphological change are directly pertinent to a consideration of this issue—that is, whether human or natural causes have been paramount with respect to prehistoric environmental change in Hawai'i. As will be seen, the answer depends mostly on what aspect of the environment is under consideration, for example, whether biological systems or the physical landscape are involved.

The significance of the study of the Hawaiian natural environment and the changes that occurred with the advent of the Polynesians is perhaps most aptly expressed by Kirch (1982a:11):

For the prehistorian, the evolutionary development of Hawaiian culture must be viewed in the context of a changing environment that continued to place selection pressures upon the human population and its adaptive strategies—pressures in large part due to the actions of humans themselves.

Although we are uncomfortable with the last phrase—just how much environmental change can be attributed to human actions and its significance for Hawaiian adaptations are open questions. It is clear that an understanding of the selective pressures to which the prehistoric Hawaiians were responding requires a precise understanding of the natural environment and the changes that occurred through time.

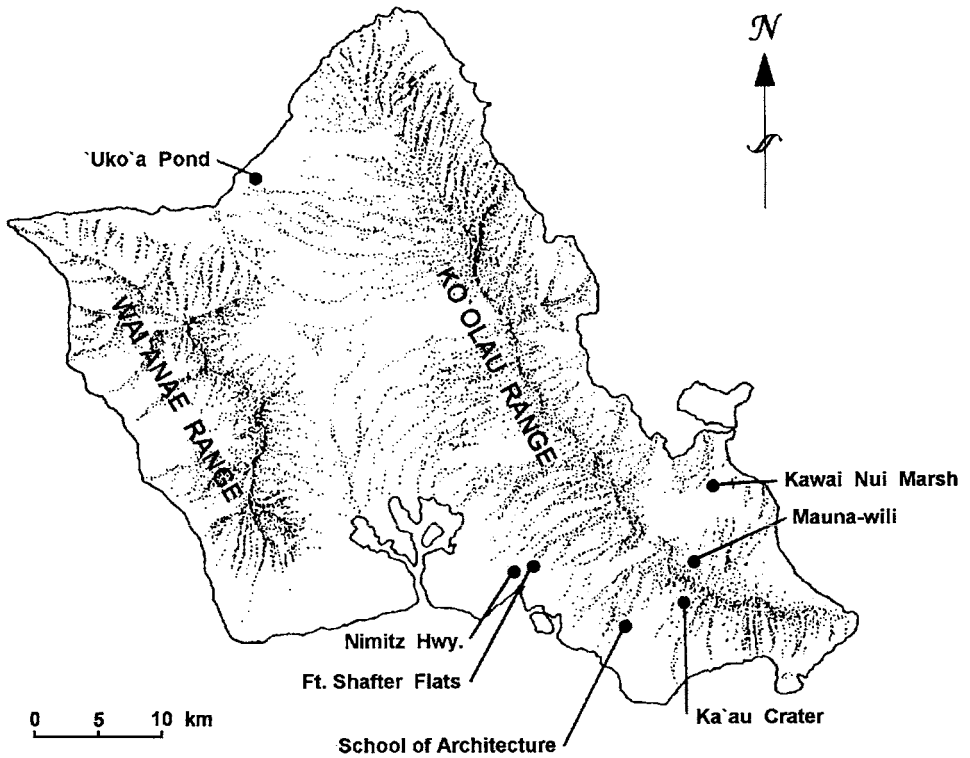


Fig. 1. Map of O'ahu showing sampling locations mentioned in text.

#### SCOPE OF THE PRESENT STUDY

Our investigations concern only the island of O'ahu in Hawai'i, where the bulk of our research has been concentrated (Fig. 1). O'ahu has a total land area of 1574 km<sup>2</sup> (608 sq. miles). Peaks in its parallel mountain chains reach 1225 and 960 m. The climate is tropical, though there are dramatic regional differences caused by variations in physiography, elevation, and rainfall patterns around the island. Rainfall is largely controlled by the orographic effect on moist northeast trade winds, which vary seasonally. There is more rain with slightly cooler temperatures in the winter months.

The Hawaiian Islands all represent the tops of volcanoes that have emerged from a hot spot on the sea floor in the middle of the Pacific Ocean. Geologically, O'ahu is one of the oldest and most dissected of the eight principal Hawaiian Islands, having formed some 2.2 and 3.4 million years ago (Stearns 1978:7). Volcanic activity during the present century, however, has been limited to Hawai'i Island. On O'ahu the last eruption appears to have occurred some 6000 to 12,000 years ago (Macdonald and Abbott 1970:369; and research in progress by Athens). Tectonically, O'ahu has been quite stable during the Holocene (Macdonald and Abbott 1970:211-212). In general, most of the island of O'ahu except the higher elevations of the interior presented quite favorable conditions for Polynesian settlement and agriculture.

Our studies rely on obtaining well-dated sediment sequences from cores and side walls of trenches from coastal wetlands, former wetlands, and former embayments and estuaries. These areas hold and trap naturally eroding sediments from the island surface, effectively providing repositories of environmental information for the length of time that sediment has accumulated. We have also investigated several interior and higher-elevation areas on O'ahu, which provide a different kind of record and an interesting contrast to the lowland data. Thus far, however, such interior records have provided only sequences of rather limited temporal depth, or have sequences that are so early as to be only marginally relevant for archaeological considerations.

