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# Late Holocene Lowland Vegetation, O'ahu, Hawai'i

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## ABSTRACT

Palaeo-environmental studies at two low-elevation wetland sites on the leeward and windward sides of O'ahu, Hawai'i, have produced long stratigraphic sedimentary records and a reliable chronological framework dating to 1200 B.C., established with 14 radiocarbon dates. Pollen analysis provides for the first time a detailed record of lowland vegetation on O'ahu both before and following Polynesian settlement. Of major significance is proof given of the presence of a *Pritchardia* palm forest on both sides of the island before A.D. 1000, its co-dominance shared on the windward side with *Dodonaea* and an unknown species. After A.D. 1000, the palm forest rapidly disappeared and its two windward co-dominants declined sharply in importance. Polynesian habitat modification would seem to be the most likely cause of the forest decline, although climatic factors may also have been involved.

*Key Words:* HAWAI'I, PALAEOENVIRONMENT, POLLEN ANALYSIS, LOWLAND VEGETATION, POLYNESIAN IMPACT, RADIOCARBON DATES.

## INTRODUCTION

This article presents findings from recent research on the composition of lowland plant communities on the Island of O'ahu in Hawai'i before Polynesian settlement and also on the changes that occurred in these communities after settlement. The data are derived primarily from pollen analysis of reliably dated sediment sequences obtained from both leeward and windward lowland sampling locations on O'ahu. These locations are, respectively, Fort Shafter flats area near Moanalua Stream in Honolulu, and Kawainui Marsh, which is just inland of Kailua (Fig. 1).

Unless otherwise indicated, all radiocarbon dates discussed in this article are adjusted for isotopic fractionation and calibrated using the computer program of Stuiver and Reimer (1986). A listing of the dates and relevant sample information is presented in Appendix 1. For purposes of this presentation, only the most probable age range is utilised at two standard deviations. Full details on the coring methodology, sediment descriptions, laboratory analyses, archaeological background information, and other aspects of the study are presented by Athens and Ward (1991) and Wickler *et al.* (1991).

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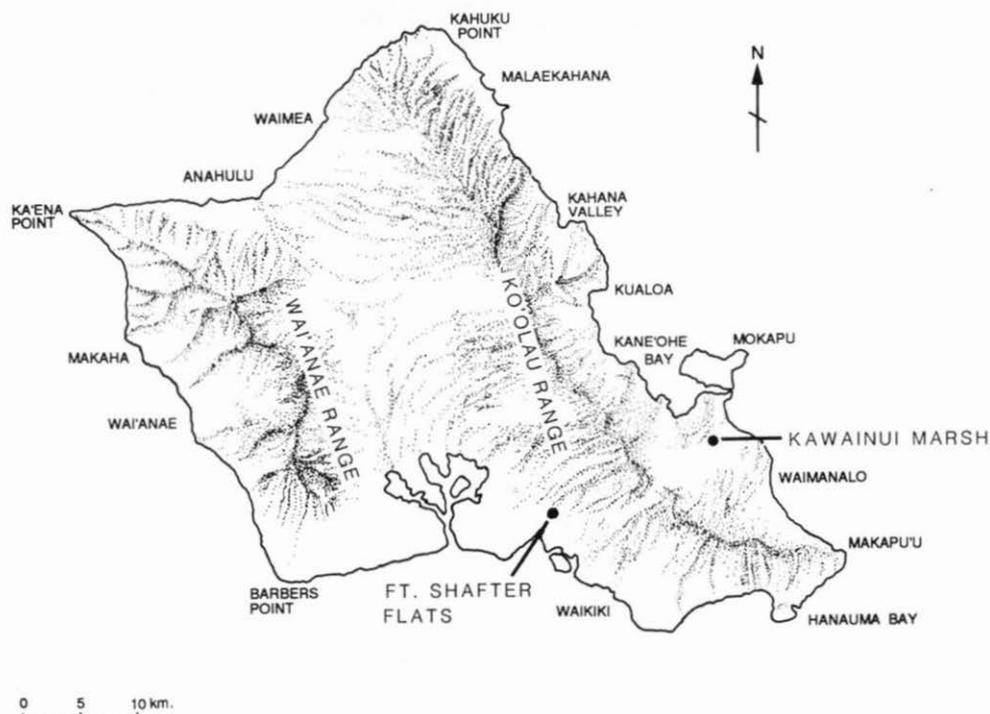


Figure 1: Map of O'ahu showing location of Fort Shafter flats and Kawainui Marsh project areas.

#### VEGETATION RECONSTRUCTION IN HAWAI'I

A recent comprehensive treatment of Hawaiian plant communities is presented by Gagné and Cuddihy (1990: 45–114). Although they attempted to emphasise “the classification of communities believed to be components of the original flora of Hawai'i, predating Polynesian colonization,” they rely almost entirely on modern botanical observations and knowledge of the ecological characteristics of the Hawaiian endemic and native flora to do this. Though their work clearly will be a baseline reference for many years to come, it is nevertheless appropriate to attempt to evaluate the accuracy of their findings using paleontological methods.

As Gagné and Cuddihy (1990: 45) suggest, the arrival of Polynesians in Hawai'i some time during the early centuries of the first millennium A.D.<sup>2</sup> initiated a process of substantial vegetation change, and this was further accelerated with European contact beginning in 1778. In this respect, Kirch (1982: 35) notes that,

<sup>2</sup>Kirch (1985: 87) suggests that Hawai'i was first settled some time between about A.D. 300 and 400. Hunt and Holsen (1991: 158), on the other hand, believe initial settlement may date “as early as the first century A.D.” Our own view is that, thus far, there is no compelling archaeological evidence for Polynesian settlement in Hawai'i until the period dating between about A.D. 500 to 700.

The impact of the Polynesians was, naturally, strongest in the lowlands, where they transformed vast areas of native forest into a cultural landscape of agricultural fields, grasslands, and habitations.

Kirch (1982: 34–35) estimates 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.

These were precisely the areas most densely occupied by Polynesians and, later, people of Western origin. It therefore stands to reason that such areas are the ones where there is likely to be the greatest uncertainty about the original nature of the vegetation communities and the rate and types of changes that occurred after human contact.

Selling's (1948) pollen investigations of montane bogs on Kaua'i, Moloka'i, and West Maui represent the only major effort to study the history of Late Quaternary plant communities in Hawai'i. This landmark work, however, was conducted in the montane or mesic-wet forest zone, which has very different plant communities from those found at lower elevations. It had also probably suffered less from anthropogenic vegetation or landscape changes.

Early accounts by European explorers and missionaries have provided valuable information on the problem of delineating Hawaiian vegetation before Western contact (see especially Cuddihy and Stone 1990; Nagata 1985). However, although these reports are helpful in reconstructing early vegetation patterns before the introduction of a multitude of new species, they fail to offer insight about the effect of ancient Polynesian settlement in a pristine, uninhabited archipelago more than 1,000 years before European discovery. Rapid population increase coupled with agricultural expansion and inland land use up to the time of Captain Cook's arrival in 1778 clearly would have had a major impact on Hawaiian vegetation (see Cuddihy and Stone 1990: 25,103). The precise nature and extent of this impact, however, have remained elusive.

The examination of extant patterns of Hawaiian vegetation, especially using relictual species and stands as guides, provides another approach to vegetation reconstruction as shown by McEldowney's study (1983) of the Waimea-Kawaihae region of Hawai'i Island. The limitation of this method, however, is that it is increasingly difficult to reconstruct plant communities, the farther back in time one tries to project the analysis.

Finally, plant macrofossils, in those rare cases in Hawai'i where they are found, can provide solid evidence of former plant communities and their species composition. For example, Lyon (1930) reported on leaf and fruit fossils from Salt Lake (O'ahu). From his preliminary analysis of these remains, Lyon suggested that the Late Quaternary leeward vegetation on O'ahu was more mesic than that of today. Similarly, in younger wetland sediments it is sometimes possible to collect identifiable wood and plant fragments (Murakami 1983; Allen 1984).

Though the above methods of vegetation reconstruction are important in palaeoecology, a limited number of data points in time and space are obtained because of the highly selective nature of fossil preservation, availability of historical data, and knowledge of community structure in relictual stands. In contrast, pollen analysis of a lengthy sediment core offers a multitude of data points through time, incorporating palynomorphs derived from a variety of plant communities. The result is an opportunity to observe change through time involving numerous species. However, pollen analysis is not without limitations,

including differential production of pollen by different species, and dispersal, preservation, and deposition factors that influence their occurrence in the sediments that are being sampled. Nevertheless, while these factors can potentially bias interpretations, they generally can be compensated for to some degree by knowledge of modern species distributions, their habitats, and other biological factors.

