

# Nonmarine Mollusks and Ecological Change at Barbers Point, O'ahu, Hawai'i

Carl C. Christensen<sup>1</sup> and Patrick V. Kirch<sup>2</sup>

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## ABSTRACT

Study of fossil nonmarine mollusks recovered from archaeological and paleontological sites at Barbers Point in the karstic 'Ewa Plain of southwestern O'ahu, Hawai'i, demonstrates that prior to human occupation this arid region supported a fauna of 16 or more native terrestrial mollusk species. Although precise ecological data are lacking for most taxa represented, the composition of this fauna is consistent with botanical evidence that the region supported open-canopy dry forest and grassland prior to human settlement. Nonmarine mollusks were analyzed from 5 sites: 2 unmodified sinkholes, 2 human habitation sites, and 1 modified sinkhole (possible pit garden). At all but the last of these, a consistent pattern was observed in which now-extirpated native land snail taxa [species of *Orobophana* (Helicinidae), *Amastra* and *Leptachatina* (Amastridae), *Nesopupa* and *Pupoidopsis* (Pupillidae), and *Cookeconcha* and *Endodonta* (Endodontidae)] were replaced over time by ecologically tolerant native taxa that still persist in the region [*Lamellidea* and *Tornatellides* (Achatinellidae), *Succinea* (Succineidae), and to a lesser extent *Lyropupa* (Pupillidae)]; eventually, alien species introduced to the Hawaiian Islands during the prehistoric and historic periods [*Lamellaxis gracilis* (Subulinidae) and *Gastrocopta servilis* (Pupillidae), respectively] became prominent elements in the fauna. *Gastrocopta servilis* is now the dominant species in the litter fauna. At a single site (the possible pit garden), an aquatic species [*Assimineea nitida* (Assimineidae)] was extremely abundant, suggesting that this site may formerly have been an anchialine pool. Temporal changes in the composition of the land snail fauna of the Barbers Point region indicate drastic ecological disturbance, undoubtedly a result of human impact. The observed co-occurrence of prehistorically introduced mollusk and vertebrate taxa with extinct or locally extirpated native species of land snails and birds provides evidence in support of the conclusion that much of this ecological change, and many of the associated extinctions, resulted from the activities of the Hawaiians prior to the advent of European influence in A.D. 1778.

## INTRODUCTION

The nature of prehistoric human impact on the Hawaiian ecosystem is a matter of considerable interest to archaeologists and biologists alike (Kirch 1982a,b; Olson & James 1982a,b, 1984). Archaeologists interested in the course of prehistoric cultural evolution in the Hawaiian Islands must consider the range of resources available for exploitation by the first colonizing Polynesians, as well as the complex process of anthropogenic ecological modification and cultural adaptation to the changing Hawaiian environment. Biologists studying Hawaiian plants and animals must consider the effects of some 1,600 years of human impact as they attempt to interpret the taxonomy, evolution, and ecology of the

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1. Bernice P. Bishop Museum, P.O. Box 19000-A, Honolulu, Hawai'i 96817, USA.

2. Thomas Burke Memorial Washington State Museum, University of Washington, Seattle, Washington 98195, USA.

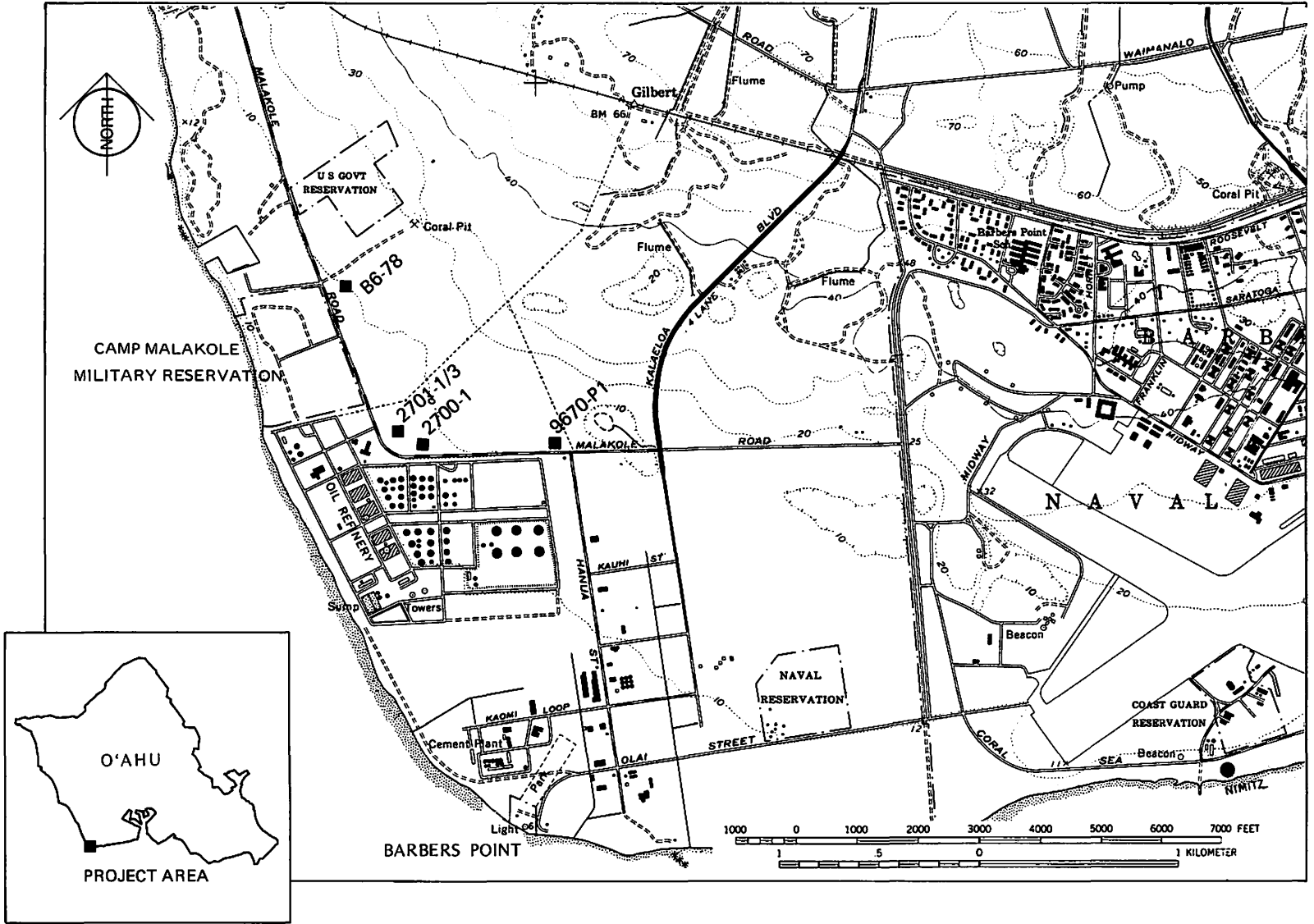
various elements of the modern biota. Several methods have been developed that aid in the task of paleoenvironmental reconstruction necessary for the interdisciplinary investigation of the interaction of the Hawaiians and their environment. One such technique is snail analysis, a process analogous to pollen analysis, in which temporal changes in the composition of nonmarine mollusk communities are used to interpret larger ecological changes. This technique has been used extensively by archaeologists and paleontologists in the reconstruction of ancient environments in Europe and North America (Kerney 1966; Evans 1972; Bobrowsky 1984). The potential value of fossil land snails as indicators of ecological change in Hawai'i has long been recognized, but although Henshaw (1904), Perkins (1913), and Zimmerman (1948) all referred to such evidence in discussions of ecological change, until recently little use was made of the technique in investigations of Hawaiian paleoenvironments. Kirch (1975) presented malacological evidence in support of conclusions regarding anthropogenic ecological change in Halawa Valley, Moloka'i. Additional studies are those of Christensen (1983, 1984) regarding fossil nonmarine mollusks from sites in South Kohala and North Kona, respectively, on the island of Hawai'i, and continuing studies of Barbers Point sites by Christensen et al. (in prep.).

In 1976 the Bishop Museum conducted an archaeological program of survey and test excavations at Barbers Point, in the karstic 'Ewa Plain of southwestern O'ahu (Sinoto 1976). Study of sediments found in solution sinkholes in emerged Pleistocene reef limestone revealed the presence of abundant avian remains. Material recovered then and subsequently included the bones of many extinct species, documenting a previously unsuspected diversity in the endemic avifauna of O'ahu (Olson & James 1982a,b, 1984). During a later salvage phase of the archaeological studies (Sinoto 1978), these sites were found to contain rich deposits of fossil nonmarine mollusks; a nonquantitative preliminary study (Kirch 1978) indicated that these were a potential source of information regarding paleoenvironmental change at Barbers Point and recommended that further investigations be undertaken.

In April 1980 we were requested by Dr. Hallett H. Hammatt, Archaeological Research Center Hawaii, Inc. (ARCH), to investigate nonmarine mollusks in archaeological and paleontological sites to be excavated under his direction (Fig. 1). This work was conducted under contract to the U.S. Army Corps of Engineers as part of environmental impact mitigation efforts for the Barbers Point Deep Draft Harbor. In cooperation with the ARCH field team (Hammatt and William H. Folk, II), we obtained column samples from a limestone sinkhole containing remains of extinct birds, from 2 human habitation sites, and from 1 small culturally sterile sink. In addition, we sampled the deep sinkhole (50-Oa-B6-78) previously excavated by Sinoto (1978). In all, 26 soil samples were analyzed, from which 21,376 shells were extracted, sorted, identified, and counted. One additional limestone sinkhole was sampled, but the material obtained was not analyzed owing to funding limitations. The present report contains the results of these analyses and is an expansion of a manuscript report (Kirch & Christensen 1980) prepared for ARCH under contract to the Department of the Army, Corps of Engineers, Pacific Ocean Division. The ARCH archaeological investigations undertaken concurrently with our malacological studies have been reported upon by Hammatt & Folk (1981). Additional archaeological studies in the Barbers Point region are those of Davis & Griffin (1978), Sinoto (1979), and Davis et al. (in prep.).

#### MATERIALS AND METHODS

This investigation was the first major application of quantitative snail analysis in Hawai'i, and therefore the methods used are described in detail.



**Site selection.** Sites to be sampled for nonmarine mollusks were selected by ARCH personnel, with the exception of Site B6-78, which we chose for study because of the abundant avian remains recovered there during Sinoto's earlier excavations.

**Sampling.** Soil samples for snail analysis were taken as continuous columns (50 or 100 cm<sup>2</sup> in cross-sectional area) cut into exposed vertical stratigraphic sections. Columns were taken at points where the stratigraphic section appeared to be relatively complete and free of disturbance. Sampling intervals ranged from 2 to 10 cm and did not cross stratigraphic boundaries. At the time of sampling, notes were made on the stratigraphic profile, although detailed stratigraphic analysis was the responsibility of the ARCH personnel.