As we have come to realize, the record of lowland and coastal infilling on O'ahu is often quite lengthy and may encompass much of the Holocene. Because the Polynesian settlement of Hawai'i dates from perhaps only 1600 to 1700 years B.P. (Kirch 1985:87), or at most a few centuries earlier (Hunt and Holsen 1991:158),<sup>1</sup> the lowland sediments, at least in theory, should be ideally suited for investigating environmental change during the period of prehistoric Polynesian settlement. The sediments also permit evaluation of the environmental record *before* Polynesian settlement. Thus, unlike many strictly archaeological investigations, the study of the lowland sedimentary record is likely to involve a consideration of conditions antecedent to the arrival of the Polynesians in Hawai'i, enabling the determination of whether changes observed during the period of Polynesian occupation might in fact be part of a larger picture of natural and on-going environmental change. This is a critical point, and one that has been inexplicably overlooked by many environmentally oriented archaeologists.

Fieldwork was most commonly performed with a modified Livingstone piston corer, which is a hand-driven instrument designed for recovery of undisturbed and unmixed sediment samples in wetland and lacustrine areas where the sediments are relatively soft (Pls. I and II; see discussion on coring techniques and instruments in Wright 1967, and Wright et al. 1965 and 1984). To date we have obtained significant data encompassing both the pre-Polynesian and Polynesian periods from four lowland locations on O'ahu. These include Kawai Nui Marsh near Kailua, the Fort Shafter Flats area in Honolulu, 'Uko'a Pond near Hale'iwa, and Nimitz Highway near Moanalua Stream in Honolulu. These samples represent three widely spaced locations and environmental situations around the island; only the Ft. Shafter Flats and Nimitz Highway sites are in relatively close proximity to one another. In addition, we have an excellent core record from a small interior marsh on windward O'ahu (above Kawai Nui Marsh). This unnamed marsh, from upper Maunawili Valley, is at an elevation of 158 m. The record appears to encompass all but the earliest period of prehistoric Polynesian settlement. Also, we have a lengthy late Pleistocene core from Ka'au Crater, an upland site just below the Ko'olau Mountain ridge line on the leeward side above Honolulu. Finally, we have a middle to early Holocene sediment record from a large construction trench in lower Mānoa Valley in east Honolulu (see Fig. 1 for locations). In addition, fieldwork for several other coring projects is in the process of being completed or is planned.

The analyses of the cores and excavation units have focused on three main aspects: sediment description and interpretation, identification of pollen and other micro- and macrofossils, and chronology, especially in terms of radiometric dating. At this time, we have completed analyses on only the Kawai Nui, Fort Shafter



Pl. I. Coring in progress at 'Uko'a Pond.



Pl. II. 'Uko'a Pond core sample showing transition from Layer XIII peat (left side) to Layer XIVa terrestrial sediments. The peat was radiocarbon dated to 7400 years B.P.

flats, and Maunawili materials. The 'Uko'a Pond sediments have been described and dated, but the pollen, diatom, and other microfossil evidence are only partially analyzed. The Nimitz Highway core, the Ka'au Crater core, and the Mānoa Valley trench record are all recent additions to our data base and much of the analysis is still ongoing for these, though radiocarbon dating results have been obtained for Ka'au Crater. The following discussion provides a brief synopsis of our

findings with regard to vegetation change and coastal infilling and progradation on O'ahu. Detailed discussions of the separate projects and data may be found elsewhere (Athens and Ward 1991; Athens et al. 1992, n.d.; Wickler et al. 1991; and forthcoming reports on the 'Uko'a Pond, Nimitz Highway, Mauna-wili, Mānoa, and Ka'au Crater projects).

#### THE CHRONOLOGICAL RECORD<sup>2</sup>

The Kawai Nui Marsh core (core B) provides a continuous sedimentary record from approximately 1200 B.C. to A.D. 1565 (six radiocarbon dates; actual dates along the core are interpolated ages based on sedimentation rates derived from the midpoints of calibrated radiocarbon date ranges—see Athens et al. n.d.). In addition there is a single test excavation unit at the edge of the marsh with a radiocarbon-dated peat layer. The Fort Shafter Flats sedimentary record provides continuous coverage from about 1200 to 200 B.C., after which the record appears to have a gap until about A.D. 1300. It continues, possibly with slight interruptions, until late in the Polynesian period or possibly the early historic period (no firm upper date was obtained; the chronology is based on eight radiocarbon dates). At 'Uko'a Pond the record begins at approximately 5400 B.C. and lasts until about A.D. 1820 (based on six radiocarbon dates). For this core we can only be certain that the sedimentary record is continuous after about 244 B.C.; the earlier record, although quite lengthy, may have had either erosional episodes or periods with essentially no deposition (in particular, Layer VIII is a lateritic horizon—which has what appears to be a very weathered upper surface). No radiocarbon dates are yet available from the Nimitz Highway core, though it is expected to contain a long and uninterrupted sedimentary record dating from well before Polynesian settlement and continuing through to the end of the prehistoric Polynesian period. The Mauna-wili core dates from about A.D. 800 or 900 at its base to the present at its surface based on two radiocarbon dates. The Ka'au Crater core has three dates, indicating a late Pleistocene age for the entire sequence from about 36,600 to 9750 years B.P. The Mānoa sequence appears to date between roughly 10,000 and 4000 B.C. (12,000 and 6000 years B.P.) as indirectly determined through volcanic cinder deposits in relation to sea level rise as observed in various marine cores (see Ferrall 1976).