### FORT SHAFTER FLATS FIELDWORK

Fieldwork was conducted at the Fort Shafter flats locations along a 296 m sewerline trench section, which averaged in depth from about 5.2 to 5.5 m (Fig. 1). All trench excavations were archaeologically monitored, and sediment samples and profiles were taken at ten localities (designated Profiles 1 to 10) along the trench. At location 10 the trench profile was supplemented with a 5.1 m deep core sample taken from the base of the trench, which resulted in a vertical profile section of just over 10 m below the present day ground surface at this locality.

### STRATIGRAPHY AND DATING

The basic sedimentary sequence at the Fort Shafter flats project area may be seen in Profile 1 and Profile 10 (Figs 2 and 3). In Profile 1 (Fig. 2), Layers I and II are modern fill used to cover formerly marshy terrain. Historic maps indicate that the southern part of the sewerline paralleled the edge of a fishpond. Adjacent areas are described as mud flats and taro pondfields. Layers III and IV are indicative of ponded conditions. Layer III is a brownish gray clay containing reddish mottling and root casts, while Layer IV is a bluish-gray gleyed clay. It is very dense and homogeneous, having few inclusions. Layer V comprises a mixture of well rounded volcanic pebbles and cobbles with volcanic sand. Layer VI consists of peat with abundant macrobotanical remains, including *Aleurites moluccana* (*kukui*) nut shells. Wood from this layer was radiocarbon dated to A.D. 768–997. Layer VII consists of fine volcanic sand. *Kukui* nut is present along with pearlshell (*Pinctada radiata*) and shells of *Quidnipagus palatam*. A radiocarbon sample of *kukui* nut shells produced a date of A.D. 1284–1422. This date should have been older than the Layer VI sample above it. It is apparent, therefore, that either one of these dates is incorrect, or else the stratigraphy somehow became inverted for Layers VI and VII.<sup>3</sup> Layer VIII consists of a 1.14-m-thick peat deposit with small amounts of crab remains and pearlshell. The bulk samples processed from this layer indicate that macro-botanical remains are present in the upper part of the deposit, but that the organics in the lower deposit (below 4.2 m) are mostly humified. *Kukui* nut was entirely absent from this layer. Two radiocarbon samples were processed from the upper part of the deposit, and one from the base. The resulting dates were 409–90 B.C., 549–167 B.C., and 450–90 B.C. The radiocarbon dates suggest that this layer formed very rapidly. Layer IX, the basal layer in Profile 1, formed in a marine

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<sup>3</sup>It is probably more likely that there is a problem with one of the radiocarbon dates than that the stratigraphy became inverted through redeposition of older sediments. For one thing, the wood sample from Layer VI could be older than the sedimentary unit, having been redeposited from another location. Another problem is that the *kukui* nut shell of Layer VII may be problematical as a dating medium; there are too few dates on this material thus far to know whether it produces reliable results.

embayment or lagoonal environment and consists of dense worm tube casings (from *Dendropoma gregaria*) and marine shell (primarily *Pinctada radiata*). A radiocarbon sample from the top of this layer dates to 630–164 B.C., which is just slightly older than the peat dates above it.

Profile 10 is basically similar to Profile 1, the main exception being that there is no marine layer at the base of the trench. The core sample, beginning at the base of the trench at this locality, penetrated just over 5 m of fine sediments, including silt loams, silt clays, and occasional bands of fine volcanic sand below Layer VIII (Fig. 3). Fine marine detritus (mostly shell fragments) was noted in the sediment throughout the core. Microforaminifera and dinoflagellates were present in very low densities in the core samples, indicating largely fresh or brackish water conditions at the time of deposition. The core sediments are interpreted to represent a brackish water estuary within an embayment. A radiocarbon date from the top of the core (at 5.9 m) dates to 852–484 B.C., while a sample from the base (at 10.15 m) dates to 1439–1047 B.C.

In order to clarify the sedimentary sequence from Profiles 1 to 10, individual strata are grouped into Depositional Units. A Depositional Unit is defined as a portion of a sedimentary sequence which is derived from a similar source and/or has experienced similar diagenesis as a result of natural processes or human activity. Depositional Units are placed in numerical order beginning with the earliest sediments and progressing to the most recent.

The sedimentary sequence is fairly uniform over the entire project area with the exception of the basal layers. Note, however, the depositional hiatus or gap between the top of Depositional Unit 2 and the bottom of Depositional Unit 3 in Profile 1 as indicated by the radiocarbon dates (Fig. 2). There may also be other smaller gaps in the record above this boundary. This hiatus is unfortunate as it encompasses the early period of Polynesian settlement in Hawai'i. Nevertheless, there is clearly a lengthy and presumably continuous sedimentary record before Polynesian settlement dating from about 1200 B.C., and also a valuable record from the later portion of the prehistoric Polynesian period.

#### POLLEN ANALYSIS<sup>4</sup>—FORT SHAFTER FLATS

At least 84 species or types of angiosperm pollen belonging to 49 families are depicted in the pollen diagram (Fig. 4). Seventy percent of the types fall into the Dry-Mesic Forest

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<sup>4</sup>Laboratory processing of all samples for pollen analysis involved the usual steps for removing inorganic minerals with HCl and HF followed by KOH and acetolysis solutions to solubilise the organic fraction (Doher 1980; Faegri et al. 1989). The resulting organic material was sieved through a 100 µm mesh nylon screen to separate the coarser particles; Calgon solution was employed for flotation of the finest unwanted organic debris. The pollen residue was mounted in glycerine jelly following Erdtman's technique (1960), since it has a favourable index of refraction for viewing and photographing palynomorphs.

The pollen types are grouped into four broad ecological categories—Dryland Forest and Shrubland, Mixed Mesic Forest, Wet Forest, and the Herb community—following the scheme of Sohmer and Gustafson (1987). Many species in Hawaiian forest communities display a broad ecological amplitude (shown in the islands by altitudinal variation), so that category distinctions become blurred. Species in the Mixed Mesic Forest, in particular, show a great deal of altitudinal flexibility. The adopted scheme, although relatively simple and generalised, probably represents the most practical approach for an initial attempt at identifying and understanding Holocene vegetation change in Hawaii.



## FT. SHAFTER FLATS

## PROFILE 10

## Sediment Core

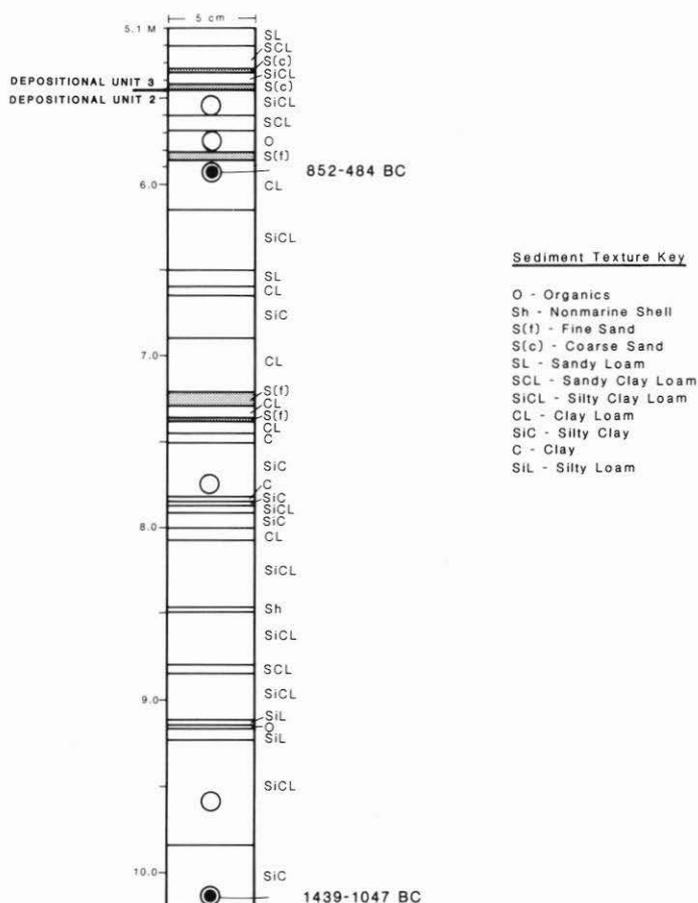


Figure 3: Sediment profile 10 at Fort Shafter flats, showing the cored interval from 5.1 to 10.2 m. The locations of six pollen samples and two radiocarbon samples are shown. Dating and pollen sample symbols follow those given in Figure 2.