**Extraction.** In the laboratory each sample was air-dried and weighed on an Ohaus triple-beam balance. The sample was then wet-sieved using 4-mm, 1-mm, and 0.5-mm standard mesh screens (material passing through the 0.5-mm screen was discarded). The fractions retained were oven-dried, weighed, and bagged. The 4-mm and 1-mm fractions were hand-sorted under a low-power (7×) binocular microscope, and all countable specimens (complete shells and those fragments including the shell apex) and fragments of species not represented in a particular sample by countable apices were removed, as well as bones, marine shells, etc. Material retained by the 0.5-mm screen was examined for the presence of shells of species not otherwise represented in a particular sample, but it was not quantitatively analyzed. Although workers in other regions routinely separate all snails retained by a 0.5-mm mesh screen, the presence of heavy calcareous deposits on shells from the deeper samples of some of the Barbers Point sites, together with the difficulty of sorting and counting the often extremely abundant immature or broken shells that make up the bulk of the molluscan material retained by the 0.5-mm screen, made it impractical to treat this fraction quantitatively.

**Counting.** In quantifying frequencies of mollusk taxa, only intact shells or fragments containing the shell apex were counted to avoid double counting of broken shells. Identifiable nonapical fragments of species not otherwise represented in a particular sample, or those present only in the 0.5-mm fraction, are indicated in the data tables with a plus sign (+). A few living individuals of *Gastrocopta servilis* (Gould, 1843) found in subsurface samples are thought to be the result of contamination; these are identified in the data tables as numbers within parentheses.

**Identification.** Identification of terrestrial mollusks was accomplished with the aid of published reports and by comparison with identified specimens in the Bernice P. Bishop Museum. In most instances, identification was to species level; where the condition of the specimens (broken, immature, etc.) or the unsettled taxonomy of the group (as in *Tornatellides*) prevented precise identification, determination was to the generic or family level. A few shells too broken or immature even for family-level identification are listed in the data tables merely as "unidentified." Vertebrate remains were identified by Carla Kishinami, Division of Vertebrate Zoology, Bishop Museum.

**Archaeological site designations.** Two archaeological site designation systems have been used in the Barbers Point region. Bishop Museum site numbers assigned by Sinoto

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Fig. 1. Location map showing Sites B6-78, 9670-P1, 2700-1, 2701-1, and 2701-3 at Barbers Point, O'ahu (base map: 'Ewa, Hawai'i, quadrangle, U.S. Geological Survey 7.5' topographic series, 1962).

(1976, 1978, 1979) carry the prefix "50-Oa-" (example: 50-Oa-B6-78), while for State of Hawai'i site numbers designated by Davis & Griffin (1978) and Hammatt & Folk (1981) the prefix is "50-80-12-" (e.g., 50-80-12-2701-1) (in this report these prefixes are omitted from text except at first mention of a particular site designation in its site report). Hammatt & Folk (1981) assigned a 2nd state number to several sites. We will use Bishop Museum numbers where designated, as well as the original State of Hawai'i number assigned to a particular site; as the revised state numbers have been cited by Christensen (1982) and Olson & James (1982a,b), they are also noted.

**Presentation of data.** Brief site descriptions are presented for each site from which samples were analyzed. Raw counts recorded for shells of each taxon in each sample are presented. To permit comparison of density of shells for various samples, we present a concentration index (countable shells per 100 g sample weight) for the total number of shells (not including eggs) of all taxa for each sample. Graphical summaries are provided for each stratigraphic column; for each sample, the relative abundance of a particular taxon is indicated by the width of the vertical bar for that taxon (species making up less than 1% of the countable shells in a particular sample are represented by a "+"). To demonstrate discontinuities and the degree of grading within the stratigraphic columns of the 2 deepest sinks (B6-78 and 9670-P1), we have made use of paleoecological similarity matrices (Pielou 1979). Whittaker's (1952) Proportional Similarity Index was used to provide a measure of the similarity between the molluscan communities represented in any 2 samples. Discontinuities within the soil column can be detected through inspection of a matrix constructed of the similarity indices for all samples within the column. The extent to which the faunal sequence at a particular site matrix is graded is determined by the use of the ratio of  $Q$ , the grading index of Pielou (1979) for a particular similarity matrix, and  $Q_{max}$ , the maximal value of  $Q$  for a matrix of such dimensions (this ratio ranges from 0 to 1, low values signifying a well-graded matrix). Similarity matrices are presented graphically.

**Ecological interpretations.** Ecological data pertinent to the various species were abstracted from published sources, where available, or from records and collecting data associated with specimens in Bishop Museum. This ecological information is much less complete than that usually available for land snail taxa in Europe and the mainland United States, where snail analysis is a relatively refined method of paleoenvironmental reconstruction. Interpretation of the Barbers Point material is complicated by the fact that many of the species represented are universally extinct, and thus direct evidence of their ecology is not available. Because of the virtual destruction of native lowland habitats in the Hawaiian Islands, modern observations of extant populations of other native taxa may not reflect the full range of habitats in which these snails once occurred. Because of these deficiencies in available ecological data, we decided to categorize taxa of native terrestrial mollusks according to whether they still inhabit the study area (NL = Native, Extant) or are now locally or universally extinct (NE = Native, Extinct). Members of the NL group we interpret as being tolerant of ecological disturbance associated with human activities, while the NE group apparently includes anthropophobic taxa intolerant of such environmental change. Christensen & Kirch (1981) demonstrated the significance of prehistorically or historically introduced land mollusks as stratigraphic markers and as indicators of human ecological impact. These taxa are categorized here either as Introduced, Prehistoric (IP) for alien taxa introduced to the Hawaiian Islands prior to A.D. 1778 or Introduced, Historic (IH) for taxa introduced during the period following the European rediscovery of the islands. A single aquatic species (AQ) occurs in the Barbers Point sites.

## SYSTEMATIC REVIEW

## Family HELICINIDAE

**Orobophana uberta** (Gould, 1847)

According to Neal (1934), this species is precinctive to O'ahu, where it has been found over a wide altitudinal range. Neal reported that these snails live on the ground on dead leaves and twigs; little is known of their habitat preferences. *Orobophana uberta* was formerly more widely distributed than today, and fossil shells may be found in abundance in localities where, as at Barbers Point, the species is now extinct.

## Family ASSIMINEIDAE

**Assiminea nitida** (Pease, 1865)

*Assiminea nitida* is an amphibious snail of wide distribution in the Indo-Pacific region (Abbott 1958). Maciolek & Brock (1974) found this euryhaline species to be a common inhabitant of anchialine ponds along the Kona coast of the island of Hawai'i, occurring over a salinity range of 2 to 30 parts per thousand.

## Family ACHATINELLIDAE

**Lamellidea** spp.

Shells of this genus were abundant in all samples studied and are a major component of the modern litter fauna of the Barbers Point region. Considerable morphological variation within the fossil material obtained suggests the presence of more than 1 species of *Lamellidea*, but no specimens could be definitely attributed to any species other than *L. gracilis* (Pease, 1871). This species occurs throughout the Hawaiian Islands from sea level to 300 m elevation (Cooke & Kondo 1960) and is one of the few native land snails commonly found in association with non-native plant communities.

**Tornatellides** spp.

At least 3 species of *Tornatellides* are represented in this material. Because of the difficulty of identifying members of this genus, particularly when immature or broken shells are involved, no attempt has been made to differentiate the various species present. One, or possibly 2, species of this genus still inhabit the Barbers Point region, and for purposes of ecological analysis all *Tornatellides* found are classified as "native extant" taxa; we do not believe that this unavoidable oversimplification results in significantly overstating the importance of the "native extant" faunal element in any sample. Little is known of the ecological preferences of species of *Tornatellides*, although their persistence in this region of exotic vegetation is indicative of a rather broad tolerance of changing ecological conditions.

## Family AMASTRIDAE

**Amastra (Cyclamastra) umbilicata umbilicata** (Pfeiffer, 1855)

A single shell fragment identifiable as this species was found in a sample from Site B6-78; additional shells were found at Site 9670-P1 in the backdirt piles of the ARCH excavations. *Amastra umbilicata* or closely related taxa have been reported from all main islands except Ni'ihau. "For the greater part, these were shells of the plains and low elevations, down to near sea level. With the passing of the low forests these Amastras have become extinct, with few exceptions" (Pilsbry & Cooke 1914-1916).

**Leptachatina (Angulidens) cookei** Pilsbry, 1914

Fossil shells of this extinct species have been found in a few scattered locations in the arid coastal regions of western O'ahu. *Angulidens*, the subgenus to which both of the Barbers Point *Leptachatina* belong, is represented by 1 or more species on each of the main islands of the Hawaiian Chain; most inhabited lowland areas, and nearly all are extinct (Pilsbry & Cooke 1914-1916).

**Leptachatina (Angulidens) subcylindracea** Cooke, 1911

Like the preceding species, this is an extinct lowland snail; it was formerly widely distributed on O'ahu and has also been reported from Moloka'i and Kaho'olawe (Pilsbry & Cooke 1914-1916).

Specimens listed in the data tables as "*Leptachatina* spp." are too fragmentary or immature for precise identification.

## Family PUPILLIDAE

**Lyropupa (Mirapupa) ovatula ovatula** Cooke & Pilsbry, 1920

This snail is restricted to O'ahu, where it is known only as a fossil; a subspecies formerly occurred on Moloka'i and Hawai'i. Dextral species of *Lyropupa* (members of the subgenus *Mirapupa*) are generally restricted to arid low-elevation sites (Pilsbry & Cooke 1918-1920). Although *Lyropupa o. ovatula* occurs in some abundance in fossil deposits elsewhere in the Barbers Point region (Christensen, in prep.), only 8 shells from a single site (2700-1) were recovered during the present study.

**Lyropupa (Mirapupa) perlonga** (Pease, 1871)

This species occurs abundantly in the fossil deposits of coastal O'ahu; it has been found also on Kaua'i and Ni'ihau (Pilsbry & Cooke 1918-1920). Living individuals of *L. perlonga* are rarely encountered, and the only live-collected Bishop Museum lot for which habitat data are available (BPBM 21939) contains numerous specimens found in 1911 in *pili* grass (*Heteropogon*) at Koko Head, O'ahu. The species is common in fossil assemblages at Barbers Point, and small numbers of living individuals were found in leaf litter in the immediate vicinity of Site B6-78; the species is thus one of the few native snails tolerant of the disturbed vegetation now found in the study area.

**Nesopupa (Nesopupilla) litoralis** Cooke & Pilsbry, 1920

This extinct species is known only from fossil shells found in a few scattered localities on the O'ahu coastal plain (Pilsbry & Cooke 1918-1920).

**Nesopupa (Limbatipupa) newcombi** (Pfeiffer, 1852)

This species occurs on most of the main Hawaiian Islands. It is often present in lowland fossil assemblages, but it has also been reported from higher elevations. Its ecology is otherwise unknown. No living or freshly dead shells were found during this study, and the species is apparently extinct in the Barbers Point region.

**Nesopupa (Nesodagys) wesleyana** Ancey, 1904

*Nesopupa wesleyana* is a variable species reported from all of the main islands from Kaua'i to Hawai'i; the numerous localities from which Pilsbry & Cooke (1918-1920) recorded living or fossil examples indicate that the species once occupied diverse habitats. Only a single fossil shell was obtained during the present study.