The essential point of the dating evidence is that we have continuous lowland sedimentary records dating from long before initial Polynesian occupation around A.D. 600 or 700 and continuing through virtually the entire period of prehistoric human occupation. In the case of 'Uko'a Pond, this record extends back in time nearly 7400 years. The various lowland sedimentary records, for the most part, were formed in low-energy environments—presumably standing water of protected embayments, estuaries, or enclosed basins. Except where noted, there is no reason to suspect any perturbations or discontinuities in the profiles. The lowland sampling localities, together with the more limited or much earlier data from inland localities, provide a means to observe vegetation and sedimentological patterning over an extended temporal sequence. Either abrupt changes or gradual trends in the makeup of plant communities or in the rate and type of sedimentation would be readily detectable. Of course, of special significance is the identification of any changes with respect to the initial establishment of Polynesian communities

on O'ahu and subsequently, during the period of prehistoric Hawaiian population growth and settlement expansion before initial Western contact in 1778.

#### VEGETATION CHANGE

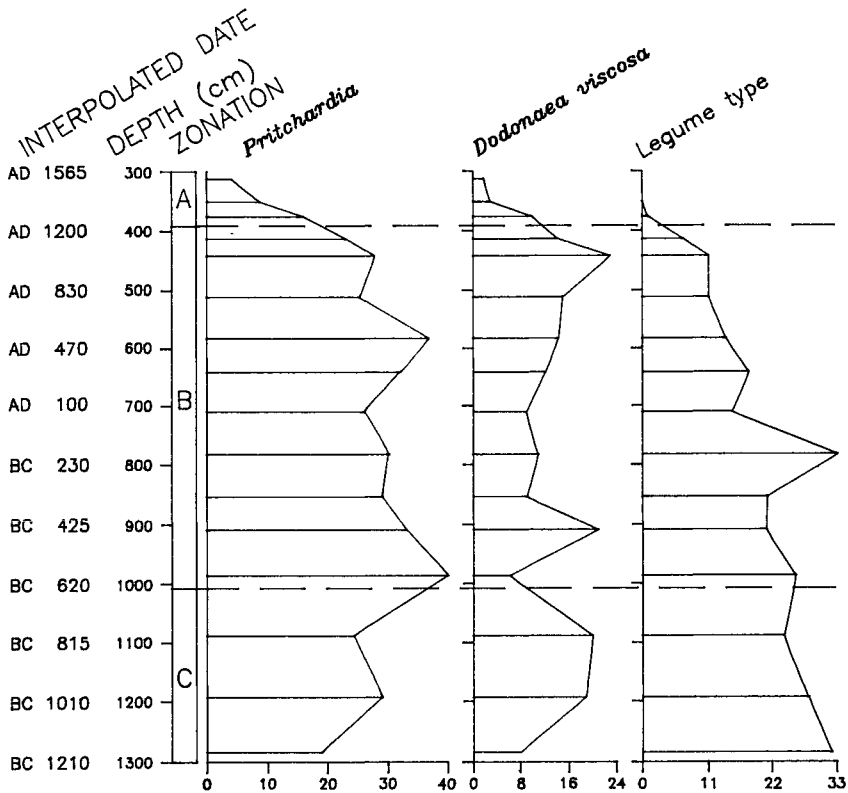
Pollen preservation was generally excellent in the various samples, revealing a very rich flora. In the Kawai Nui samples 88 species or types of angiosperm pollen belonging to 46 families are represented, excluding unknowns. At Fort Shafter Flats the totals are 84 species in 49 families. For 'Uko'a Pond the pollen counts are still in progress, though it appears that the samples are significantly less diverse in terms of species. This is likely attributable to 'Uko'a Pond's much smaller watershed or catchment area, which does not appear to extend into the higher-elevation zones as do the catchments of the other sampling areas. In addition to pollen, all of the sampling areas contained a diverse assemblage of pteridophyte spores and other organic-walled microfossils. To aid the interpretation of the pollen and spore record, graphs illustrating the percentage contribution of each type or vegetation group were constructed (see Athens and Ward 1991; Athens et al. 1992; Wickler et al. 1991).

The Kawai Nui pollen record is the most striking because it has the longest uninterrupted sequence that includes most of the Polynesian period. Here we see a pre-Polynesian and early Polynesian period environment dominated by *Pritchardia* palms, *Dodonaea* shrubs, and a legume shrub (see Fig. 2).<sup>3</sup>

The Mauna-wili record also shows an early dominance by *Pritchardia*, while pollen of *Dodonaea* and the legume is present only in negligible quantities in the basal samples (see Fig. 3). It is believed that low counts for the latter two types must be related to the relatively high elevation (158 m) and high precipitation of the coring location (2500 mm/year) compared with the Kawai Nui Marsh area (near sea level and much less rain), suggesting biogeographical zonation within the *Pritchardia* forest community.

The early record at Fort Shafter Flats on the leeward side of the island also shows a dominance by *Pritchardia* palms, but there does not seem to have been a significant *Dodonaea* shrubland, nor does the legume type appear to contribute any more to the pollen record than the multitude of other taxa. The evidence, therefore, points to a difference in floristic pattern between windward and leeward lowland environments, with the latter area having numerous species contributing relatively more to the overall community composition than was the case in the windward area.