The pollen spectra may be grouped into three pollen zones covering the stratigraphy below about 300 cm. Pollen Zone A is based on a single sample at 340 cm and corresponds to Layer VI from Profile 1. This pollen zone may extend to Layer VII since *kukui* nut occurred in both layers; however, no pollen analysis was attempted because of the coarseness of the sediment. Pollen Zone B begins near the 375 cm sample level and extends to ca. 560 cm, just into the Profile 10 sediment core. Pollen Zone C spans the remainder of the Profile 10 core from at least 590 cm to the base at 1010 cm. Its upper boundary is not firmly

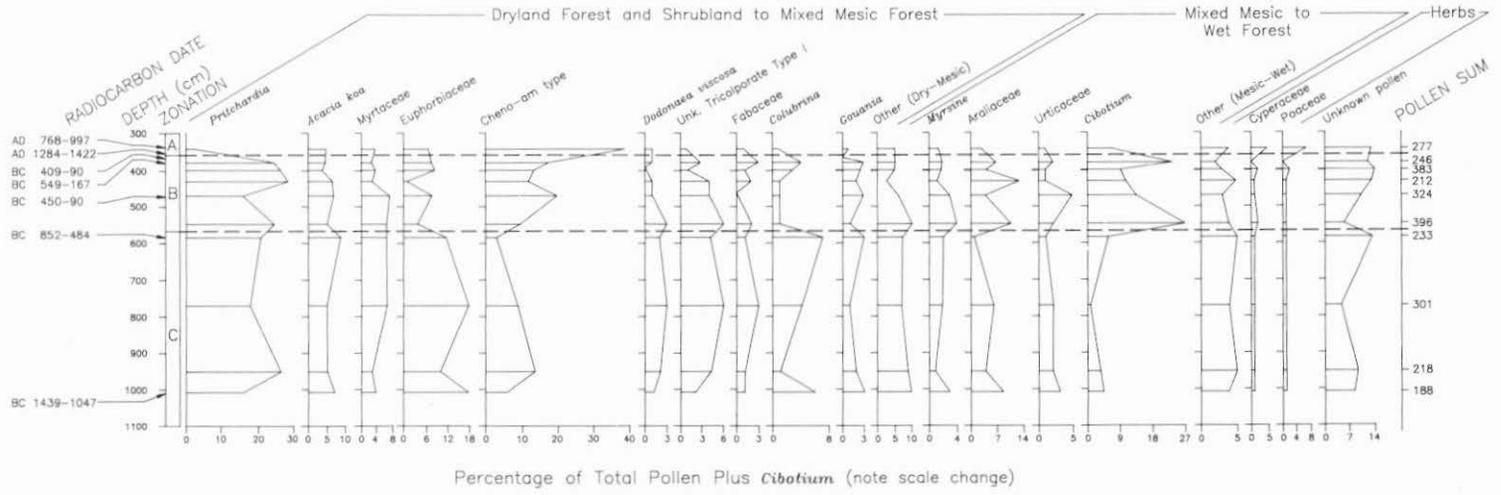


Figure 4: Pollen diagram from Fort Shafter flats. Sampled intervals, from both Profile 1 and the Profile 10 core, are indicated by parallel lines in each pollen curve. Datum is present surface; no samples were obtained between 0 and 3.4 m since it consisted of fill and ponded sediments. Three vegetation groups are indicated by the pollen types recovered: Dryland Forest and Shrubland, Mixed Mesic Forest to Wet Forest, and the Herb community represented by the Cyperaceae (sedge) and Poaceae (grass) curves. Values are given as percentages of the pollen sum consisting of total pollen plus *Cibotium*. In a few cases, values fell below 1 percent, and these are plotted as 1 percent in the diagram.

established because the sample at 575 cm had such poor recovery of pollen grains and spores.

In Pollen Zone C, which dates from about 1200 BC to 200 BC, the dominants are *Pritchardia* (*loulou*), peaking at 27 percent at the 958 cm level, and Euphorbiaceae which reaches 18 percent at 778 cm and at the base. *Acacia koa* and Myrtaceae maintain levels around 4 to 6 percent here and in the Zone B samples, showing little change. *Dodonaea viscosa*, the Unknown Tricolporate Type 1, and Fabaceae all have similar curves showing low values at the base but increasing with slight peaks in the 768 cm level. An inverse relationship is seen with the curves of *Colubrina*, which increases from the base and cheno-ams, which decreases toward the top of this zone. The early cheno-am record represents shrubby native members of the chenopod (*Chenopodium oahuense*) and amaranth (*Charpentiera* sp. and *Nototrichium* sp.) families. Later, weedy herbs and subshrubs of these families were introduced, producing copious amounts of pollen in disturbed habitats. The cheno-am increase in Zone A is a result of this. *Gouania* shows a slight drop at the 768 cm level but otherwise does not change significantly throughout this zone as in Zone B. In the Mesic-Wet category, all types—*Myrsine*, Araliaceae, Urticaceae, and *Cibotium*—while generally represented by low numbers, reach slightly higher levels in the basal sample at 1006 cm. The pteridophyte spores serve to delineate this zone further, since spiny types (both monolete and trilete) show an increase in frequency while psilate monolete and *Cibotium* spores are more common in Zone B (see Wickler et al. 1991).

Pollen Zone B, dated at about 200 B.C., has a dominance of *Pritchardia*, which peaks at 28 percent in the 430 cm sample. The cheno-am type, peaking at 19 percent in the 470 cm sample, is another major contributor. The Euphorbiaceae, which were well represented in Zone C, fall to about half of their former level. *Acacia*, Myrtaceae, *Dodonaea*, Unknown Tricolporate Type 1, and Other (Dry-Mesic) maintain low values, while some members show an increase in the base of this zone (sample 558 cm). In the Mesic-Wet category, *Myrsine* and *Cibotium* display similar patterns, with the latter of greater importance and peaking at 27 percent in the basal sample. The Araliaceae and Urticaceae show no consistent trend. All types in the Mesic-Wet group are more frequent overall than they were in Zone C.

The abrupt shift in the pollen diagram from Zone C to B is probably related to a change in depositional context (i.e., from the lagoonal sediments of Zone C to the peat sediments of Zone B) as opposed to some type of environmental perturbation. Here we refer to the relatively higher contribution of Mesic to Wet forest pollen types (*Myrsine*, Araliaceae, and Urticaceae) and pteridophyte spores including *Cibotium* in Zone B, which was accompanied by relatively lower Dry to Mesic forest types, especially Euphorbiaceae, in this zone.

Pollen Zone A, dating to either about A.D. 800–900 or A.D. 1300–1400 (the radiocarbon dating evidence being ambiguous), is dominated by a cheno-am signal at 39 percent with very low levels of *Pritchardia*, Fabaceae, Rhamnaceae (*Colubrina* and *Gouania*), and *Myrsine*. *Acacia*, Myrtaceae, Euphorbiaceae, and *Cibotium* hold to moderate levels. The Cyperaceae (sedge) and Poaceae (grass) curves climb to 5 and 7 percent, respectively, having been at 1 percent or less in Zones B and C. The sedge and grass curves suggest marshy conditions near the site of deposition. The cheno-am peak would also point to the presence of weedy patches with introduced species, presumably resulting from vegetation clearance and agricultural activity or, alternatively, drier conditions due to climatic change.

*Pritchardia* is dominant in all but the uppermost part of the profile; it averages around 25 percent in Zones B and C, falling to 2 percent of the total in Zone A. This pollen probably derives largely from a lowland palm forest, which before at least about A.D. 800–900,

occupied large areas in the Fort Shafter watershed, along the coastal plain, or on the slopes. Although greatly fragmented from its former range, a *Pritchardia* Coastal Forest type occurs today in isolated tracts on Moloka'i, Hawai'i, and Nihoa, and a *Pritchardia* Lowland Forest type occasionally dominates upland slopes and gulches on Kaua'i and O'ahu (Gagné and Cuddihy 1990).

Significant vegetation changes occurred in the watershed between about 200 B.C. (Pollen Zone B) and A.D. 800–900 or A.D. 1300–1400 (Pollen Zone A). Problems with radiocarbon dating and the hiatus in sediments do not permit a more precise determination of when the changes occurred at the Fort Shafter flats locality.

Since the *Acacia* and *Myrtaceae* curves are fairly uniform throughout the diagram, their pollen is probably derived from a site away from direct human impact, perhaps from a mid-elevation mixed mesic forest. Among those pollen types included in the mesic forest, all in low frequencies, are: *Antidesma*, *Bobea*, *Cyrtandra*, *Diospyros*, *Dodonaea*, *Elaeocarpus*, *Freycinetia*, *Gardenia*, *Hedyotis*, *Myrsine*, *Melicope*, *Pisonia*, *Pleomele*, *Psychotria*, *Sapindus*, and *Wikstroemia* (these are lumped within the Other category in Fig. 4).