**Pupoidopsis hawaiiensis** Pilsbry & Cooke, 1921

Fossil shells of *P. hawaiiensis* are often abundant in aeolian sandstones and other sedimentary deposits in the coastal lowlands of the main Hawaiian Islands, but the species is thought to be extinct throughout the state. On Christmas Island living snails of this species have been found on the bunchgrass *Lepturus*, a habitat thought by Cooke & Neal (1928) to be similar to that of Hawaiian *Pupoidopsis*. At Hao, Tuamotu Islands, *Pupoidopsis* has been found "on tree trunks and twigs" and "under *Tournefortia* [= *Messerchmidia*]" (BPBM 136562-3 and 136597-8, respectively).

**Gastrocopta servilis** (Gould, 1843)

This Neotropical species has been present in Hawai'i since the late 19th century (Ancey 1892, as *Pupa lyonsiana*). It has been transported throughout the islands of the Pacific by modern commerce and may occur also on islands in the Indian Ocean [*Gastrocopta seignaciana* (Crosse & Fischer, 1879), *G. microscopica* (Martens, 1898), and related taxa are very similar and may prove to be conspecific (Pilsbry 1916–1918)]. *Gastrocopta servilis* is the most abundant snail in the modern litter fauna at Barbers Point and is well represented in the uppermost levels of the sites examined (its apparent presence in deeper levels at Site B6-78 is undoubtedly due to contamination, as explained in the discussion of that site elsewhere in this report).

## Family ENDODONTIDAE

**Cookeconcha** undescribed sp.?

The numerous specimens of *Cookeconcha* recovered probably represent an undescribed species of the *C. henshawi* group (as defined by Solem 1976), although until the many O'ahu species of this genus are fully reviewed the possibility cannot be excluded that the specimens may be referable to a known species. No representatives of the group now inhabit the Barbers Point region.

Pilsbry & Vanatta (1906) stated that species of *Cookeconcha* "live on dead stumps and logs, and under the bark of dead trees, but also under fallen leaves." Solem (1976) added that these snails "have also been found in heavy moss on large boulders and at low levels on tree trunks." These remarks are probably more relevant to species of the mountain forests than to those of arid low-elevation sites, most of which had become extinct prior to the activities of modern malacologists. Records of undescribed species of *Cookeconcha* living in *pili* grass at Koko Head, O'ahu (BPBM 21938), and in clumps of the bunchgrass *Eragrostis* on Nihoa, Northwestern Hawaiian Islands (Conant et al. 1984), may be more indicative of the preferred habitat of the Barbers Point species.

**Endodonta kalaeloana** Christensen, 1982

This extinct species has been recorded from several sites in the 'Ewa Plain (Christensen 1982). As with *Cookeconcha*, published ecological data are most pertinent to species of high elevations or other moist habitats. An exception is the report by Cooke (1928) of the occurrence of living *Endodonta* "in talus slopes of the Waianae Mountains, some of them in dry and exposed situations." An undescribed *Endodonta* occurs with *Cookeconcha* in bunchgrass on Nihoa (Conant et al. 1984), and the Barbers Point species may have existed under similar conditions.



Table 1. Stratigraphic profile for Site B6-78.

Layer	Depth (cm)	Description
I	0-5	Black (10YR 2/1) organic A <sub>0</sub> and A <sub>1</sub> horizons, relatively loose.
II	5-35	Brown (7.5YR 5/4) silt and sand with angular fragments of limestone; primary zone of bird bones.
III	35-85+	Reddish yellow (5YR 5/6) deposit of limestone breccia in a matrix of silt and sand.

#### Family SUCCINEIDAE

##### *Succinea caduca* Mighels, 1845

Succineids recovered from excavations at Barbers Point exhibit a considerable range of shell form but all appear referable to *S. caduca*, a native species found throughout the main Hawaiian chain at low elevations, often in extremely arid conditions. The species currently inhabits the study area, and estivating individuals can often be found in abundance, sealed to the undersides of limestone slabs.

#### Family SUBULINIDAE

##### *Lamellaxis gracilis* (Hutton, 1834)

This adventive species became established in several Pacific island groups during the prehistoric period (Christensen & Kirch 1981, unpubl. observ.; Hunt 1981; Sinoto 1983); Christensen (1984) demonstrated its presence in Hawai'i in the late prehistoric period.

Fossil snail eggs of the type produced by *L. gracilis* were obtained at Sites B6-78 and 9670-P1, always in association with identifiable shells of *L. gracilis*. We cannot exclude the possibility that some may be those of *Leptachatina*, however.

Kirch & Christensen (1980) erroneously identified some of the subulinids from Site B6-78 as *Pseudopeas tuckeri* (Pfeiffer, 1846). In fact, all are *L. gracilis*.

#### Site Descriptions

##### Site 50-Oa-B6-78

This site, a sinkhole with an opening 2.5 × 1.5 m and a depth of 1.9 m to the top of the deposit, was excavated by Sinoto (1978: 21-24). The sink's deposits yielded many fossil bird bones, particularly in the upper 35 cm. Fortunately, the previous excavators had left intact some of the upper levels of deposit near the walls of the sink, and half of the lower breccia zone remained unexcavated. Thus we were able to obtain a complete column of 9 samples, to 85 cm below the original floor of the sink. The modern terrestrial mollusk fauna of the site was sampled by counting all living snails recovered from leaf litter under vegetation immediately adjacent to the sinkhole opening.

The stratigraphy of the site was reported by Sinoto (1978: fig. 11, table 4) and was also the subject of a detailed sedimentological analysis by Morgenstein (1978). The 2 reports differ in terms of layer designations and thicknesses, although they generally agree in description of the sediments. Sinoto's "overburden" is essentially equivalent to Morgenstein's Layer I. Morgenstein's Layer II, stated by him to be the primary zone of bird-bone deposition, coincides with Sinoto's Layer I and part of Layer II (based on depth data presented in Sinoto's table 4). Morgenstein's Layer III is divided by Sinoto into Layers III and IV.

The depositional sequence is summarized in Table 1 (layer designations are from Morgenstein, but with depths as measured at the time of collection of the land snail sample). The results of snail analysis are given in Table 2 and are plotted in Fig. 2.

Table 2. Nonmarine mollusks recovered from Site B6-78.

	Sample no.										
	—	6	7	8	9	1	2	3	4	5	
Layer	Litter	I	II	II	II	III	III	III	III	III	
Depth (cm below surface)	—	0-5	5-15	15-25	25-35	35-45	45-55	55-65	65-75	75-85	
Sample weight (g)	—	247.9	354.6	460.0	176.3	419.0	351.7	500.0	707.9	230.0	
Total snails counted	499	5,039	1,311	2,056	536	258	207	197	351	752	
Shells/100 g sample weight	—	2,033	370	447	304	62	59	39	50	327	
		No. specimens collected									
<i>Orobophana uberta</i>	0	376	203	325	91	55	45	40	60	109	
<i>Assiminea nitida</i>	0	4	0	2	0	0	0	0	0	0	
<i>Lamellidea</i> spp.	146	1,378	219	308	65	32	30	28	52	159	
<i>Tornatellides</i> spp.	18	555	112	43	5	0	+	1	4	9	
<i>Leptachatina cookei</i>	0	22	18	32	3	3	0	0	7	12	
<i>L. subcylindracea</i>	0	116	231	459	103	58	35	29	34	29	
<i>L. spp.</i>	0	110	1	0	0	0	0	0	0	18	
<i>Amastra u. umbilicata</i>	0	+	0	0	0	0	0	0	0	0	
<i>Lyropupa (Mirapupa) perlonga</i>	16	490	55	15	3	2	0	3	9	48	
<i>Nesopupa litoralis</i>	0	78	10	30	18	7	4	1	7	43	
<i>N. newcombi</i>	0	1	0	0	0	0	0	0	0	0	
<i>N. wesleyana</i>	0	0	0	1	0	0	0	0	0	0	
<i>Pupoidopsis hawaiiensis</i>	0	39	2	2	1	0	0	0	0	0	
<i>Gastrocopta servilis</i>	318	456	1	(5)**	(3)	(5)	(1)	(1)	(1)	(2)	
<i>Cookeconcha</i> undescribed sp.?	0	181	273	586	180	69	53	59	91	190	
<i>Endodonta kalaeloana</i>	0	103	137	236	60	32	40	34	87	132	
<i>Succinea caduca</i>	1	781	44	12	7	0	+	1	0	2	
<i>Lamellaxis gracilis</i>	0	349	5	4	0	0	0	0	0	0	
Unidentified	0	0	0	1	0	0	0	1	0	1	

\* Plus sign indicates nonapical fragments of species not otherwise represented in a sample.

\*\* Numbers in parentheses represent probable contaminants.



The Layer I faunal assemblage is the most divergent of the entire set, with significantly reduced quantities of the native genera *Orobophana*, *Leptachatina*, *Cookeconcha*, and *Endodonta*. Abundance of the historically introduced *Gastrocopta servilis* indicates that Layer I represents historic-period change. Vertebrate remains from this level (Sample 6) included *Mus musculus* (the House Mouse, a postcontact introduction), *Rattus exulans* (the Polynesian Rat), and scincid and gekkonid lizards (depending on the species, pre- or postcontact introductions).

Layer II (Samples 7–9) is clearly a zone of change. During the depositional span of this stratum there was a significant decrease in the abundance of *Cookeconcha* and increased abundance of *Lamellidea*, *Tornatellides*, *Lyropupa*, and *Succinea*. Most interestingly, *Lamellaxis gracilis* is present in the upper two-thirds of Layer II. This species was spread throughout the inner Pacific by prehistoric Austronesian peoples (cf. Christensen & Kirch 1981), and its presence in Layer II would suggest that humans were also active in the Barbers Point area by the time these sediments were deposited. Because Layer II is the principal zone of occurrence of avian fossils (Morgenstein 1978), including remains of extinct species, this indication of human activity is of considerable interest. Also noteworthy is the presence of remains of scincid lizards in Samples 7 and 8; additionally, remains of an unidentified rodent and of the seabird *Pterodroma phaeopygia* (Dark-rumped Petrel) were present in Sample 7. Vertebrate remains found in and below Sample 9 were not identifiable. Individuals of *Gastrocopta servilis* found at depths in excess of 15 cm below surface (Samples 8–9, 1–5) were either living or freshly dead. As the excavation had been open for some 2 years prior to our sampling, we believe these to be contaminants; they are undoubtedly recent shells that were living on the exposed face of the excavation, not true constituents of the fossil assemblage. For this reason these shells are listed in parentheses in Table 2 and are omitted from consideration in Fig. 2.

Layer III (Samples 1–5) shows a total absence of any introduced snail species (except *Gastrocopta servilis* as a contaminant, as discussed above), although there are changes in its faunal composition from top to bottom.

The extent to which the faunal sequence illustrated in Fig. 2 is graded can be tested with the use of a similarity matrix, as described above. Proportional similarity values for the B6-78 samples are plotted as a shaded matrix in Fig. 3. The grading index  $Q$  for this matrix is 123 ( $Q = 0$  for a perfectly graded matrix). For a  $9 \times 9$  matrix, as with B6-78,  $Q_{max} = 546$ . The  $Q/Q_{max}$  ratio for site B6-78 is thus 0.23, which indicates that the stratigraphic sequence is definitely nonrandom (Pielou 1979: fig. 3) and reasonably well graded. Examination of the shaded matrix also reveals (1) the divergence of the Layer I assemblage, and (2) a slightly higher internal clustering between samples from Layers II and III (i.e., a stepped sequence), thus supporting the interpretation of the faunal succession in terms of the observed stratigraphic units. That is, within Layer III, Sample 2 links most closely with Samples 1 and 3 (above and below it), and within Layer II, Sample 8 links most closely with Samples 9 and 1, both lower in the column.