The most interesting aspect of our work was that it revealed the presence of a lowland palm forest as the original native vegetation on O'ahu (and the other Hawaiian Islands as our other studies are beginning to show), which was scarcely suspected (for example, see Gagné and Cuddihy 1990).<sup>4</sup> Today wild *Pritchardia* palms are generally quite rare on O'ahu. Reconstruction of vegetation communities based on historical documents has failed to indicate the former significance of *Pritchardia*. The pollen evidence from the Kawai Nui catchment (Kawai Nui cores A and B, Mauna-wili core 1) may offer an explanation. As seen in Figures 2 and 3, pollen counts for *Pritchardia* began a precipitous decline at about A.D. 1000 at Kawai Nui and about 1200 at Mauna-wili. For the Kawai Nui cores, *Dodonaea* and the legume type also decline steeply at the same time. Late in the Polynesian



Percentage of Total Pollen Plus *Cibotium* (note scale change)

Fig. 2. Pollen diagram of dominant species, Kawai Nui Marsh.

period—by A.D. 1565 when the Kawai Nui core record ends—*Pritchardia* and *Dodonaea* are represented by only a fraction of their former levels, and the legume has disappeared from the record altogether (this pattern is replicated in core A). In the Mauna-wili core *Pritchardia* likewise has a very negligible presence late in the sequence. The Fort Shafter Flats pollen data from the leeward side, also shows a steep decline in *Pritchardia* from its early position of dominance. Unfortunately, however, the timing of this decline cannot be determined so precisely because of the absence of pollen within sediments dating between 200 B.C. and roughly A.D. 1300 to 1500.

There are, of course, many other interesting details concerning the pollen and spore data. However, with respect to the problem under consideration here, what is important to note is that the pollen profiles clearly document the replacement of lowland *Pritchardia* forests all around O'ahu by a landscape filled with grasses, shrubs, herbs, and ferns. The arboreal types that appear in pollen records are minor in terms of their relative significance to overall community structure.<sup>5</sup> In short, we seem to be seeing the replacement of what ecologists refer to as a mature plant community by an immature one (Margalef 1968; Odum 1969). Also, the A.D. 1000 to 1200 time frame for the initiation of sudden and dramatic change probably



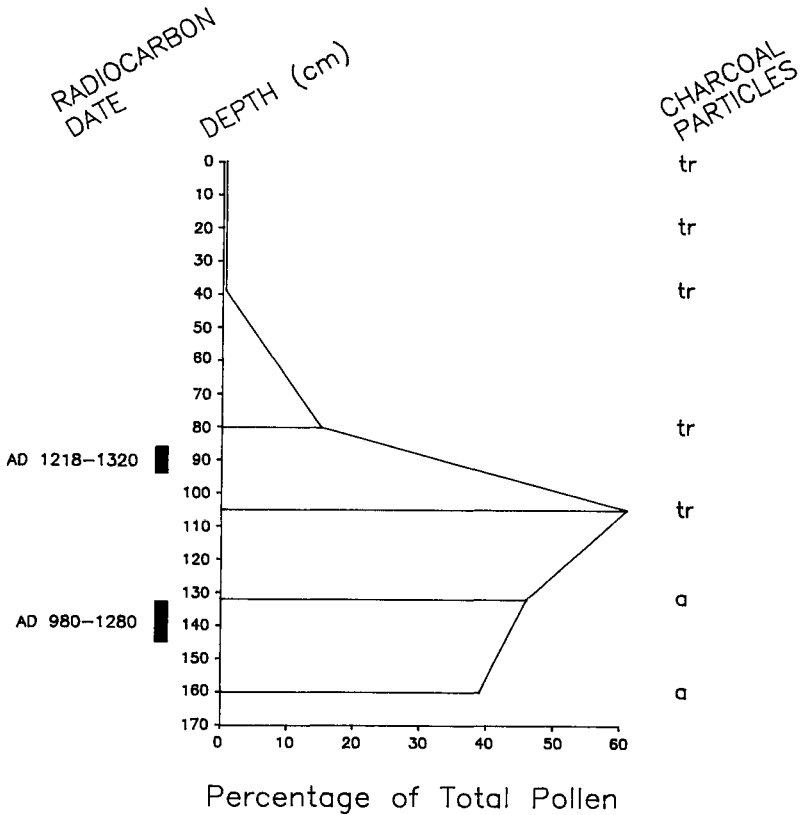


Fig. 3. Pollen frequency diagram of *Pritchardia*, upper Mauna-wili Valley, core 1. Charcoal particles are indicated by "tr" for trace, and "a" for absent. The 105-106 cm slide contained only a single particle. The radiocarbon dates were calibrated using the Calib 3.0 program; the ranges represent a 95% confidence interval of the highest probability range.

marks a watershed point in the natural history of O'ahu. We are anxious to see whether this date range holds up for our as-yet unanalyzed cores.

Various prehistoric human population growth curves, including one by Kirch (1985:288) (others have been developed by Tom Dye and Eric Komori, pers. comm., and Hommon 1980), show that population size apparently remained quite low for a lengthy period and did not begin to increase rapidly until about A.D. 1200 to 1300. As depicted in our Kawai Nui pollen diagram, this was 200 to 300 years after the start of the steep decline of the *Pritchardia* forest. For the Mauna-wili core, the environmental change appears to occur either at or only slightly before the start of the major onset of population growth. Although the difference in the dating between the two cores could be more apparent than real because of the lack of precision inherent in radiocarbon chronologies, it may be the case that the *Pritchardia* forest was seriously impacted in the coastal region earlier than for the more inland areas. Such a perspective fits with the generally accepted view in Hawaiian archaeology of coastal settlement followed by inland expansion with population increase.