Another forest type indicated by the pollen data is a diverse mesic forest which would be expected on wetter sites in the Ko'olau Mountains and may extend up to 1,600 m elevation today (Gagné and Cuddihy 1990). These forests comprise a variety of tree species forming open stands with no clear dominants in the canopy. The consistent contribution from *Colubrina* and *Gouania* throughout the diagram, species which are very restricted in their distribution today on O'ahu, would suggest a source for this forest type. Species characteristic of this forest and included in the pollen record are *Aleurites*, *Bobea*, *Claoxylon*, *Diospyros*, *Myrsine*, *Nesoluma*, *Nestegis*, *Pisonia*, *Pouteria*, *Psychotria*, *Strongylodon*, and *Zanthoxylum*. A wetter phase at the base of Pollen Zone C may be suggested by the increase in *Euphorbiaceae*, *Colubrina*, *Gouania*, Other (Dry-Mesic), *Myrsine*, *Araliaceae*, *Urticaceae*, and *Cibotium*.

## KAWAINUI MARSH SEDIMENT CORING

Kawainui Marsh, located on the windward side of O'ahu (Fig. 1), is the largest remaining freshwater marsh in the Hawaiian Islands (Elliott and Hall 1977: 101). It covers approximately 280 ha (692 acres) at the base of the Ko'olau Mountains and has an elevation above sea level of about 1.5 m. Hilly terrain of volcanic origin surrounds the marsh to the west and north; it is somewhat less hilly to the south. To the east it is separated from Kailua Bay by a calcareous sand barrier or berm roughly 1.6 km wide. Much of Kailua town is built upon this sand barrier (see topographic map in Athens and Ward 1991: 2). As well as taking two deep cores in the interior of the marsh, we excavated 37 core/auger units along the eastern levee, and several hand-dug excavation units at the marsh edge near the southern end of the levee. The discussion here will be limited to the deeper cores, which provide a continuous sedimentary record from about 1200 B.C. to about A.D. 1565.

## STRATIGRAPHY AND DATING

Core A reached a depth of 9.98 m and Core B 13 m below the marsh surface, which everywhere consisted of a floating root mat supporting mainly grasses and sedges. Deeper

penetration in Core A was not possible owing to the fine calcareous sand that constituted Layer VIII. This layer was not encountered in Core B, where coring was halted at 13 m because of stiffness of the sediment. Details of the stratigraphy are presented in the core profiles (Fig. 5), along with six radiocarbon dates (see Appendix 1) and pollen sample locations. In general the sediments were all very fine-grained, indicative of very low energy environments provided by a protected marine lagoon before about 200 B.C., and a fresh/brackish water pond afterwards. The marine portion of the cores contained small amounts of shell, small coral fragments, and abundant marine dinoflagellate cysts. There is no reason to suspect any temporal gaps in the sedimentary record.

#### RADIOCARBON DATING: CORE B

The six radiocarbon dates from Core B permitted the estimation of sediment influx into the Kawainui basin. On the basis of the two very regular rates of sediment accumulation—one for the marine sediments (average of 1.95 years/cm) and another, slower rate for the fresh/brackish water portion of the core (average of 3.75 years/cm)—ages have been interpolated for each 1 m interval of the core starting at 3 m (see discussion in Athens and Ward 1991: 69–74; Athens *et al.* n.d.). The dates are indicated on the Core B pollen diagram (see Fig. 6). The top of the sediment column dates to about A.D. 1565, while the base dates to 1210 B.C. Intervening dates can also be calculated, and one of the most significant of these concerns the transition from a marine to a fresh/brackish water basin at about 200 B.C., which has been corroborated by another coring project (Hammatt *et al.* 1990). Another significant date concerns the emergence of the Kailua sand berm, which must have occurred before about 600 B.C. but not earlier than about 1000 B.C. (see discussion in Athens and Ward 1991: 59).

#### POLLEN ANALYSIS—KAWAINUI MARSH

In this study, at least 88 species or types of angiosperm pollen belonging to 46 families are represented in the samples from Core A and Core B (the total number of species could well exceed 100 if the unknowns were identified and the generalised pollen types such as grasses, sedges, cheno-ams, and high-spined Asteraceae could be separated). Sixty-five percent of the types are in the Dry-Mesic Forest category, followed by 29 percent of the types in the Mesic-Wet Forest group, and 2 percent for the Herb category, which represents only locally derived sedge and grass pollen from the coastal marsh community. Results of the pollen analysis for Core B are presented in Figure 6. The key pollen types are graphed separately or by families, while the less frequent types are lumped as "Other" and depicted as a composite pollen curve. The Core A pollen data produced a virtually identical diagram (see Athens and Ward 1991).

Counts were also made of other palynomorphs that were not included in the pollen sum. Of importance here are the fern spores, separated into the broad monolete or trilete morphological categories; unknowns were further grouped according to their sculpturing types. *Lycopodium cernuum*, a fern ally, is included with other trilete spore types. In addition, many types of algal spores or cysts were seen throughout the deposit. Chief among these were *Pediastrum*, *Zygnema*, and *Pseudoschizaea* from freshwater environments, with *Gonyaulax* sp. and an undetermined dinoflagellate from the marine portions of the cores.

## KAWAINUI MARSH

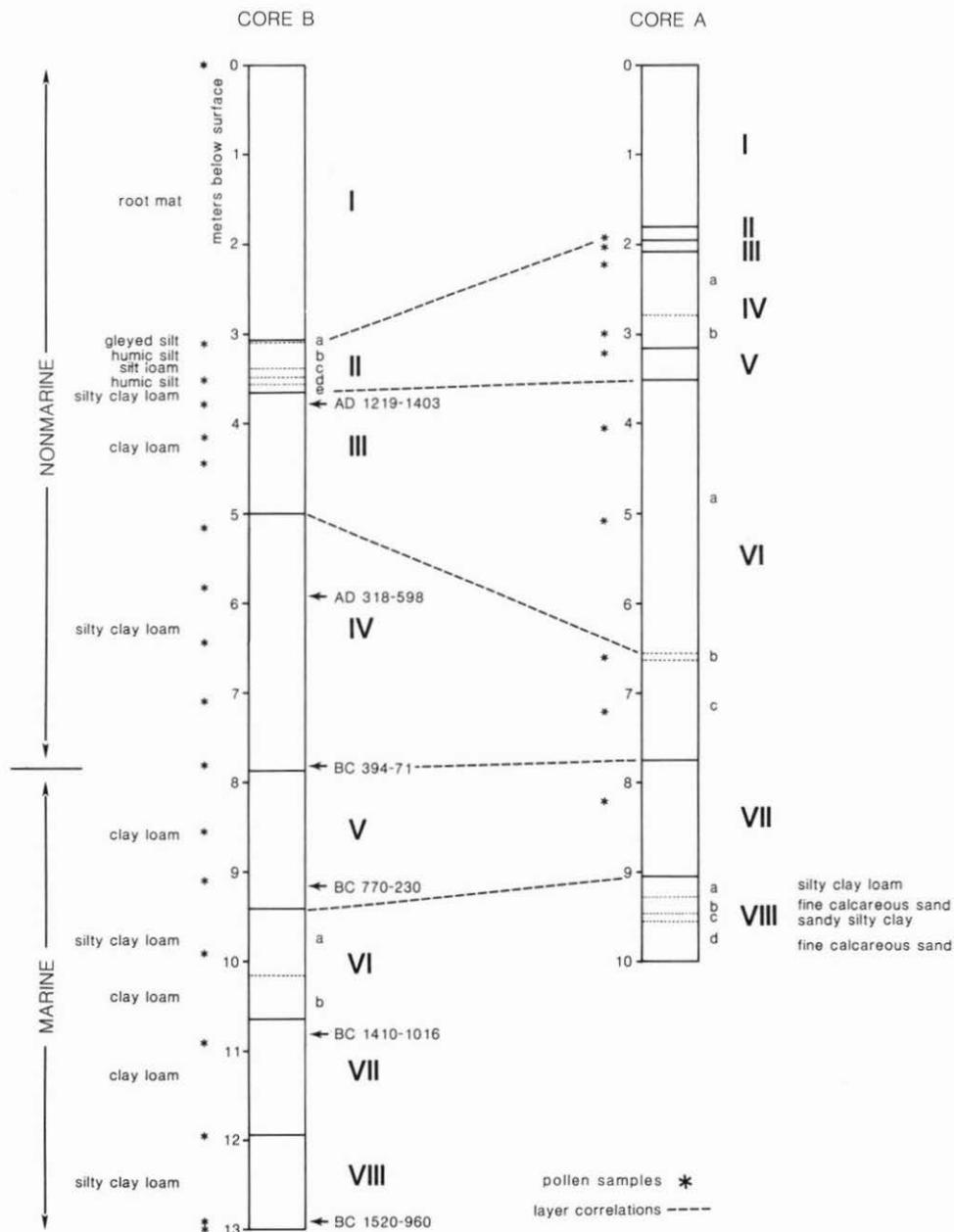


Figure 5: Sediment profiles of Cores A and B, Kawainui Marsh showing lithology, locations of pollen samples (10 from Core A, 18 from Core B), and locations of the six radiocarbon samples taken in Core B.