In sum, the land snail sequence from Site B6-78 can be interpreted as a nonrandom, reasonably well-graded but stepped faunal succession. Gradual changes in Layer III may reflect local vegetational changes. More drastic change is indicated for Layer II (the zone of greatest abundance of fossil bird bones), and the possible role of humans is suggested by the presence of *Lamellaxis* and adventive vertebrates. Historic-period changes are clearly evident in Layer I.

#### Site 50-80-12-9670-P1

Site 9670-P1 (Site 50-80-12-2624 of Hammatt & Folk 1981) is a large sinkhole about 3 to 4 m in diam and 3 m deep. At the time of sampling for land snails, most of the deposit had been excavated for fossil bird bones by the ARCH team. The snail column was taken

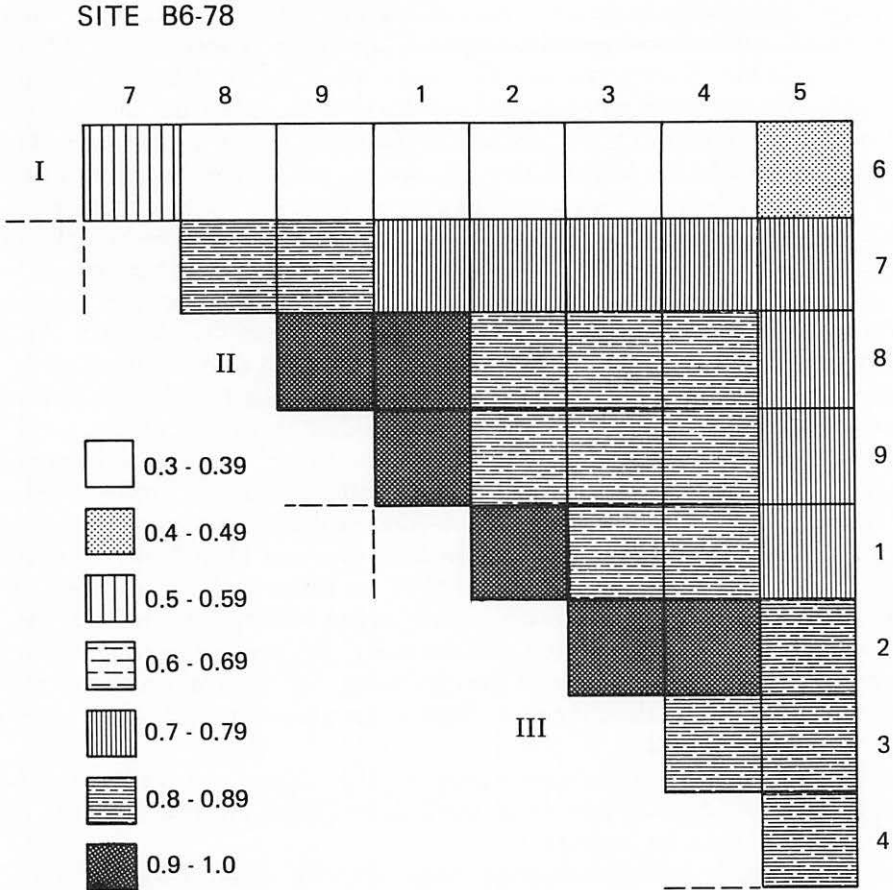


Fig. 3. Proportional similarity matrix for Site B6-78.

from an undisturbed face in the center of the sink, about 1 m from the limestone walls (adjacent to TP-4, E face). The stratigraphic profile is summarized in Table 3. Results of the snail analysis are given in Table 4 and plotted in Fig. 4. This series of samples represents a well-graded progression of faunal change. Most salient are the continual decreases in *Orobophana* and *Endodonta* and the increases in *Lamellidea*, *Tornatellides*, and *Succinea*. The historically introduced *Gastrocopta* increases in abundance in the upper 7 cm (the presence of 2 specimens in the 7–12-cm sample probably derives from the contact zone of Samples 2 and 3). Most significantly, the prehistorically introduced *Lamellaxis* is present in all samples, suggesting a potential human role in this sequence of faunal, and presumably vegetational, change. Vertebrate remains provide additional evidence: the Polynesian Rat

Table 3. Stratigraphic profile for Site 9670-P1.

Layer	Depth (cm)	Description
I	0–2	A <sub>0</sub> and A <sub>1</sub> horizons of organic matter and litter.
II	2–23/24	Silt-loam composed of aeolian material with fine limestone gravel. A reddish tint in the upper part of the deposit grades into a creamy color at the base.
III	23/24–27	Compacted deposit of unconsolidated limestone breccia in cream-colored silt matrix. Not sampled.

Table 4. Nonmarine mollusks recovered from Site 9670-P1.

	Sample no.					
	1	2	3	4	5	6
Layer	I	II	II	II	II	II
Depth (cm below surface)	0-2	2-7	7-12	12-17	17-22	22-23/24
Sample weight (g)	62.0	208.3	145.9	97.7	98.0	56.7
Total snails counted	373	1,599	1,758	1,559	889	260
Shells/100 g sample weight	602	768	1,205	1,596	907	459

	No. specimens collected					
	1	2	3	4	5	6
<i>Orobophana uberta</i>	43	236	328	306	225	70
<i>Assiminea nitida</i>	1	1	1	1	0	2
<i>Lamellidea</i> spp.	68	349	339	305	147	36
<i>Tornatellides</i> spp.	53	346	330	291	93	15
<i>Leptachatina cookei</i>	0	0	8	9	3	0
<i>L. subcylindracea</i>	14	47	94	112	55	9
<i>L.</i> spp.	0	0	0	0	0	2
<i>Lypopupa (Mirapupa) perlonga</i>	21	60	115	87	33	12
<i>Nesopupa litoralis</i>	+*	10	4	16	12	2
<i>N. newcombi</i>	18	75	53	16	12	2
<i>Pupoidopsis hawaiiensis</i>	5	21	27	11	4	1
<i>Gastrocopta servilis</i>	46	69	2	0	0	0
<i>Cookeconcha</i> undescribed sp.?	18	52	85	73	64	9
<i>Endodonta kalaeloana</i>	52	168	297	304	216	93
<i>Succinea caduca</i>	20	120	63	26	22	3
<i>Lamellaxis gracilis</i>	14	45	10	2	3	3
Unidentified	0	0	2	0	0	1

\* Plus sign indicates nonapical fragments of species not otherwise represented in a sample.

was present in Samples 2 and 3 and probably also in Samples 4 and 5 (the species of *Rattus* represented in the latter 2 samples could not be determined), and bones of lizards were also found (Gekkonidae in Samples, 1, 2, and 4, Scincidae in Samples 2-4). According to Olson & James (1982b: 27), "Bones of birds, including extinct species, occurred throughout these sediments [to a depth of 30-40 cm] but were more abundant in the upper 20 cm; extinct species were often found within the upper 5-10 cm." Those authors also remark on the co-occurrence of remains of *R. exulans* with those of extinct birds.

The interpretation of the 9670-P1 stratigraphic column as a well-graded series is borne out by matrix analysis (Fig. 5). The grading index  $Q$  for this matrix is only 3, and the  $Q/Q_{max}$  ratio of 0.04 ( $Q_{max} = 85$ ) indicates a highly significant nonrandom pattern.

#### Site 50-80-12-2700-1

This site (Site 50-80-12-2712 of Hammatt & Folk 1981) is a late prehistoric/early historic Hawaiian habitation feature chosen for snail analysis to contrast the faunal assemblage of an open occupation site with those of the paleontological sink deposits. The main structural feature at the site was a nearly square enclosure (5 × 5 m) constructed of limestone boulders and cobbles (a plan of the site is given in Hammatt & Folk 1981: fig. 9). A cultural deposit (Layer I) up to 15 cm thick underlay the enclosure and extended out around the structure for an unspecified distance. Our snail column (taken after completion of the major excavations and dismantling of the enclosure walls) was cut from the E face of the SE quadrant of grid unit N1/E1. This point previously underlay the western wall of the enclosure and thus had been protected from historic-period land disturbance or contamination. The stratigraphic profile is summarized in Table 5. Results of the snail analysis are presented in Table

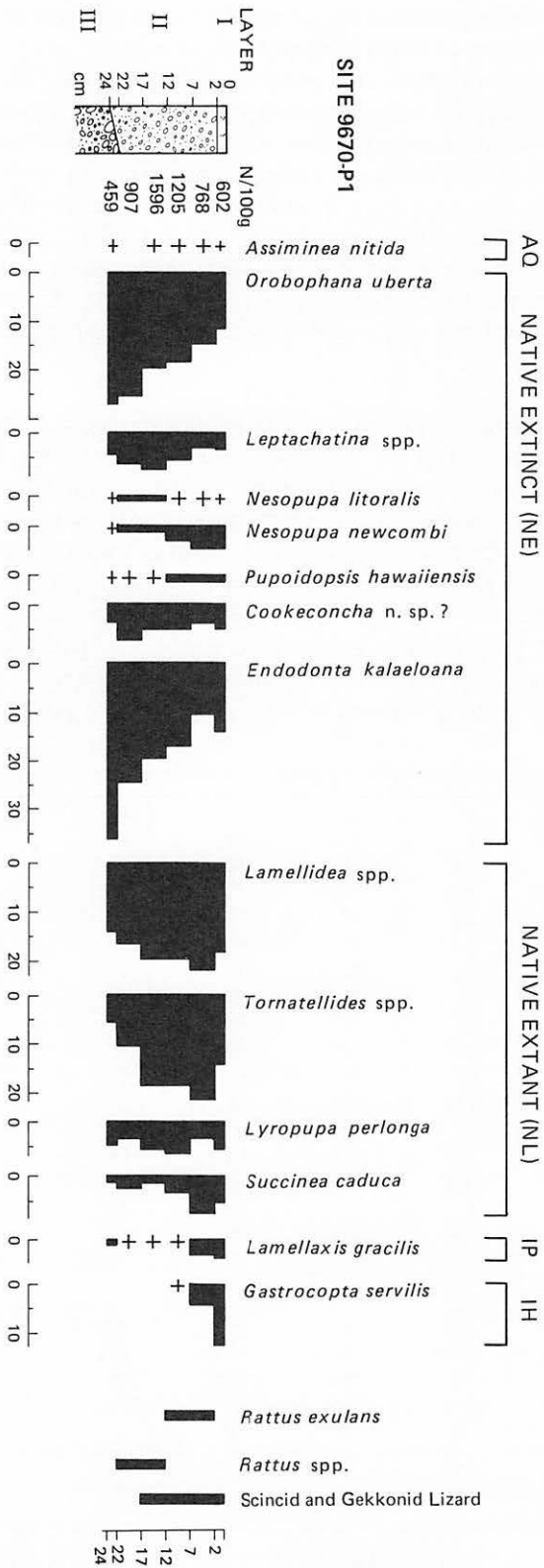


Fig. 4. Mollusk diagram for Site 9670-P1.