Based on the above, we believe we have documented a profound change in the

natural environment of the Hawaiian landscape, at least on O'ahu. Furthermore, it is clear that the change coincides with the period of prehistoric Polynesian occupation. Concerning evidence for pre-human vegetational change, there may be a slight indication for a very gradual transition to moister conditions with increasing age. However, this change, if it can be verified with further investigation, was relatively subtle and certainly not of the same order of magnitude as the later change.

### *Destruction of the Native Forest*

Although the recently identified loss of the lowland *Pritchardia* forest and the relatively precise dating of this event represent a significant advance, the fact that there was a transition really does not. Here we refer to Kirch (1982a:6), who made the following observations:

As a result of population increase and concomitant agricultural development, the greater part of the lowland landscape of the archipelago had been converted to a thoroughly artificial ecosystem prior to European advent. Only the higher forested regions (generally above 760 m) and alpine zones were left relatively undisturbed . . .

In another paper, Kirch (1982b:34–35) suggested that by A.D. 1600, “. . . probably 80 percent of all of the lands in Hawaii below about 1,500 feet in elevation had been extensively altered by the human inhabitants.” In consideration of our pollen evidence, we have no difficulty envisioning that the transformation of the formerly forested lowlands of O'ahu was on the scale of that suggested by Kirch. It is also reasonable to infer that Polynesians were in some way involved. However, just how may be a subject requiring additional investigation. Kirch (1982a) unhesitatingly attributed the change to the conversion of the natural environment to an agricultural landscape through the use of fire. As he said (Kirch 1982a:8),

The primary tool that effected these great modifications of the prehuman vegetation was undoubtedly fire. Burning for agricultural purposes was one application of fire, but there were certainly others [e.g., burning to encourage the growth of *pili* grass (*Heteropogon*) for use as thatching material].

Although we do not feel we have the information to seriously challenge Kirch's assertion, our data certainly make us ask if fire and the conversion of much of the lowlands to an agricultural landscape were really the causes of the disappearance of the *Pritchardia* forest and, furthermore, if Kirch may have exaggerated the significance of fire in the cultivation systems used by the Hawaiians.

The reason for our concern is that the pollen slides from Kawai Nui Marsh scarcely show a particle of charcoal on them. In fact, only the uppermost sample from core A at Kawai Nui Marsh had any charcoal particles. In the Maunawili core, charcoal is absent from the two basal samples, with only a single grain noted on the entire slide at 105–106 cm, and only minor traces were observed for the upper samples (see Fig. 3). The Fort Shafter Flats samples also contained no charcoal, but, as previously noted, most of the relevant time period is missing from this sequence.

Quantification of charcoal particles preserved on pollen slides is a common technique for evaluating forest clearance for agricultural activities in a pollen profile (see, for example, Byrne and Horn 1989; Clark 1988; Piperno 1990; Tolonen 1986). Indeed, we have an extensive record of charcoal particles in another series of

slides from a lake core in highland Ecuador. Thus, we do not think the absence of charcoal in our O'ahu pollen records can be attributed to laboratory technique, especially because the uppermost Kawai Nui sample had charcoal and the upper five samples at Maunawili all had at least traces of charcoal. For now, we point out this problem as a curiosity and something to investigate further in the future. Certainly not all Pacific Island horticulturalists rely on fire for clearing agricultural land (e.g., Pohnpei and Kosrae, pers. observations), and it is possible that in Hawai'i it may have been either less significant or a later phenomenon (following the decline of the *Pritchardia* forest rather than causing it) than is generally believed.<sup>6</sup>

Another concern we have with Kirch's mechanism for lowland vegetation transformation has to do with its completeness. Is it really reasonable to assume that agriculture and fire would have eliminated virtually every *Pritchardia* palm on the island of O'ahu? We think that surely there would have remained numerous relict stands in uncultivated areas, or that trees would have been preserved around habitation areas, land borders, trails, and especially in the marginal lands of higher elevations, deep gulches, and so forth. However, these trees for the most part simply vanished. This is also true of the legume type, in the pollen record, which disappears from our Kawai Nui profile altogether late in the Polynesian period. The implication is that we are possibly dealing with the local extirpation of this plant on O'ahu during the prehistoric Polynesian period. The recent discovery of two such plants in a virtually inaccessible location on Kaho'olawe Island suggests just how close this plant has come to extinction (see Hawai'i Heritage Program 1992:61–62).

Others have proposed different mechanisms for the prehistoric decline of native vegetation. Cuddihy and Stone (1990) provided a comprehensive discussion of the various possibilities without singling out any particular one or providing data demonstrating how the various mechanisms can lead to a significant decline in species numbers. These include predation and competition from Polynesian-introduced plants (some 32 species—see Athens and Ward 1991:20–21) and animals (the latter include the Polynesian rat [*Rattus exulans*] and the domestic pig) as well as human exploitation for various purposes.

Although the Polynesian rat, introduced prehistorically to Hawai'i by the Polynesian settlers, is commonly regarded as having had a major impact on native vegetation, including *Pritchardia* (e.g., Neal 1965:98), we have not yet located any literature that associates this species with the destruction of *Pritchardia* palms or their failure to propagate. Thus, we feel that the exact role of the Polynesian rat with regard to destruction of *Pritchardia* palms remains unclear and/or undemonstrated.