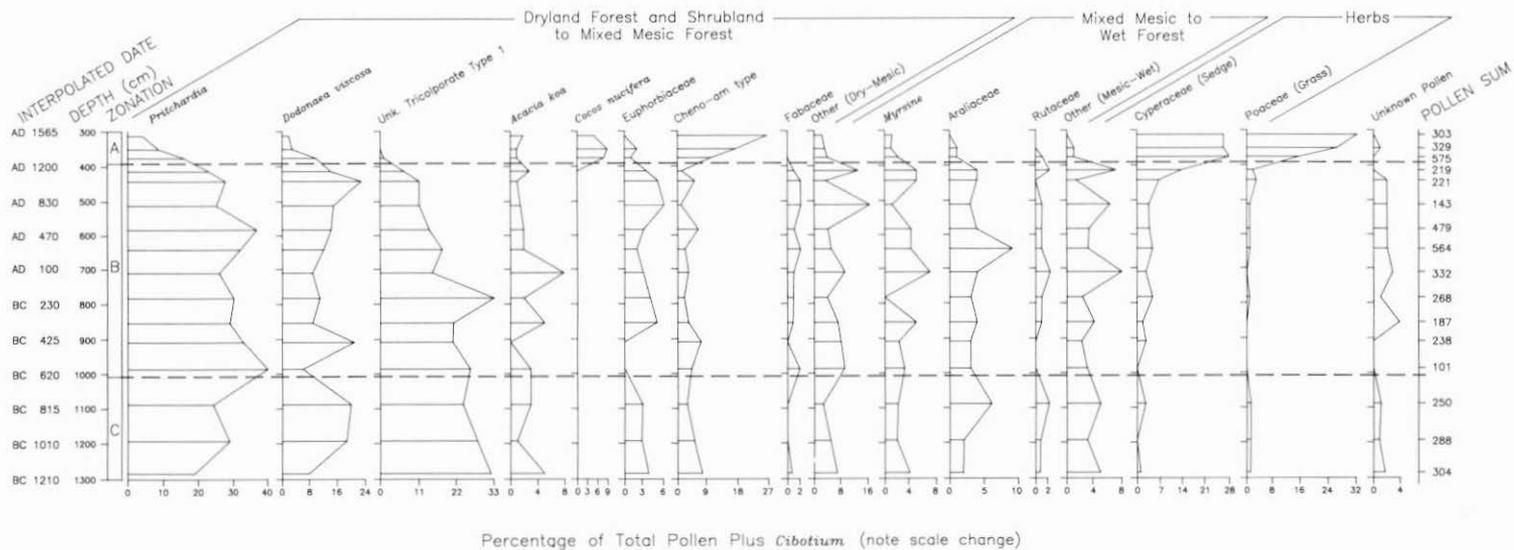


Figure 6: Pollen diagram from Core B, Kawainui Marsh. Datum is present marsh surface; no samples were obtained between 0 and 3 m owing to the unconsolidated nature of the sediment. Values are given as percentages of total pollen and the diagram format is identical to that in Figure 4. Dates were interpolated at 1 m intervals from the sediment accumulation plot (see Athens and Ward 1991: 69–74).

The Kawainui Marsh pollen slides, except for a probable historic sample in Core A (Layer II at 1.92–1.96 m), were devoid of charcoal particles. As with the Fort Shafter flats data, this suggests that fires of a natural or cultural origin were either quite limited or nonexistent within the Kawainui Marsh catchment. The fact that charcoal particles do occur in the uppermost Core A sample (Athens and Ward 1991) but not in any of the lower levels studied, is compelling evidence that fires were probably not important in the history of the site. The laboratory extraction technique is unlikely to be at fault since it is identical to that used for samples from other lowland Hawaiian sites that contain well-preserved charcoal particles.

The pollen spectra are grouped into three pollen zones roughly corresponding to the stratigraphic sequence. The base of Pollen Zone A occurs at about 3.8–4.0 m, just below the Layer II/III boundary, and dates to about A.D. 1200. The upper boundary of Zone A, dating to A.D. 1565, may continue to Layer I; however, no data were obtained owing to the nature of the sediments. Pollen Zone B extends from about 4.0 m to the base of Layer VIa around 10.2 m. Within this zone is the transition from fresh/brackish water to marine at about 7.9 m (200 B.C.). Pollen Zone C, spanning Layers VIb, VII, and VIII from 10.2 m to 13.0 m, has a basal date of 1200 B.C.

In Zone C, *Pritchardia*, *Dodonaea* and the Unknown Tricolporate Type 1 are heavily co-dominant throughout, with other species accounting for about 20 percent of the total sum. *Acacia* pollen occurs at values between 2 and 5 percent while Myrtaceae only reaches 1 percent or less throughout the profile. Because of its relative unimportance here compared to Fort Shafter, Myrtaceae is not shown on the pollen diagram. Values for the Unknown Tricolporate Type 1 are especially high and uniform, but decline with the marked rise of *Pritchardia* values near the top of the zone. At this level (985–995 cm), *Dodonaea* has dropped to about 8 percent. Other dry mesic and wet mesic types are represented by low but rather uniform percentages.

Other important components of Zone C microfossil assemblages are cysts of dinoflagellates, including *Gonyaulax* sp. and an unidentified type indicative of open bay or lagoonal environments. These exclusively marine types also occur up to the Layer IV/V boundary as well as sporadically above it, probably having been transported there by ocean spray.

In pollen Zone B, three main types are co-dominant. *Pritchardia* maintains relatively constant frequency, *Dodonaea* increases, and the Unknown Tricolporate Type 1, which peaks at about 780 cm, gradually declines before disappearing altogether in Zone A. The grass, sedge, and cheno-am curves, so characteristic of Zone A, comprise only, at most, 10 percent of the total sum throughout this zone and Zone C. Most other types maintain fairly high and uniform values throughout these two zones, as evidenced by *Acacia*, Fabaceae, Rutaceae, and the Other categories, with an increase of *Myrsine* and Araliaceae and certain other mesic to wet indicators more frequent at mid levels of Zone B.

Zone A, including Layer II (and possibly I) records the modern history of the marsh with a dominance of grass, sedge, and cheno-am pollen in the upper levels, reaching 80–90 percent of the total pollen. Coconut (*Cocos nucifera*) has a 5–9 percent frequency in this zone but is not represented in the remainder of the profile. Here, *Pritchardia* and *Dodonaea* decrease toward the uppermost sample while the Unknown Tricolporate Type 1 is weakly represented at 2 percent in the basal sample. Types in the Other categories (Dry-Mesic and Mesic-Wet) peak at 13 and 7 percent, respectively. This zone records a minor surge of Euphorbiaceae, while *Myrsine*, Araliaceae, and Rutaceae are on the decline, and Fabaceae pollen is absent.

The Kawainui pollen analyses show that the dominance of the three main types ended suddenly around A.D. 1000. *Pritchardia*, the only certain arboreal member, after reaching 37 percent around 1000 cm, fell steadily in value to the top of Zone B to well under 20 percent. After that the decline was abrupt, as it also was for the two other earlier dominants.

Since the pollen diagram is based on relative percentages of total pollen, there was a concern that the large surge of presumably locally derived sedge and grass values in Zone A might have made the decline in values of the dominants more apparent than real. Therefore, in an effort to evaluate the possible over-representation of sedge and grass pollen, raw number counts of the dominants along with those of sedge and grass were plotted. The data show that the surge in herb pollen and diminution of *Pritchardia*, *Dodonaea*, and the Unknown Tricolporate Type 1 in Zone A represent real trends.

From these data we infer that a fairly open lowland palm forest, unlike anything on the main islands at the present time, formerly covered very large tracts from coast areas to inland slopes and gulches of windward O'ahu. This finding mirrors that of the coeval Fort Shafter flats area.