Table 5. Stratigraphic profile for Site 2700-1.

Layer	Depth (cm)	Description
—	0-3	A <sub>0</sub> horizon; organic litter.
—	3-6	A <sub>1</sub> horizon. Overburden of aeolian dust and organic matter. Very dark gray (5YR 3.1).
I	6-7/9	Gray to light gray (5YR 5-7/1) cultural deposit, color becoming lighter with increasing depth. Compacted, with marine shells and other midden material.
I/II	7/9-11	Irregular contact zone between layers I-II; land snails very abundant.
II	7/9-27	Culturally sterile, decomposed limestone; compacted; gravelly. Light gray (5YR 7/1).

6 and are plotted in Fig. 6. The faunal sequence indicates rather drastic changes beginning with the onset of human habitation. The Layer II assemblage correlates fairly closely with the upper part of Layer III at Site B6-78. With the beginning of habitation, there is a major decrease in *Orobophana* and *Leptachatina*, increases in *Lamellidea* and *Lyropupa*, and the significant addition of *Tornatellides* and *Succinea*. The Polynesian introduction *Lamellaxis* also appears (the presence of a few *Gastrocopta* is probably due to contamination from upper levels during sampling). Following abandonment of the habitation site, further change occurred, including continued increases in *Lamellidea* and *Tornatellides*, drastic decrease in *Orobophana*, extirpation of *Leptachatina*, and major increase in *Gastrocopta*. The influence of humans on the local ecology seems unquestionable in the present case. Interestingly, the pattern of change in this habitation site largely mirrors that in the upper portions of the 2 limestone sinks examined, where avian as well as molluscan remains were present.

#### Site 50-80-12-2701-1

This site (50-80-12-2723 of Hammatt & Folk 1981) is a small C-shaped shelter built of limestone slabs, with an interior floor area of ca. 4 m<sup>2</sup>, on open limestone. A test pit, 50 ×

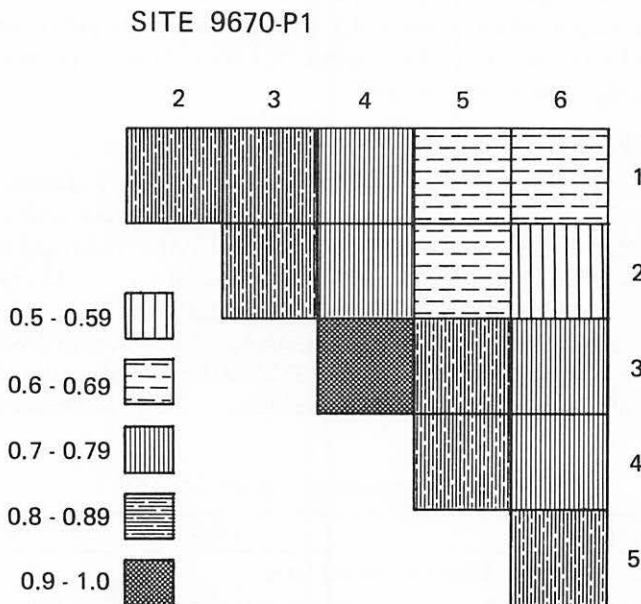


Fig. 5. Proportional similarity matrix for Site 9670-P1.



Table 6. Nonmarine mollusks recovered from site 2700-1.

	Sample no.				
	1	2	3	4	5
Layer	—	—	—	—	—
Depth (cm below surface)	0-3	3-6	6-7/9	7/9-18	18-27
Sample weight (g)	59.1	100.1	250.4	99.1	112.4
Total snails counted	227	133	318	183	33
Shells/100 g sample weight	384	133	127	185	29

	No. specimens collected				
	1	2	3	4	5
<i>Orobophana uberta</i>	5	5	111	89	16
<i>Lamellidea</i> spp.	58	44	69	30	5
<i>Tornatellides</i> spp.	28	14	12	0	0
<i>Leptachatina cookei</i>	0	0	11	11	+
<i>L. subcylindracea</i>	0	0	14	28	0
<i>L.</i> spp.	1	0	0	0	0
<i>Lyropupa (Mirapupa) o. ovatula</i>	0	0	1	3	1
<i>L. (M.) perlonga</i>	+	1	40	4	1
<i>Nesopupa litoralis</i>	+	+	6	1	3
<i>Gastrocopta servilis</i>	119	59	3	0	0
<i>Cookeconcha</i> undescribed sp.?	0	0	2	2	0
<i>Endodonta kalaaloana</i>	+	+	19	13	7
<i>Succinea caduca</i>	16	10	28	0	0
<i>Lamellaxis gracilis</i>	0	+	1	0	0
Unidentified	0	0	1	2	0

\* Plus sign indicates nonapical fragments of species not otherwise represented in a sample.

50 cm, had been excavated by the ARCH team, exposing a thin cultural deposit with limited quantities of shellfish and bone midden. The stratigraphic column is summarized in Table 7. Results of snail analysis are reported in Table 8 and plotted in Fig. 7. The sequence of faunal change closely parallels that described for Site 2700-1. We doubt, however, that *Gastrocopta servilis* was actually associated with the prehistoric cultural layer, as the shallow and loose nature of the sediments here may have permitted some down-washing of empty shells or mixing of soil.

### Site 50-80-12-2701-3

The final site chosen for snail analysis (Site 50-80-12-2725 of Hammatt & Folk 1981) is a small sinkhole 3 m in diam and 0.5 to 0.75 m deep, with a low wall of limestone slabs built up on the E edge of the sink. Davis (pers. comm., 13 Apr. 1984) believes this structure to have been a pit garden. The ARCH team had excavated a 25 × 25-cm test pit into the floor of the sink and had judged the feature to be culturally sterile. A column of 3 samples was taken for comparison with the deep sinks containing bird bones and with the habitation sites. The stratigraphic profile is summarized in Table 9. Results of snail analysis are reported in Table 10 and plotted in Fig. 8. This faunal sequence differs markedly from those from

Table 7. Stratigraphic profile for Site 2701-1.

Layer	Depth (cm)	Description
—	0-3	A <sub>0</sub> horizon; organic litter.
—	3-8	A <sub>1</sub> horizon and zone of cultural material; light gray.
—	8-13/20	Decomposed limestone distributed in pockets in the limestone bedrock.

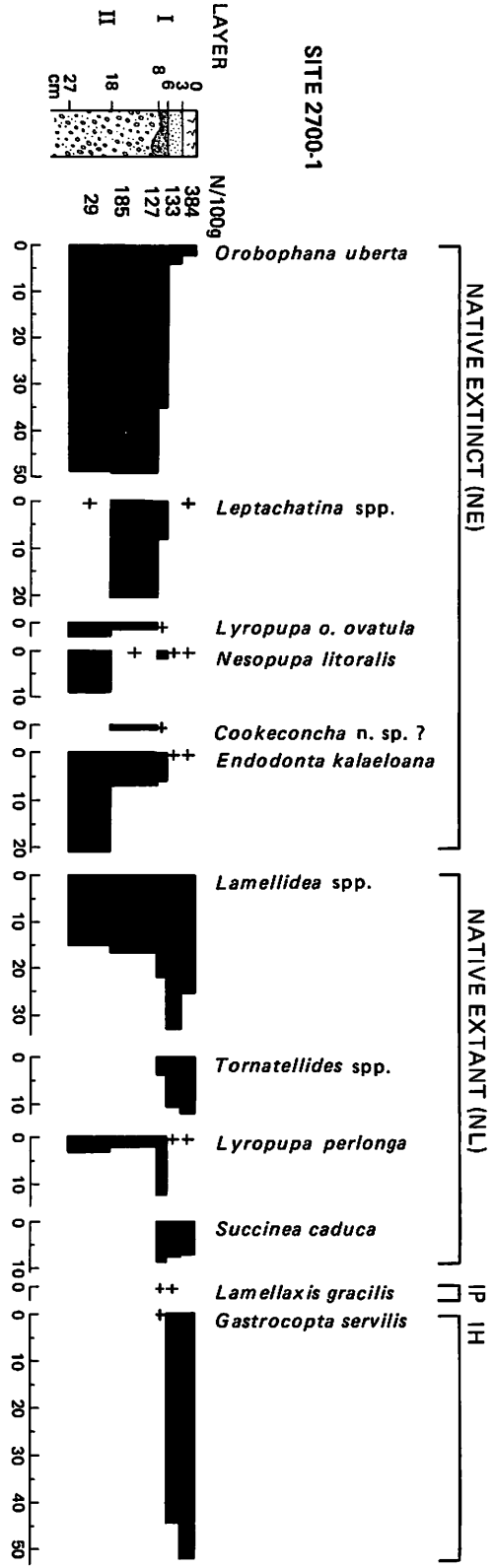


Fig. 6. Mollusk diagram for Site 2700-1.

Table 8. Nonmarine mollusks recovered from Site 2701-1.

	Sample no.		
	1	2	3
Layer	—	—	—
Depth (cm below surface)	0-3	3-8	8-13/20
Sample weight (g)	44.2	120.2	64.5
Total shells counted	164	605	112
Shells/100 g sample weight	371	503	174

	No. specimens collected		
	1	2	3
<i>Orobophana uberta</i>	1	+	12
<i>Assiminea nitida</i>	0	3	1
<i>Lamellidea</i> spp.	28	198	27
<i>Tornatellides</i> spp.	33	245	19
<i>Leptachatina cookei</i>	0	0	5
<i>L. subcylindracea</i>	0	0	4
<i>L.</i> spp.	0	+	0
<i>Lyropupa (Mirapupa) perlonga</i>	+	19	19
<i>Nesopupa litoralis</i>	0	+	+
<i>Gastrocopta servilis</i>	83	84	5
<i>Succinea</i> spp.	16	55	20
Unidentified	3	1	0

\* Plus sign indicates nonapical fragments of species not otherwise represented in a sample.

all other sites, as 89-98% of each sample consisted of shells of *Assiminea nitida*, an aquatic or amphibious snail normally associated with brackish water environments. Kirch & Christensen (1980) hypothesized that the unusual abundance of this species was the result of transport of mud from a nearby brackish pond to improve soil quality for agriculture. Subsequent investigations in the area (Christensen et al., in prep.) suggest, however, that this sink may formerly have been an anchialine pool; in some nearby shallow sinks the top of the water table lies a short distance below the modern ground surface, while other sinks are permanently or intermittently flooded by brackish water under tidal influence (Davis & Griffin 1978; Miura & Sato 1978). The 2701-3 sinkhole was not observed to be subject to such flooding; however, prior to infilling by sediment, or under conditions of a slightly higher water table, this site may well have provided an environment suitable for *Assiminea*.

## DISCUSSION

Having reviewed the specific results from each of the 5 sites studied, we now turn to a discussion of certain wider implications. Of particular concern are (1) temporal correlations between the stratigraphic columns; (2) the implications for patterns of ecological change in the Barbers Point area; and (3) the possible role of both prehistoric and historic man in initiating or hastening ecological change in the region.

Table 9. Stratigraphic profile for Site 2701-3.