Regarding human predation, Hammatt et al. (1990) argue that use of the seeds for food (seeds were eaten unripe and tasted somewhat like coconut—Neal 1965:98) was a major factor in their decline. However, this suggestion seems a little far-fetched considering that no *Pritchardia* seed remains have ever been recovered from archaeological sites.

Our own opinion on the matter—and it is just an opinion—is that we may be dealing with a plant disease that perhaps was inadvertently introduced to Hawai'i by the Polynesians with one of the plants brought with them. Another possibility is that there could be a complex symbiotic relationship involved in the reproduction of *Pritchardia* and perhaps the legume type as well, and that this was interrupted or

somehow adversely affected by one or more of the Polynesian plant or animal introductions. This issue cannot be resolved here; it is a problem that needs further research.

#### COASTAL INFILLING AND PROGRADATION

The other major concern of our studies is with the process of coastal infilling and progradation and the extent to which the ancient Polynesians were responsible for these in any significant way. Kirch (1982a:10) cited examples of lowland geomorphological changes on a number of Hawaiian Islands, including Kawai Nui Marsh on O'ahu, arguing that they were induced by the Polynesians as a result of cultivation practices (for Kawai Nui Marsh see discussion of previous work and interpretations in Athens and Ward 1991). Our data on sedimentation and the infilling of Kawai Nui Marsh and 'Uko'a Pond basins bear directly on this issue.

Briefly, we have calculated sedimentation rates for the pre-Polynesian period, the early Polynesian period, and the late Polynesian period from core samples at both Kawai Nui Marsh and 'Uko'a Pond (Table 1). We can also augment the Kawai Nui Marsh data with sedimentation data from our Test Pit 2 on the edge of the marsh. The expectation is that if the Polynesians had a role in causing or accelerating the ongoing process of coastal infilling and progradation, there should

TABLE 1. SEDIMENT ACCUMULATION RATES FOR KAWAI NUI MARSH AND 'UKO'A POND

| MEASUREMENT<br>AREA <sup>a</sup><br>(BETWEEN DATES) | DEPTH<br>(cm) | SEDIMENT<br>THICKNESS<br>(cm) | YEARS<br>REPRESENTED | SEDIMENT RATE<br>(cm/year) | POLYNESIAN<br>TIME PERIOD <sup>b</sup> |
|---|---------------|-------------------------------|----------------------|----------------------------|--|
| Kawai Nui Marsh                                     |               |                               |                      |                            |  |
| A.D. 1565 <sup>c</sup>                              | 306           |                               |                      |                            |  |
| A.D. 1276   | 378           | 72                            | 289                  | 0.25                       | Late                                   |
| A.D. 458 &<br>A.D. 1276                             | 591<br>378    | 213                           | 818                  | 0.26                       | Middle                                 |
| 243 B.C. &<br>A.D. 458                              | 782<br>591    | 191                           | 701                  | 0.27                       | Early                                  |
| 500 B.C. &<br>243 B.C.                              | 915<br>782    | 133                           | 257                  | 0.52                       | Pre-                                   |
| 1240 B.C. &<br>500 B.C.                             | 1291<br>915   | 376                           | 740                  | 0.51                       | Pre-                                   |
| 'Uko 'a Pond  |               |                               |                      |                            |  |
| A.D. 1460 &<br>A.D. 913                             | 138<br>196    | 58                            | 547                  | 0.11                       | Mid to Late                            |
| A.D. 913 &<br>A.D. 394                              | 196<br>245    | 49                            | 518                  | 0.09                       | Early                                  |
| A.D. 394 &<br>244 B.C.                              | 245<br>276    | 31                            | 638                  | 0.005                      | Pre-                                   |
| 244 B.C. &<br>543 B.C.                              | 276<br>635    | 359                           | 5,190                | 0.07                       | Pre-                                   |

<sup>a</sup>Midpoint of most probable date range of calibrated date at 95% confidence interval.

<sup>b</sup>Intended as only an approximate ordinal scale.

<sup>c</sup>Interpolated date at top of consolidated sediment.

be clear evidence for an *increase* in sedimentation rates during the late part of the Polynesian period. In actual fact, however, the data show a slight *decrease* over time for the rate of infilling for Kawai Nui Marsh during the Polynesian period (for the nonmarine part of the core sequence above 782 cm) and only the slightest increase in the rate during the time of Polynesian occupation represented at 'Uko'a Pond (above 245 cm; see detailed discussion of Kawai Nui infilling data in Athens et al. n.d.; a more complete discussion of the 'Uko'a Pond data is forthcoming). The rate change between the early and late part of the 'Uko'a Pond Polynesian period, however, is so slight as to be irrelevant for consideration; some variation is expected because of sampling error, which may also be true for the slight rate decrease observed in the Kawai Nui data. Our Test Pit 2 data from the edge of Kawai Nui Marsh indicate a sediment accumulation rate of 0.13 cm per year for the period from about A.D. 1100 (when sediment first begins to accumulate during the Polynesian period) to the present, which is significantly *slower* than the rates observed for the interior of the marsh (see Athens and Ward 1991:72).

The Kawai Nui sediment accumulation data also indicate that the terrestrial part of the sequence has a rate that is approximately half of that for the marine part. This means that in the upper part of the core it took twice as long for a centimeter of sediment to accumulate as in the lower part. Thus, when rates are viewed in terms of the entire core sequence, the minimal effect of the Polynesians on processes of infilling and coastal progradation compared with natural processes can be readily appreciated. The situation at 'Uko'a Pond, however, is somewhat different. Here, rates were extremely slow during the pre-Polynesian period and substantially increased only during the Polynesian period. The largest of the rate transitions, however, occurred by A.D. 394, which is before the earliest Polynesian settlers, if any were even present in Hawai'i by that date, could reasonably have been expected to have impacted the landscape significantly. Thus, sediment accumulation rates, especially when viewed in the context of the entire sequences represented by the cores, appear to be responding clearly to natural rather than to cultural causes.