Although the *Pritchardia* palm species cannot yet be separated on pollen morphological grounds, a wide range in size, from 40 to 90  $\mu\text{m}$ , suggests that at least two species are represented in the spectra (Fig. 7k-n). These species may have co-existed in the lowland palm forest, or the pollen of one or more may have been derived by wind or water from upland communities. Second in importance to *Pritchardia* pollen is the type we have designated as Unknown Tricolporate Type 1. It belongs to a very large group of non-magnoliid dicotyledons that presents many difficulties in identification because of its generalised characters, such as medium size (ca. 33-37  $\mu\text{m}$ ), finely reticulate sculpture and circular ora. These characters and details of the pollen wall may be seen in Figure 7a-f, which we offer in hopes of obtaining an identification. Judging by its pollen frequencies, this type must have been produced by a conspicuous member of the vegetation: it was probably a tree or shrub. The pollen diagram for Kawainui Marsh (Fig. 6) shows this taxon entering the record with 32 percent in the basal sample and remaining very high until about 230 B.C. at 790 cm, where it begins a steady decline for the next 100 cm, disappearing altogether by A.D. 1200. Although well represented in the Fort Shafter flats profile, its frequencies are nowhere high and it disappears synchronously with the dominant species in Zone A. Its complete and precipitous disappearance in the Polynesian period suggests the possibility that human-induced environmental changes may have been the cause of disappearance, but as it has shared the dwindling importance of several key types, other factors, notably climatic, could have played a part. Since we have been unable to secure a positive identification, we have not eliminated the possibility of extinction of the Unknown Tricolporate Type 1 late in prehistory.

Another conspicuous type seen in the pollen diagram is *Dodonaea* (Fig. 7g-i), which appears to be responding more erratically to plant community changes. This pollen type is abundant throughout with about 20 percent of the total pollen. It peaks at the base of Zone A at approximately A.D. 1000, whereupon it begins a steep decline. In Zone B it reaches 23 percent before falling to lower frequencies. It is close to 20 percent in Zone C except for the base, where it falls to 8 percent (along with a similar decline in *Pritchardia*). This is perhaps indicative of a slight shift toward a more mesic forest. A *Dodonaea* community probably covered the adjacent slopes as a shrubland along with *Chamaesyce* (included in the Euphorbiaceae curve), *Diospyros*, *Erythrina*, *Sapindus*, *Sida*, and *Wikstroemia*, all included in the Other (Dry-Mesic) category.

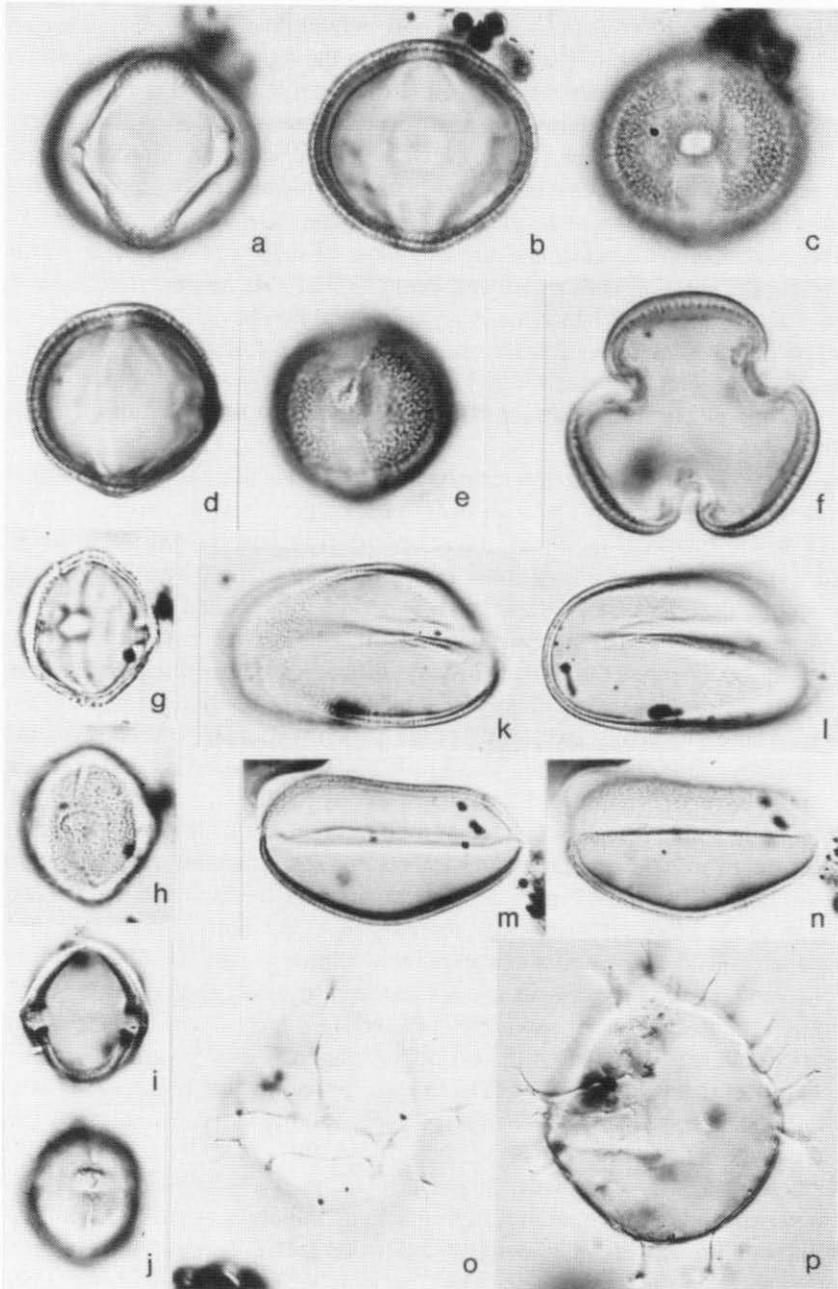


Figure 7: Photomicrographs of selected palynomorphs from Core B, Kawainui Marsh. Magnification is 630x unless otherwise indicated. a-f, Unknown Tricolporate Type 1 x 1000; a-c in equatorial view from 643-645 cm; d, e, in equatorial view from 850-860 cm; f, in polar view from 583-585 cm; g-i, *Dodonaea viscosa* in equatorial view; g, h, from 583-585 cm; i, j, from 850-860 cm; k-n, *Pritchardia* sp. in polar view; k, l, from 583-585 cm; m, n, from 643-645 cm. o, p, *Gonaulax* sp. from 1282-1300 cm.

The pollen records of *Acacia koa* (*koa*) and *Metrosideros* ('*ōhi'a*) are important for an understanding of Hawaiian pollen diagrams because both types are dominant or co-dominant over a variety of moisture regimes (dry, mesic, wet) and over a broad elevational range (lowland, montane, subalpine). Unfortunately, in the present profile their pollen signals are weak, *koa* usually reaching 1–2 percent and peaking at the base with 5 percent, which may indicate a wetter interval near the beginning of Zone C. *Metrosideros* was included with Myrtaceae since pollen of this family is difficult to separate, but their numbers were even lower than for *koa* and always less than 1 percent of the total, so the pollen curve was not shown.

The record of *koa* and '*ōhi'a* probably represents a lowland mesic forest, but one unlike that developed on leeward O'ahu. There, the pollen curves for *Acacia* and Myrtaceae clearly show the steady presence of these types with values between 3 and 10 percent. In contrast, the pollen record from the windward site at Kawainui Marsh shows comparable levels of *Acacia* but values mostly below 1 percent for Myrtaceae. Included in this forest would be *Antidesma*, *Bobea*, *Cyrtandra*, *Diospyros*, *Dodonaea*, *Elaeocarpus*, *Freycinetia*, *Gardenia*, *Hedyotis*, *Myrsine*, *Melicope*, *Pisonia*, *Pleomele*, *Psychotria*, *Sapindus*, and *Wikstroemia*, all recorded in this profile.

A diverse mesic forest is probably also indicated by the pollen data. Such forests, comprising a variety of tree species, would be expected on wetter sites extending up to 1600 m elevation (Gagné and Cuddihy 1990). They form open stands with no clear dominants in the over-story. The pollen types from the Kawainui assemblage representing this forest community include *Alectryon*, *Aleurites*, *Bobea*, *Bonamia*, *Claoxylon*, *Colubrina*, *Diospyros*, *Gouania*, *Myrsine*, *Nesoluma*, *Nestegis*, *Pisonia*, *Pouteria*, *Psychotria*, *Strongylodon*, and *Zanthoxylum*. *Syzygium* may be represented here but would be included with the Myrtaceae sum. A wetter phase of this type of forest may have attained greater importance at the base of the Kawainui profile, as *Acacia*, *Myrsine*, Other types (Dry, Mesic, Wet), and the Unknown Tricolporate Type 1 are slightly higher, while *Pritchardia* and *Dodonaea* are in decline. Conflicting data from the Araliaceae curve (including *Cheirodendron* and *Tetraplasandra*) show a slight decrease during this interval, whereas they should be favoured during a wet phase.