Layer	Depth (cm)	Description
—	0-10	A <sub>0</sub> and A <sub>1</sub> horizons. Gravelly soil with charcoal flecks. Very dark gray.
—	10-16/17	Compacted, transitional zone from dark organic layer into decomposed limestone floor of sink.

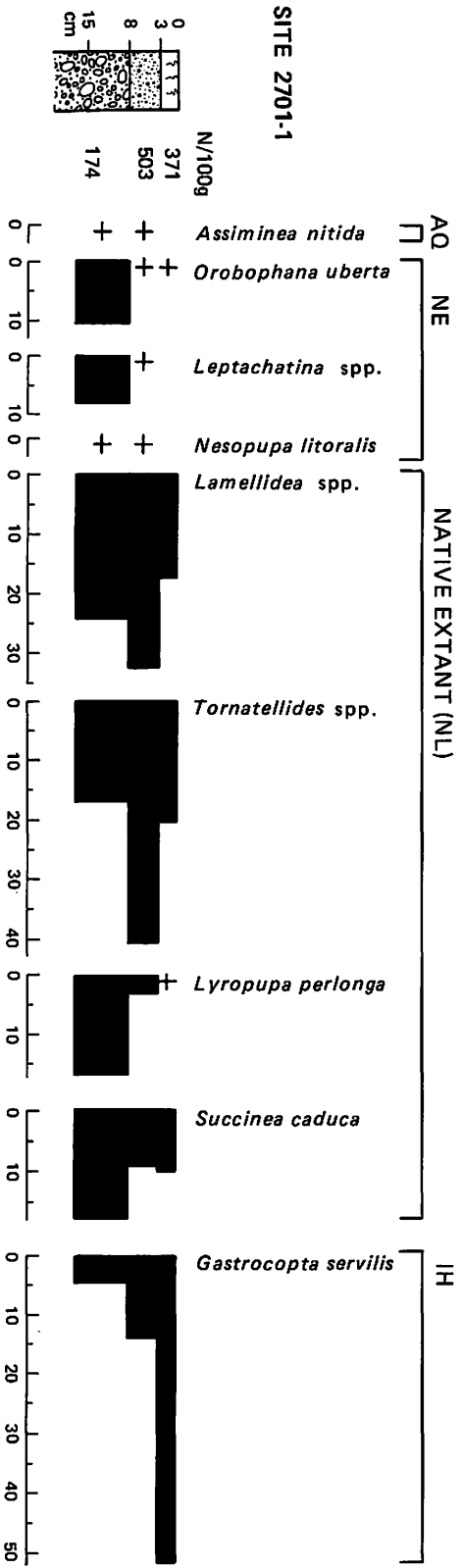


Fig. 7. Mollusk diagram for Site 2701-1.

Table 10. Nonmarine mollusks recovered from Site 2701-3.

	Sample no.		
	1	2	3
Layer	—	—	—
Depth (cm below surface)	0-5	5-10	10-16/17
Sample weight (g)	168.1	159.5	100.3
Total shells counted	365	893	1,180
Shells/100 g sample weight	217	560	1,176

	No. specimens collected		
	1	2	3
<i>Orobophana uberta</i>	3	9	5
<i>Assiminea nitida</i>	321	818	1,162
<i>Lamellidea</i> spp.	6	21	8
<i>Tornatellides</i> spp.	22	26	3
<i>Leptachatina cookei</i>	0	1	0
<i>L. subcylindracea</i>	2	4	0
<i>L.</i> spp.	0	0	+
<i>Lyropupa (Mirapupa) perlonga</i>	1	4	0
<i>Nesopupa litoralis</i>	+	+	+
<i>Endodonta kalaeloana</i>	+	+	0
<i>Gastrocopta servilis</i>	4	2	0
<i>Succinea caduca</i>	2	8	2
Unidentified	4	0	0

\* Plus sign indicates nonapical fragments of species not otherwise represented in a sample.

### Intersite correlations

Although there are differences in the stratigraphic columns of the sites studied, the overall pattern of faunal change is remarkably consistent and thus allows us to propose tentative temporal correlations between columns. Major time markers include (1) the onset of decreases in the relative abundance of *Orobophana*, *Leptachatina*, *Cookeconcha*, and *Endodonta*, and of corresponding increases in the abundance of *Lamellidea*, *Tornatellides*, *Lyropupa perlonga*, and *Succinea*; (2) the appearance of taxa known or believed to have been introduced prehistorically (the snail *Lamellaxis gracilis*, certain gekkonid and scincid lizards, and *Rattus exulans*, the Polynesian Rat); and (3) the appearance of historically introduced taxa (the land snail *Gastrocopta servilis*, the House Mouse *Mus musculus*, and species of *Rattus* other than *R. exulans*).

Figure 9 illustrates our proposed correlations between the stratigraphic columns, based solely upon evidence from our analysis of land snails and associated vertebrate remains [no radiometric or other "absolute" dates were obtained by Hammatt & Folk (1981) for sites examined by us]. Site B6-78 provides the longest stratigraphic sequence and is thus of critical importance in assessing long-term ecological change at Barbers Point. The column at Site 9670-P1 appears to correlate with the upper portion of the B6-78 sequence. The 2 habitation sites may span a lengthy time period, as suggested in the diagram, but their stratigraphic sections are greatly compressed and are less amenable to detailed interpretation than are the 2 sinkhole sequences.

Based upon the presence or absence of introduced taxa and the relative abundance of extinct and extant native taxa, it is possible to suggest that the temporal sequence shown in Fig. 9 spans 3 major time periods: (1) a period prior to the advent of human impact; (2) a period of prehistoric Polynesian use and/or occupation of the area; and (3) the recent historic period. Highly significant is the co-occurrence of prehistorically introduced mollusk

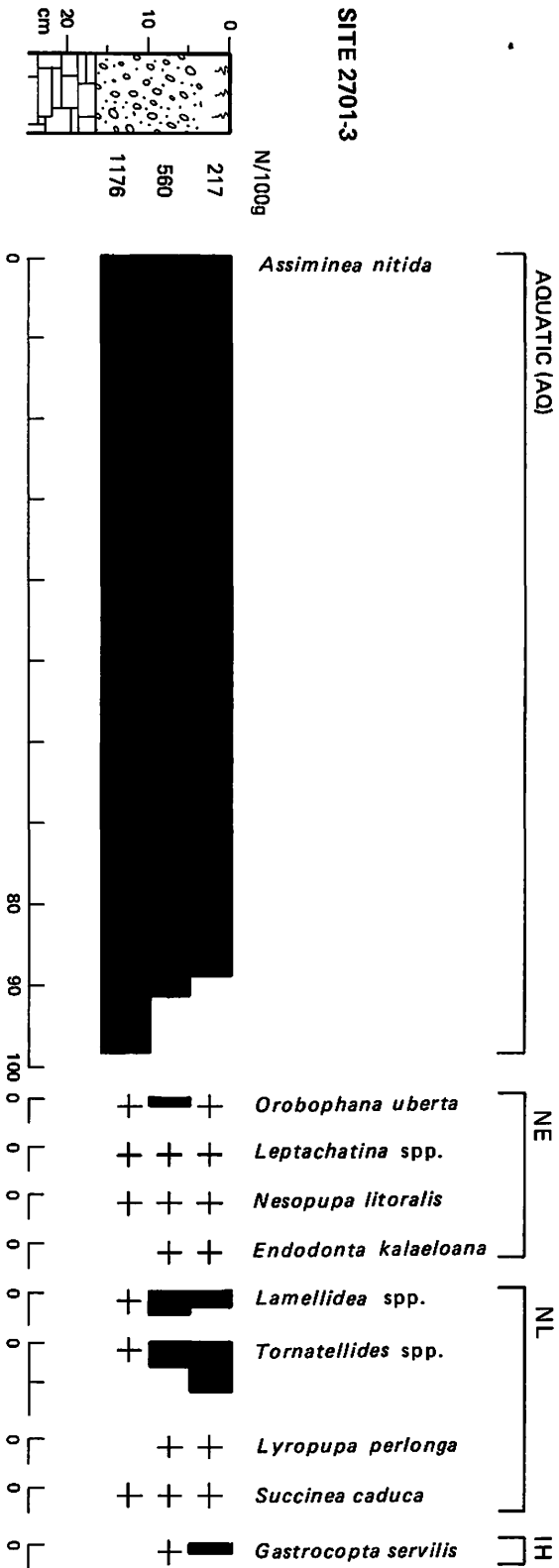


Fig. 8. Mollusk diagram for Site 2701-3.

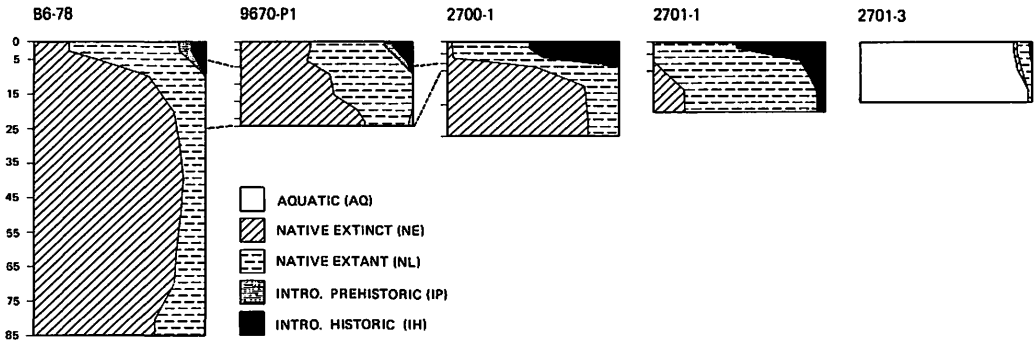


Fig. 9. Relative abundance of nonmarine mollusks by ecological group, including tentative stratigraphic correlations between Sites B6-78, 9670-P1, and 2700-1.

and vertebrate taxa and locally or universally extinct avian taxa, a finding that suggests that Polynesian man was present at the time when these avian remains were deposited and may indeed have played a role in the extinction of these birds. We stress that these tentative correlations are based solely on the stratigraphic evidence presented above, and have not been confirmed by results of radiometric analysis or other absolute dating techniques. While the consistent faunal succession revealed by our analysis gives us confidence in our proposed correlations, a program of careful excavation and precise stratigraphic control combined with quantitative faunal analysis and extensive dating would be required to more clearly determine the chronology of extinction and the extent of prehistoric or modern man's involvement.