Although the Mauna-wili core does not lend itself to the calculation of sedimentation rates in the same way as the Kawai Nui Marsh and 'Uko'a Pond cores, it does provide additional useful information. Here there is evidence for a major alteration in depositional regimes only in the midsection of the core, when *Pritchardia* begins to decline about A.D. 1200. From that time to the present, which includes the period of major prehistoric population growth, there is no indication of the occurrence of any changes or disruptions to the established pattern of soil deposition in the marsh. Thus, the only major episode of depositional change occurred just after the start of the decline of the *Pritchardia* forest, at roughly A.D. 1300. Occasional subangular basalt cobbles and rounded pebbles in the humic silty loam matrix suggest some colluvial or fluvial deposition within the marsh at that time through to the present, though the marsh must have remained largely a quiescent wetland. In fact, the pollen record indicates its use as a taro pondfield after about A.D. 1300.

The two coastal cores indicate that sea level change is the overwhelming factor conditioning infilling and coastal progradation. At 'Uko'a Pond we see the initial formation of a wetland at about 7400 years B.P. when sea level first began to stabilize and sediments accumulated on the coastal shelf after a very rapid rise with the retreat of the continental glaciers. Apparently the sea level paused briefly at that

time before completing its rise to modern levels. It is also at this time that the Kawai Nui embayment appears to have formed (see Athens et al. n.d.).

At about 200 B.C. we see another shift in sedimentary regimes, this time resulting from a slight decrease in sea level after the Holocene Climatic Optimum when sea levels were slightly higher than those of modern times (see Nunn 1991:10–15). At that time many formerly marine-dominated embayments and estuaries changed to freshwater and/or brackish-water environments, and marine sediments were replaced by terrestrial sediments. The retreat of the sea was evidently not sufficient to cause serious erosion or downcutting as the process of establishing a new equilibrium proceeded.

With respect to Kawai Nui Marsh, some investigators have believed that the transformation of the embayment to a closed lagoon and its infilling with terrestrial sediments occurred after initial Polynesian settlement (Allen 1987:258–260; Allen-Wheeler 1981:82, 87, 100; Kirch 1985:74). As suggested by Allen (1987:260), “. . . human occupation and cultivation in the islands, and the erosion and redeposition these produce . . . may well have begun before A.D. 500.” However, it is now clear that the transition to a closed nonmarine basin at Kawai Nui occurred long before the arrival of the Polynesians. The 200 B.C. date for this transition, in fact, appears to occur repeatedly around the Islands (see discussion in Athens et al. n.d.). As the work of Nunn (1991) made clear, the coastal landscape of Hawai‘i responded to sea level changes in the same way many other Pacific Islands did. However, the chronology of these events throughout the central and south Pacific does show some variation. Because of the apparent considerable tectonic stability of O‘ahu during the Holocene (Macdonald and Abbott 1970:211–212), the case of Hawai‘i may be of special interest for establishing a more precise understanding of Holocene sea level and climate change for the central Pacific.

#### CONCLUSION

The question of human or nonhuman impacts on environmental change is not exactly an “either/or” issue. We have documented very definite and substantial change in the native lowland vegetation on O‘ahu, which was long suspected before our work. However, we have been able to describe and date this change with some precision. The observed vegetation change—essentially the destruction of the *Pritchardia* forest—clearly correlates with the Polynesian occupation of Hawai‘i. There is little doubt that the Polynesians were involved in the loss of the *Pritchardia* forest beginning at about A.D. 1000 in the coastal lowlands and perhaps somewhat later in the interior regions. However, a key question is how this happened. Kirch (1982a) argued for the importance of fire for clearing agricultural fields and other purposes. We are not so sure but our charcoal particle data do not provide any evidence for the wholesale use of fire. We also wonder whether fire, even if it was important, would have caused the virtual disappearance of these trees and several other plants. We suspect that a far greater impact on the lowland vegetation community may have resulted from either introduced plant diseases directly, or indirectly through disruption of symbiotic relationships involved in species reproduction. Identification of the mechanism is an important goal for fu-

ture research. Polynesian responsibility for the disappearance of the lowland forest community, therefore, may be of a more indirect nature than heretofore realized.

With respect to geomorphological change—at least as it pertains to coastal infilling and progradation—our evidence favors nonhuman impacts and noninvolvement by the prehistoric Polynesians in Hawai'i. Whether this is true for other forms of geomorphological change is unclear. Coastal changes were extensive during the Holocene, and changes are still ongoing. However, the rise and fall of sea level rather than erosion induced by prehistoric Polynesian agricultural practices clearly has been the responsible agent in the formation of the coastal plains, wetlands, and alluvial flats of the recent past. The activities of the prehistoric Polynesians were negligible in terms of any measurable effect on the formation of these areas. However, this is not to deny the often extensive landscape modifications produced by prehistoric Hawaiians in their extensive development of taro pond-field cultivation systems in the coastal lowlands and valley bottoms (e.g., Earle 1980).