#### SUMMARY OF FINDINGS: LOWLAND VEGETATION ON O'AHU DURING THE LATE HOLOCENE

The principal findings of this research, especially with regard to past lowland vegetation on O'ahu, may be briefly summarised as follows:

1. The sediments of Kawainui Marsh provide a continuous record of sedimentation and infilling from about 1200 B.C. to A.D. 1565. The sedimentary record at Fort Shafter flats, on the other hand, is probably continuous from about 1200 B.C. to about 200 B.C., whereupon the nature of the sedimentary record changes with the advent of probable stream erosion and depositional events (Depositional Unit 3, dating to either A.D. 800–900 or A.D. 1300–1400), which in turn is followed by a long period of ponded conditions (Depositional Unit 4), which evidently lasted into the historic period.
2. A rich assemblage of angiosperm pollen was recovered: Kawainui Marsh yielded 88 species or types belonging to 46 families, and the Fort Shafter flats record contained

84 species or types belonging to 49 families. In addition, a diverse assemblage of pteridophyte spores and other organic-walled microfossils was recorded.

3. The lowlands of both sampling areas (windward and leeward O'ahu) before Polynesian contact and up to roughly A.D. 1000 were dominated by *Pritchardia* palm forests (see also Hammatt *et al.* 1990). After about A.D. 1000, the palm forests rapidly declined. Today there are only a few widely scattered relict stands. The earlier importance of *Pritchardia* in lowland Hawaiian plant communities generally has not been appreciated by previous investigators (an exception was MacCaughy as mentioned by Selling 1948: 85-86).
4. Floristically, the pollen diagrams of Kawainui and Fort Shafter are quite different. At Kawainui, a lowland *Pritchardia* forest was present along with *Dodonaea* shrubland probably on the lower elevations and slopes, while a mixed mesic forest occupied valleys and higher slopes. The species represented by the Unknown Tricolporate Type 1 was probably a conspicuous member of the lowland environment, judging by the frequency of its pollen in the profile.

In the Fort Shafter watershed, a *Pritchardia* forest must also have covered vast areas of the lower elevations judging by its dominance in the pollen record. In contrast to windward O'ahu though, no *Dodonaea* shrubland occurred on the leeward side. Rather, a diverse dryland to mixed mesic forest comprising a multitude of species was present. Wet forest elements seen in both profiles are presumably derived from higher elevation forest communities.

5. At both Fort Shafter and Kawainui Marsh, *Pritchardia* declined precipitously late in their respective sequences, which was after about A.D. 1000 at Kawainui. At Kawainui, *Dodonaea* also follows this pattern. In contrast, the Unknown Tricolporate Type 1, the third member of the dominants, declines steadily from about 1200 B.C. (though there is a small rise at about 200 B.C.). Nevertheless, it likewise drops precipitously after about A.D. 1000, disappearing from the assemblage altogether in the latest samples. These data provide strong evidence that late in prehistory the lowland communities had been extensively transformed. This transformation is most probably in some way related to the settling of Hawai'i by Polynesians.

In the case of *Pritchardia*, predation on the seeds by Polynesian-introduced rats has been cited by some investigators as a likely cause of its decline (Hammatt *et al.* 1990), though insect predation has also been suggested (see Clarke in Selling 1948: 86). Although these may be contributing factors, the fact that *Dodonaea* and the Unknown Tricolporate Type 1 also declined precipitously and coincidentally with *Pritchardia* suggests that another mechanism (or mechanisms) is probably involved. What the cause or causes might be have not been satisfactorily determined. The role of prehistoric Polynesian population growth with inland expansion of settlement and agriculture, though probably related, is unclear.

6. The pollen record from Fort Shafter flats is comparable in diversity to that recovered from Kawainui Marsh despite substantial floristic differences. Although *Pritchardia* appears to have occupied a similar level of dominance at both Kawainui and Fort Shafter, the leeward vegetation community appears to have had numerous secondary species that were of relatively greater significance than these same species at Kawainui.

7. The pollen record for the 32 presumed Polynesian-introduced species (see Athens and Ward 1991: 20–21 for a listing) is very sparse. Only three species were found—*Aleurites moluccana* (*kukui*), *Cocos nucifera* (*niu*), and *Cordyline fruticosa* (*ki*)—and these occurred in late stratigraphic contexts, dating after about A.D. 1000 to 1200 at Kawainui Marsh. *Kukui* appears to be present by either A.D. 800–900 or A.D. 1300–1400 at Fort Shafter flats: the age of the late part of this sequence is uncertain. Although the stratigraphic integrity of the cores taken by Hammatt *et al.* (1990) is open to question (see discussion in Athens and Ward 1991: 13–14), it appears that a case can be made for the pre-Polynesian presence of *Hibiscus tiliaceus* in their Core 6 at levels dating to 2700–2800 years B.P. and 2200 years B.P. and later. Unfortunately, only single pollen grain occurrences were noted in the pre-Polynesian levels.

Because information on Polynesian-introduced species was much more limited than had been anticipated, it remains inconclusive whether some of the species might be native to Hawai'i. In any case it is curious that not a single pollen grain of such ordinarily common plants as *Hibiscus tiliaceus*, *Morinda citrifolia*, and *Thespesia populnea* was found within the stratigraphic sequences of this study. With so little pollen from the so-called Polynesian introductions entering the sedimentary record late in the sequence when they are definitely known to have been present, it is possible that some species might actually have been present in Hawai'i before the arrival of the Polynesians. Nevertheless, because two locations—Kawainui and Fort Shafter flats—yielded similar negative results in the context of abundant pollen assemblages, the case for further challenges to conventional wisdom regarding Polynesian plant introductions is weakened (but note the evidence of Hammatt *et al.* 1990 for *Hibiscus tiliaceus*). Other catchment areas in Hawai'i should be sampled before most of the non-cultivated, supposed Polynesian, introductions should be definitely regarded as introduced.

8. Although not discussed in this article, it is perhaps appropriate to mention that the Kawainui sedimentation data indicate highly regular but substantially different rates for the lower marine layers compared to the upper non-marine layers in Core B. Of particular significance was the demonstration—at least insofar as these data are concerned—that the commonly held belief that agricultural practices of prehistoric Hawaiians were responsible for infilling of the basin and coastal progradation is incorrect. The rate of infilling, in fact, slowed for the fresh/brackish water layers to almost half of what it was for the marine layers. And even within the fresh/brackish water zone, the rate appears to have slowed slightly following the time of the arrival of the initial Polynesian settlers. Thus, there is no indication that the sedimentation rate increased during the later part of the prehistoric occupation sequence, when inland occupation and agriculture in the Kawainui catchment area had become much more widespread and intensive. These data accord with recent findings elsewhere in the Pacific (Nunn 1991) and in Micronesia (Athens *et al.* 1989) that suggest natural processes rather than human activities (particularly agriculture) are paramount in causing coastal progradation and basin infilling (see Athens and Ward 1991, and Athens *et al.* n.d. for detailed discussion of this point with respect to the Kawainui data).
9. The lack of charcoal particles in all of the pollen slides except for the latest in Core A suggests that fire has had little or no effect on natural vegetation communities in the Kawainui Marsh or Fort Shafter flats watersheds. There is no evidence for large-scale

or frequent vegetation burning either before or after Polynesian settlement in Hawai'i. Thus, at least so far as indicated by these data, natural fires do not appear to have occurred on O'ahu before human settlement. This finding favours the various critics of Vogl (1969) concerning the unlikely role of fire in the evolution of the Hawaiian flora and plant communities (e.g., Mueller-Dombois 1981; Smith and Tunison n.d.).

The fact that no evidence of fire was observed in sediments pertaining to the period of ancient Hawaiian occupation seems unusual. Charcoal particles have been documented in sediment cores elsewhere in Hawai'i (Kahana Valley on windward O'ahu—see Beggerly 1990), and from other areas of Polynesia (D. Steadman, pers. comm.). This suggests that prehistoric swidden (also called shifting or slash and burn) agriculture (Kirch 1977: 263, 272; 1985: 224) in some areas of Hawai'i might not have involved the burning of the cuttings (slash), which instead may have been used for mulch. On the other hand, if there had been extensive burning in the Kawainui and Fort Shafter watersheds, it is unclear why the charcoal did not reach the marsh basin or the lowlands of the Fort Shafter area. The fact that charcoal was present in the uppermost sample of Core A suggests that laboratory processing procedures of the pollen samples are an unlikely reason for its absence in the samples.