### Patterns of ecological change

The median annual rainfall recorded at stations in the Barbers Point region is generally 50 cm (20 in.) or less. Most rain falls in the winter months, and in most years the median monthly rainfall is 1.25 cm (0.5 in.) or less from May to September; months without rain may occur at virtually any time during the year (Taliaferro 1959). These conditions suggest the former presence of a native dry-land vegetation community. Char & Balakrishnan (1979) surveyed the modern vegetation of the 'Ewa Plain and offered an interpretation of the presumed original (prehuman) vegetation of the region, based upon analysis of relict native plants and other evidence; a portion of their remarks is quoted here:

Inland, the vegetation on the coralline plains may have consisted of an open savannah with scattered trees of *Erythrina sandwichensis* (wiliwili) and *Sapindus oahuensis* (aulu). *Santalum ellipticum* ('ili-ahi-a-lo'e), *S. freycinetianum* (i'ili-ahi) and *Myoporum* probably occurred as small trees in the more sheltered areas, or as large shrubs. Smaller shrubs such as *Abutilon incanum* (ko'oloo), *Gossypium sandwichense* (ma'o), the two varieties of *Euphorbia skottsbergii* ('akoko), *Achyranthes*, *Capparis sandwichiana* (maiapilo), *Sida* spp. and *Plumbago zeylanica* ('ilie'e) could occasionally have formed thickets between the trees. Such grasses as *Eragrostis paupera*, *Panicum torrida* (kakonakona), perhaps several other native *Panicum* spp., and probably *Heteropogon contortus* (pili) would occur in the herb layer. Vines such as *Sicyos microcarpus* (kupala), *Cocculus ferrandianus* (huehue), *Ipomea congesta* (koali-a'awania), *Cassytha filiformis* (kauna-'oa pehu) and probably a few species of *Canavalia* ('awikiwiki) probably were climbing over the shrubs and trees. In areas with a thin layer of alluvium and that were subject to occasional flooding during the rainy season there would be patches of the fern *Marsilea villosa* and perhaps *Ophioglossum concinnum* (pololei). The ravines and gulches farther inland probably would have supported

a number of larger trees and much more vegetation as they are wetter. (Char & Balakrishnan 1979: 60)

Paleoecological interpretation based upon the occurrence of land snails in the earliest levels of the Barbers Point excavations (i.e., those presumed to antedate human impact in the region) is hindered by our incomplete knowledge of the ecological requirements of the various species present. Several of the species common in these early levels are now extinct, making direct observation of their habitat preferences impossible. Data on other species are often incomplete. Malacological studies of Hawaiian terrestrial mollusks have focused almost exclusively upon taxonomy, while the ecology of these snails has received only passing consideration. In general, however, those inferences that can be drawn are consistent with the paleobotanical conclusions of Char & Balakrishnan. Of particular importance is the fact that snails characteristic of moist forest conditions are absent from the fossil assemblages studied here. Such taxa as *Achatinella*, *Auriculella*, *Amastra* (excluding the xerophilous subgenus *Cyclamastra*), *Laminella*, sinistral *Lyropupa*, low-spined Succineidae (principally the genus *Catinella*), and *Philonesia* are absent or virtually so,<sup>3</sup> although all of these occur (or formerly occurred) in forested locations in the nearby Waianae Mountains. Several of these (*Achatinella*, *Catinella*, and *Philonesia*) are abundantly represented in coastal deposits in windward O'ahu, where they presumably indicate that moist forest conditions formerly extended to considerably lower elevations than at present (cf. Perkins 1913: xxxvi-xxxvii).

In contrast, the assemblage of native land snail species present in the Barbers Point sites is indicative of a relatively arid environment and, to the extent that the limited ecological data available can be used to infer vegetation associations, is consistent with the inference by Char & Balakrishnan (1979) of the former presence of a plant community characterized by native grasses, shrubs, and sparse, open-canopy dry-forest tree species. *Leptachatina cookei*, *L. subcylindracea*, *Amastra u. umbilicata*, and *Nesopupa litoralis* are universally extinct, and their ecological preferences are therefore not directly observable, although their occurrence only in low-elevation fossil deposits, including those of the dry leeward coast of O'ahu, indicates a preference for arid conditions. *Cookeconcha* undescribed sp.? and *Endodonta ka-laeloana* are likewise extinct, but closely related living species found at low elevations are recorded only from grasses in arid locations. *Pupoidopsis hawaiiensis* was probably restricted to grasses and strand vegetation. The species is now extinct in Hawai'i but inhabits clumps of bunchgrass (*Lepturus* sp.) on Christmas Island (Cooke & Neal 1928) and occurs in strand vegetation in the Tuamotus (BPBM collection). *Orobophana* has been collected on dead leaves and twigs (Neal 1934), but additional data are lacking.

*Nesopupa newcombi* and *N. wesleyana* are extinct in the Barbers Point region but probably persist elsewhere on O'ahu; *Tornatellides* is represented in the modern Barbers Point fauna by 1 or possibly 2 species, and *Lamellidea* now inhabits the region. All of these are tolerant of a broad range of environments, but their presence is consistent with the postulated arid, grassland-parkland conditions.

In later stratigraphic levels, individuals of now-extinct taxa are reduced in numbers; land snail assemblages at these depths are dominated by native taxa tolerant of disturbed conditions (as evidenced by their presence in the modern fauna of the area), such as *Lamellidea*, *Tornatellides*, *Lyropupa* (*Mirapupa*) *perlonga*, and *Succinea caduca*. The first 2 of these frequently inhabit areas of disturbed vegetation (Cooke & Kondo 1960). Species of *Lyropupa* (*Mirapupa*) are tolerant of very arid conditions, and Pilsbry & Cooke (1918-1920: 259) remarked, "In

3. Christensen (in prep.) has recovered shell fragments of *Achatinella mustelina* Mighels, 1845, a single immature shell of a sinistral *Lyropupa*, and a few specimens of *Amastra* (*Metamastra*) sp. from recently excavated sites at Barbers Point.



every case where the junior author found living examples they were taken in open country under dead sticks and stones." *Succinea caduca* is also highly tolerant of aridity and environmental disturbance. We hypothesize that this change in the land snail assemblage reflects a reduction in vegetative cover and a concomitant decrease in availability of moisture resulting from human-induced environmental modification.

In the upper levels exotic snails also appear, becoming dominant in the topmost levels. This transition from a fauna exclusively of native taxa, many of them now extinct in the Barbers Point area, to a fauna in which exotic forms predominate or are at least prominent, may be recognized in all but 1 of the sites studied (*Assimineea nitida*, an aquatic snail, is dominant in the highly aberrant Site 2701-3 assemblage). In the absence of chronometric data indicating the contemporaneity of this transition with the advent of human occupation, it can be argued that it is perhaps premature to conclude with certainty that the Polynesians were responsible (through forest clearance and agriculture) for the extinction of much of the native land snail fauna (and avifauna?). We believe, however, that such data, when available, will be consistent with that conclusion.

In sum, the overall patterns of ecological change suggested by land snail analysis are of (1) an original grassland-parkland vegetation, giving way to (2) decreased vegetative cover and resultant decrease in the availability of moisture, probably due to prehistoric Polynesian interference, and finally (3) a drastic change in local flora and fauna in historic times.

### CONCLUSIONS

Stratigraphic analyses of land snail assemblages from both paleontological and cultural sites at Barbers Point demonstrate a consistent pattern of faunal succession. The sequence begins with a snail fauna containing a full range of endemic taxa, proceeds through a phase of marked decrease in certain native taxa that do not now inhabit the site and of increase in more resilient extant native taxa, and ends with a modern assemblage characterized by the presence of abundant non-native synanthropic species. It is significant that the phase of major change in the mollusk fauna corresponds, in the sinkhole sites, with the zone of heaviest concentration of bones of extinct or locally extirpated birds. This zone unquestionably represents a period of local environmental change, and it is furthermore highly likely that the extirpation of the Barbers Point avifauna was directly related to this ecological disturbance and change.

The occurrence of shells of the synanthropic land snail *Lamellaxis gracilis* and bones of rats and gekkonid and scincid lizards in the same stratigraphic zone with the fossil bird bones provided the first direct evidence that the extinct Barbers Point avifauna persisted into the period of human occupation of the island. All of these synanthropic species are known to have been transported by early Pacific island peoples (Stejneger 1899; Tate 1951; Christensen & Kirch 1981; Christensen 1984). Thus Polynesians were clearly present in the leeward O'ahu region at the time that the Barbers Point area was undergoing the phase of major environmental change revealed in the sinkhole deposits.

The further implication of this demonstrated contemporaneity of Polynesian occupation and local environmental change is, of course, the attribution of causality on the part of the human population. The role of Oceanic peoples in the modification of island ecosystems has been increasingly demonstrated in recent archaeological studies (Kirch 1982a,b, 1984). In our view, the Barbers Point evidence offers clear support for the hypothesis of substantial anthropogenic modification of lowland Hawaiian ecosystems in the centuries following initial Polynesian colonization of the archipelago. Such human-induced modification of local biota and landscapes was effected by both direct and indirect processes, including the

transport and introduction of exotic animal and plant species (such as *Lamellaxis*, *Rattus exulans*, and gekkonid and scincid lizards), hunting and collecting of native fauna and flora for subsistence and other uses, forest clearance for agriculture and settlement, repeated firing of vegetation, initiation of local erosion, and other processes. At Barbers Point, the archaeological evidence to date (Davis et al., in prep.) suggests that long-term human settlement did not occur until after about A.D. 1200 and was not substantial until perhaps the 16th or 17th centuries. We know from a variety of other sites on O'ahu, however, that Polynesians were established on the island by the 5th century, and that expansion into leeward regions was well underway by A.D. 1000 (Kirch 1985). Thus, it is likely that the Barbers Point area and the 'Ewa Plain in general began to be subjected to human activities and ecological modification by the 11th century, even prior to the local establishment of permanent settlement.

Despite the demonstration of a significant faunal succession and of its co-occurrence with human occupation, the attribution of causality for ecological change (including avifaunal and other extinctions) to the Polynesians remains a hypothesis that, while highly plausible, requires additional research. The discovery of a fantastically rich former avifauna in the Hawaiian Islands and of massive avian extinctions has generated worldwide interest (Olson & James 1982a,b, 1984; Boag 1983; James & Olson 1983). Demonstration that extinct animal species co-occurred with prehistoric Hawaiians, while extremely important in itself, does not *prove* that prehistoric Hawaiian activities were the cause of extinction, even though this is a highly probable and favored hypothesis. Alternative hypotheses, particularly those of naturally occurring extinction owing to climatic change and of anthropogenic extinction occurring primarily since the arrival of Europeans, must also be addressed. Unfortunately, few reports of the sort needed to resolve the matter (quantitative faunal analysis coupled with precise stratigraphic and, ideally, chronological control) have yet been published for paleontological or archaeological sites in the Hawaiian Islands.

In New Zealand, where prehistoric extinctions of moas and other birds provide a situation analogous to the Hawaiian case, the controversy regarding climatic change vs. prehistoric human impact as a cause of recent extinctions has apparently been resolved in favor of the latter explanation (Anderson 1984; Trotter & McCulloch 1984). In Hawai'i, Olson & James (1982b) noted that there is little to support the hypothesis that these are natural extinctions resulting from climatic change. While naturally occurring climatic fluctuations have undoubtedly taken place since initial human settlement of the Hawaiian Islands, there is no evidence to suggest that such fluctuations were more extreme than those to which the Hawaiian biota was subjected during the Pleistocene.