Our parting comment is that this research has only just begun. One of the important questions remaining to be answered concerning vegetation change is whether the timing and rate of change were the same everywhere on O'ahu and the other Hawaiian Islands. Of course the mechanism for change, as noted above, will be quite important to determine with some certainty. We would also like to know the ecological limits, particularly with respect to elevation, of the *Pritchardia* forest, and also the range of variation of this community type in the different environmental zones of Hawai'i. Furthermore, we would like to better identify other plant community types and their ecological tolerances. In this respect, the data obtained on *Dodonaea* and the legume type on the windward side of O'ahu, as well as the floristic differences suggested between the leeward and windward sides, demonstrate the potential for obtaining this type of information. Concerning sea level change and coastal infilling, we certainly need a larger number of sampling locations to more firmly establish the patterns we have suggested.

Eventually we would like to be able to understand just what kind of place Hawai'i was when the first Polynesians arrived sometime before about A.D. 600 or 700. What were the resources, opportunities, and limitations of this pristine environment, how did these change over time, what role did Polynesian settlement practices play in these changes, and how did the Polynesian adaptive strategies change through time to accommodate changing conditions of their altered physical and biotic environment? There are other questions, of course, but our point should be clear: we as archaeologists and biologists have much research to do in Hawai'i to truly understand what happened in the past and why things are the way they are today.

#### NOTES

1. In our view, there is no compelling published archaeological evidence for Polynesian settlement in Hawai'i until the period dating between about A.D. 500 to 700.
2. All radiocarbon dates are calibrated and adjusted for isotopic fractionation unless otherwise indicated. Also, single point dates should be understood to represent the midpoint of the most probable calibrated date range as determined from the Stuiver and Reimer (1986, 1993) CALIB 2.0 and 3.0 calibration programs. Marine samples have been calibrated using the marine program (Stuiver et al. 1986). Details concerning the dating samples are presented in the respective field reports.

3. The genus *Pritchardia* belongs to the palm family, Arecaceae. *Pritchardia* palms, restricted to tropical Pacific islands, comprise 19 species endemic to the Hawaiian Islands, which presumably descended from a single colonizing species (Wagner et al. 1990:5, 1364–1365). The various species, having restricted geographical distributions and habitat preferences, range in height from about 1–2 m to 30 m. Although one species is documented as growing between 1000 and 2000 m in elevation (*Pritchardia lanigera*) and several occur to 1200 m or so (*Pritchardia beccariana* and *Pritchardia arecina*), most occur at about 600 to 800 m and below (see Wagner et al. 1990:1367–1375). Unfortunately, *Pritchardia* species cannot be accurately determined from pollen morphology. However, in the Kawai Nui pollen study a wide size range of *Pritchardia* pollen was noted (from 40 to 90  $\mu\text{m}$ ), suggesting that at least two species are represented (Athens and Ward 1991:100).

*Dodonaea* is an extremely polymorphic indigenous taxon in Hawai'i. Members of the genus grow as shrubs or small trees from 2 to 8 m tall and occur up to 2300 m (Wagner et al. 1990:1226–1228).

Pollen of the legume type was previously designated as the Unknown Tricolporate Type 1 (Athens and Ward 1991), which was subsequently matched to modern pollen obtained from two shrubs found in 1992 on a remote sea cliff on Kaho'olawe Island. (Hawai'i Heritage Program 1992:61–62). A formal description and name for the new species are forthcoming.

4. MacCaughy, mentioned by Selling (1948:85–86), believed that *Pritchardia* was formerly much more extensive in the lowlands. Cuddihy and Stone (1990:7–8) also attributed a larger role to *Pritchardia* in the coastal lowland communities in the past. Lyon (1930) reported its occurrence in a 100,000-year-old fossil deposit on O'ahu, suggesting its former more widespread occurrence. Despite occasional references from the above sources and a few others, the real significance of *Pritchardia* in lowland vegetation communities seems to have been largely overlooked and/or unappreciated.
5. Most arboreal species that are present in the pollen diagram tend to be characteristic of more mesic environments, and thus their pollen is likely to be derived from the higher elevations within the catchment (i.e., many of these species may not have occurred in lowland vegetation communities).
6. Beggerly (1990) reported extensive charcoal in the sediments of Kahana Valley on the northeastern side of O'ahu. J.V.W. (pers. observations) confirms that charcoal particles are present in the pollen slides, though counts were not undertaken. As a result of her findings, Beggerly considers fire to have been a significant factor leading to slope instability and the infilling of Kahana Valley. It would be of interest to undertake charcoal particle counts on the pollen slides at some time in the future so that the findings would be more directly comparable with those of other areas of O'ahu.

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#### ABSTRACT

Prehistoric environmental change in Hawai'i is evaluated through the analysis of sediment and pollen samples from dated cores and excavation profiles in the coastal lowlands of O'ahu. It is suggested that a lowland *Pritchardia* palm forest and associated species underwent rapid decline starting between about A.D. 1000 to 1200. This decline seems to have occurred earlier in coastal areas than in inland areas. By the time of Western contact in A.D. 1778 the native palm forest community had all but disappeared. Though prehistoric Polynesians are implicated in the decline, the actual mechanism remains to be demonstrated. The question of coastal infilling and progradation is also considered. Sea level change appears to be the overwhelming controlling variable. It is concluded that prehistoric Polynesians had little if anything to do with large-scale geomorphological alteration of the landscape, which has been a continuing process throughout the Holocene. KEYWORDS: paleoenvironment, Hawai'i, prehistory, impacts, vegetation, geomorphology, Holocene.