10. Frequencies of the cheno-am type and grass pollen begin to rise dramatically after approximately A.D. 1200, as indicated by the Kawainui Marsh data and equally late, as mentioned, for Fort Shafter flats. Such vegetation is indicative of disturbed environments, and is presumably related to gardening activities and other landscape disturbances due to prehistoric Hawaiian occupation. The significance of this information is that it provides a time frame—about A.D. 1200—for the onset of what was probably the rapid growth of a previously small prehistoric population (see for example Stannard 1989) with inland expansion of settlement and agriculture (Allen 1987).
11. At Kawainui Marsh the sedge pollen curve begins a steep rise after about A.D. 1000. Before this date, the water in Kawainui Marsh must have been too deep to support a marsh community except for a narrow band along its margins. Thus, before about A.D. 1000, Kawainui Marsh was almost entirely an open body of water, and afterwards the marsh community expanded very rapidly. The pollen data also support the findings by Athens and Ward (1991) that the peat layer documented along the marsh's southeastern margin (see discussion of excavations in Athens and Ward (1991), and in Allen-Wheeler (1981)) did not begin to form until about A.D. 1000 or shortly thereafter.<sup>5</sup>

## CONCLUSION

The palynostratigraphic investigations at Fort Shafter flats and Kawainui Marsh on leeward and windward O'ahu provide lengthy records of Hawaiian lowland plant communities and

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<sup>5</sup>Allen-Wheeler (1981) reports four radiocarbon dates ranging from A.D. 588–748 to A.D. 1249–1369 (calibrated date ranges) for her peat layer. Although Allen-Wheeler (1981: 62) believes the peat layer began to form about A.D. 500–600, the low frequency of palm pollen (less than 5 percent) for the peat layer makes it doubtful that it could date before A.D. 1000, given the results of our pollen data.

landscape change dating from about 1200 B.C. The earlier part of the sequence dates well before the arrival of the Polynesians, who probably did not settle in Hawai'i until some time during the first half of the first millennium A.D., or possibly even slightly later. Because of this time difference, it has been possible to investigate the possible impact of the Polynesians on a pristine environment, especially in the lowlands, where land use and settlement had been far more intensive than elsewhere. The sediment sequences from Fort Shafter flats and Kawainui Marsh yielded a rich pollen record bracketed by 14 radiocarbon dates. The Kawainui Marsh record was particularly useful because it provided a continuous, uninterrupted sediment sequence until about A.D. 1565.

The pollen record clearly shows a substantially different environment in lowland O'ahu than has been previously appreciated or documented for the period before Polynesian contact and during the early period of Polynesian settlement. It also demonstrates the remarkable extent to which the landscape had already been changed by the time of the earliest Western contact with Hawai'i. Palm forest, *Dodonaea* shrubland, vegetation represented by the Unknown Tricolporate Type 1, and mixed mesic lowland forest had been drastically reduced. The involvement of the Polynesian settlers in Hawai'i in this transformation is quite likely, though the possibility of climate change as a contributing factor must also be considered.

One lesson to be learned from these findings is that investigators should not rely on early written descriptions as reliable sources of information about the natural environment (i.e., undisturbed and unchanged by human intervention) of the Hawai'i lowlands. As Kirch (1982: 32) noted a decade ago, the assumption that the most pronounced changes occurred only with the advent of highly competitive exotic plant and animal species brought in after Captain Cook's visit in 1778 is erroneous. The present study provides another empirical case demonstrating the fragility of island ecosystems and what seem to be the extreme consequences that even pre-industrial societies can have on their natural environment.

#### ADDENDUM

As this paper was going to press, the likely identity of the Unknown Tricolporate Type 1 pollen was revealed to us in an unusual fashion. Even though we attempted to identify this type by referring to available pollen floras and by sending material to palynologists with extensive pollen reference collections, we were unsuccessful, although we knew it had to be a dicotyledon, possibly in the legume family (Athens and Ward 1991: 100). Recently, members of the Nature Conservancy, conducting a botanical survey of Kaho'olawe Island (140 km southeast of O'ahu) for the Kaho'olawe Island Conveyance Commission, discovered a new species (possibly a new genus), a legume, on a steep-sided hill at the base of the seacliffs. This species, which is represented by only two individuals, is currently being formally described by David Lorence at the National Tropical Botanical Garden in Lawa'i, Kaua'i. The two known plants, legumes from the subfamily Mimusoideae, were shrubs 1 m tall and 2 m across.

Because of our participation in the palaeoenvironmental component of the same project, we became aware of the new find and asked for flower samples to attempt a match with our fossil pollen that we presumed was also legume. Analysis of pollen collected from flowers in the leaf litter under the plants (fresh flowers were not available at the time) suggests that it is indistinguishable from that of the Unknown Tricolporate Type 1. Under light microscopy it appears that the wall structure and sculpture are similar, the aperture type is

identical, and the overall size fits the range observed in the fossil samples. We are currently conducting ultrastructural studies using electron microscopy (SEM, TEM) of the fossil pollen type and the pollen of the new species to determine with greater precision how closely they compare. If the identification is confirmed, then this development will have important implications for the history of lowland vegetation in Hawai'i and tropical islands in general.

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**Appendix 1. Radiocarbon results, Fort Shafter flats and Kawainui Marsh Core B.**

Lab #	Provenance/Material	Wgt g	CRA	$\delta^{13}\text{C}$	CAL AD/BC
FT. SHAFTER FLATS					
B32504	Profile 1, VI 335 cm b.s./wood	128	1150±60	-26.9	A.D. 768-997 (96%) A.D. 725-746 (3%) A.D. 714-724 (1%)
B35834	Profile 1, VII 346-360 cm b.s./kukui endocarp	54	580±55	-26.3	A.D. 1284-1422 (100%)
B32505	Profile 1, VIII 365-370 cm b.s./wood	20.7	2210±80	-29.4	B.C. 409-90 99%
B34769	Profile 1, VIII 372-376 cm b.s./peat/silt	250.0	2290±80	-43.8	B.C. 549-167 (90%) B.C. 759-686 (7%) B.C. 591-571 (1%) B.C. 141-123 (1%)
B32506	Profile 1, VIII 467-472 cm b.s./peat/silt	311.0	2230±100	-27.2	B.C. 450-90 (90%) B.C. 522-460 (4%) B.C. 754-692 (3%) B.C. 83-66 (1%) B.C. 539-531 (0%)
B34770	Profile 1, IX 480-500 cm b.s./shell <sup>1</sup>	98.9	2760±60	+0.3	B.C. 630-164 (100%)
B35835	Core 1 589-597 cm b.s./peat/silty clay loam	136.8	2580±80	-31.2	B.C. 852-484 (88%) B.C. 471-429 (7%) B.C. 899-857 (5%)
B34771 <sup>2</sup>	Core 1 1006-1010 b.s./silty clay	113.1	3010±80	-39.0	B.C. 1439-1047 (98%) B.C. 1043-1013 (2%)

## KAWAINUI MARSH

B38918	Core B, III 373–383.5 cm b.s./clay loam	148.5	690±60	-22.2	A.D. 1219–1333 (69%) A.D. 1339–1403 (31%)
B40608	Core B, IV 585–597.5 cm b.s./silty clay loam	226.7	1610±70	-25.2	A.D. 318–598 (92%) A.D. 257–303 (8%)
B38919	Core B, IV 777–786.5 cm b.s./silty clay loam	130.4	2170±70	-25.3	B.C. 394–91 (99%) B.C. 79–71 (1%)
B38920 <sup>2</sup>	Core B, V 911–919 cm b.s./clay loam	209.0	2850±100	-21.3	B.C. 770–230 (100%)
B38921	Core B, VII 1070–1090 cm b.s./shell <sup>3</sup> and coral	61.0	3450±50	+1.47	B.C. 1410–1016 (100%)
B38922 <sup>2</sup>	Core B, VIII 1282–1300 cm b.s./silty clay	430.0	3480±100	-19.1	B.C. 1520–960 (100%)

Note: All samples were processed by Beta Analytic Inc. of Miami, Florida, U.S.A. Calibration from Stuiver and Reimer (1986); all sample ranges encompass 95% confidence interval (probability estimate in parentheses).

For terrestrial samples calibration is from 10 year data set for atmospheric radiocarbon. For marine samples calibration is from 20 year data set for marine radiocarbon; Delta R value of 115±50 years.

<sup>1</sup> Marine shell, *Pinctada radiata*

<sup>2</sup> Small sample size; carbon weights after pretreatment of 0.9 (Beta-34771), 0.4 (Beta-38920), and 0.5 grams (Beta-38922); quadruple-normal counting time to reduce statistical error.

<sup>3</sup> Mixed marine shells (see listing in Athens and Ward 1991).