Less easily dismissed is the contention that extinctions in Hawai'i have been primarily a result of Western influence in the period since Cook's expedition of 1778-1779. Until recent paleontological and archaeological findings demonstrated the true diversity of the original Hawaiian avifauna, the dominant view of extinctions was that these were almost exclusively a feature of the modern era, the Hawaiians having had little impact on the biota (see discussion in Kirch 1982a). Although this interpretation still has adherents, we believe it is highly unlikely that such conspicuous animals as flightless geese and ibises could have persisted into the historic period without leaving evidence in the form of specimens or ethnological references. Similarly, the great seabird colonies formerly present at Barbers Point must have been extirpated prehistorically. The status of some other members of the Hawaiian avifauna is less certain. As Olson & James (1982b, 1984) point out, it is possible that several of the extinct species represented in fossil deposits at Barbers Point and elsewhere may have persisted into the historic period. In an analysis of ornithological observations

by members of Cook's expedition, Medway (1981: 107, 109–10) cites reports of a brown hawk observed on Kaua'i and of a large, whitish pigeon and a dark-green dove seen on Hawai'i Island. Doubts have been expressed about the accuracy of one of these reports [the "whitish pigeon" may actually have been the White Tern, *Gygis alba* (Medway 1981: 109)], and none of them have been confirmed by other historical accounts or by recent fossil discoveries. Nevertheless, these observations may record island populations that became extinct during the period between A.D. 1778 and the initiation of serious ornithological collecting in the Hawaiian Islands in the later 19th century. This was clearly a time of extensive ecological disturbance, and it would be surprising if some avian species did not die out during this period without having attracted the attention of naturalists; extinction and reduction in range are known to have occurred at this time in O'ahu tree snails of the genus *Achatinella* (Hadfield 1986). Nonetheless, we consider the older view that the prehistoric Hawaiians had only a minimal impact on lowland habitats of the archipelago to be without foundation and in conflict with a wealth of recent archaeological, geomorphological, and paleoenvironmental data. We believe that human interaction with the native plants and animals of Hawai'i, with the resulting extinction of many elements of the native biota, is a process characteristic of both the prehistoric and historic periods, and we anticipate that study of the ecological consequences of human activities in these islands will be of continuing interest to both anthropologists and biologists; we hope that recent discoveries in this area will usher in a period of intense cooperative effort between students of these and other disciplines to elucidate the nature and chronology of this complex interaction.

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#### REFERENCES CITED

- Abbott, R.T.** 1958. The gastropod genus *Assiminea* in the Philippines. Proc. Acad. Nat. Sci. Phila. 110: 213–87, pl. 15–25.
- Ancey, C.F.** 1892. Etudes sur la faune malacologique des Iles Sandwich. Mem. Soc. Zool. Fr. 5: 708–22.
- Anderson, A.** 1984. The extinction of moa in southern New Zealand. p. 728–40. In: P.S. Martin & R.G. Klein, eds., Quaternary extinctions: A prehistoric revolution. University of Arizona Press, Tucson.
- Boag, P.T.** 1983. Species extinction: More extinct island birds. Nature 305: 274–75.
- Bobrowsky, P.T.** 1984. The history and science of gastropods in archaeology. Am. Antiq. 49: 77–93.
- Char, W.P. & N. Balakrishnan.** 1979. 'Ewa Plains botanical survey. Clifford W. Smith, principal investigator, vi + 119 p., 4 append. Unpubl. rep. prepared for U.S. Dep. Interior, Fish & Wildlife Serv., Contract No. 14-16-0001-78171.
- Christensen, C.C.** 1982. A new species of *Endodonta* (Pulmonata, Endodontidae) from Oahu, Hawaii. Malacol. Rev. 15: 135–36.
- . 1983. Analysis of land snails. p. 449–71. In: J.T. Clark & P.V. Kirch, eds., Archaeological investigations of the Mudlane-Waimea-Kawaihae Road Corridor, Island of Hawaii: An interdisciplinary study of an environmental transect. Dep. Rep. Ser. 83-1, Dep. Anthropol., B.P. Bishop Museum.

- . 1984. Analysis of nonmarine mollusks. p. 355–76. In: A.R. Schilt, Subsistence and conflict in Kona, Hawai'i: An archaeological study of the Kuakini Highway Realignment Corridor. Dep. Rep. Ser. 84-1, Dep. Anthropol., B.P. Bishop Museum.
- Christensen, C.C. & P.V. Kirch.** 1981. Nonmarine mollusks from archaeological sites on Tikopia, Southeastern Solomon Islands. *Pac. Sci.* 35: 75–88.
- Conant, S., C.C. Christensen, P. Conant, W.C. Gagné & M.L. Goff.** 1984. The unique terrestrial biota of the Northwestern Hawaiian Islands. p. 77–94. In: R.W. Grigg & K.Y. Tanoue, eds., Proceedings of the Second Symposium on Resource Investigations in the Northwestern Hawaiian Islands, 25–27 May 1983. Vol. 1. University of Hawaii Sea Grant College Program.
- Cooke, C.M., Jr.** 1928. Three new *Endodonta* from Oahu. *Bernice P. Bishop Mus. Bull.* 47: 13–27.
- Cooke, C.M., Jr. & Y. Kondo.** 1960. Revision of Tornatellinidae and Achatinellidae (Gastropoda, Pulmonata). *Bernice P. Bishop Mus. Bull.* 221. 303 p.
- Cooke, C.M., Jr. & M.C. Neal.** 1928. Distribution and anatomy of *Pupoidopsis hawaiiensis*. *Bernice P. Bishop Mus. Bull.* 47: 28–33.
- Davis, B.D. & P.B. Griffin, eds.** 1978. Studies in natural history and human settlement at Barbers Point, O'ahu. Interim report I: Present environmental and archaeological survey of the proposed deep-draft harbor area, Honouliuli, Ewa, Oahu, Hawaii. Unpubl. rep. prepared for Water Transport Div., Dep. Transportation, State of Hawaii, by Archaeological Research Center Hawaii, Inc. Ms. No. ARCH 14-115.
- Evans, J.G.** 1972. Land snails in archaeology. Seminar Press, London. xii + 436 p.
- Hadfield, M.G.** 1986. Extinction in Hawaiian achatinelline snails. *Malacologia* 27: 67–81.
- Hammatt, H.H. & W.H. Folk, II.** 1981. Archaeological and paleontological investigations at Kalaeloa (Barber's Point), Honouliuli, 'Ewa, O'ahu, Federal Study Areas 1a and 1b, and State of Hawaii Optional Area 1. xxxi + 398 p., 130 figs., 16 tables, 5 append. Unpubl. rep. prepared for U.S. Army Corps of Engineers, U.S. Army Engineer Distr., Honolulu, by Archaeological Research Center Hawaii, Inc. Ms. No. ARCH 14-115.
- Henshaw, H.W.** 1904. On certain deposits of semi-fossil shells in Hamakua District, Hawaii, with descriptions of new species. *J. Malacol.* 11: 56–64.
- Hunt, T.L.** 1981. New evidence for early horticulture in Fiji. *J. Polynesian Soc.* 90: 259–66.
- James, H.F. & S.L. Olson.** 1983. Flightless birds. *Nat. Hist.* 92(9): 30–40.
- Kerney, M.P.** 1966. Snails and man in Britain. *J. Conchol.* 26: 3–14.
- Kirch, P.V.** 1975. Excavations at Sites A1-3 and A1-4: Early settlement and ecology in Halawa Valley. p. 17–70. In: P.V. Kirch & M. Kelly, eds., Prehistory and ecology in a windward Hawaiian valley: Halawa Valley, Molokai. *Pac. Anthropol. Rec.* 24.
- . 1978. Report on recent and subfossil land Mollusca from Barber's Point, O'ahu. Appendix II. In: A. Sinoto, 1978 (see below).
- . 1982a. The impact of the prehistoric Polynesians on the Hawaiian ecosystem. *Pac. Sci.* 36: 1–14.
- . 1982b. Man's role in modifying tropical and subtropical Polynesian ecosystems. *Archaeol. Oceania* 18: 26–31.
- . 1984. The evolution of the Polynesian chiefdoms. Cambridge University Press, Cambridge. xii + 314 p.
- . 1985. Feathered gods and fishhooks: An introduction to Hawaiian archaeology and prehistory. University of Hawaii Press, Honolulu. x + 349 p.
- Kirch, P.V. & C.C. Christensen.** 1980. Nonmarine molluscs and paleoecology at Barbers Point, O'ahu. Unpubl. rep. prepared for Archaeological Research Center Hawaii, Inc. 40 p., 8 figs. Dep. Anthropol., B.P. Bishop Museum.
- Maciolek, J.A. & R.E. Brock.** 1974. Aquatic survey of the Kona Coast ponds, Hawaii Island. University of Hawaii Sea Grant Advisory Rep. AR-74-04. 73 p.
- Medway, D.G.** 1981. The contribution of Cook's third voyage to the ornithology of the Hawaiian Islands. *Pac. Sci.* 35: 105–75.
- Miura, M.T. & G. Sato.** 1978. Botanical and faunal survey of the proposed deep-draft harbor area, Barbers Point, Oahu. Tech. Rep. 1. In: B.D. Davis & P.B. Griffin, eds., Studies in natural history and human settlement at Barbers Point, O'ahu. Interim Rep. 1: Present environment and ar-

- chaeological survey of the proposed deep-draft harbor area, Barbers Point, O'ahu, Hawaii. Archaeological Research Center Hawaii, Inc. Ms. No. ARCH 14-115-I.
- Morgenstein, M.** 1978. Geoarchaeological reconnaissance of Barber's Point. Appendix I. In: A. Sinoto, 1978. (See below.)
- Neal, M.C.** 1934. Hawaiian Helicinidae. Bernice P. Bishop Mus. Bull. 125. 102 p.
- Olson, S.L. & H.F. James.** 1982a. Fossil birds from the Hawaiian Islands: Evidence for wholesale extinction by man before Western contact. *Science* 217: 633-35.
- . 1982b. Prodrum of the fossil avifauna of the Hawaiian Islands. *Smithson. Contrib. Zool.* 365. vi + 59 p.
- . 1984. The role of Polynesians in the extinction of the avifauna of the Hawaiian Islands. p. 768-80. In: P.S. Martin & R.G. Klein, eds., *Quaternary extinctions: A prehistoric revolution.* University of Arizona Press, Tucson.
- Perkins, R.C.L.** 1913. Introductory essay on the fauna. p. i-cxxviii, pl. 1-16. In: D. Sharp, ed., *Fauna Hawaiiensis.* Vol. 1, Pt. 6. Cambridge University Press, Cambridge.
- Pielou, E.C.** 1979. Interpretation of paleoecological similarity matrices. *Paleobiology* 5: 435-43.
- Pilsbry, H.A.** 1916-1918. Pupillidae (Gastrocoptinae). *Manual of Conchology (2nd ser.).* Vol. 24. Academy of Natural Sciences, Philadelphia. xii + 380 p., 49 pl.
- Pilsbry, H.A. & C.M. Cooke, Jr.** 1914-1916. Appendix to Amastridae. Tornatellinidae. Index to vol. 31-33. *Manual of Conchology (2nd ser.).* Vol. 23. Academy of Natural Sciences, Philadelphia. xi + 302 p., 55 pl.
- . 1918-1920. Pupillidae (Gastrocoptinae, Vertigininae). *Manual of Conchology (2nd ser.).* Vol. 25. Academy of Natural Sciences, Philadelphia. ix + 401 p., 34 pl.
- Pilsbry, H.A. & E.G. Vanatta.** 1906. New Hawaiian species of *Endodonta* and *Opeas*. *Proc. Acad. Nat. Sci. Phila.* 1905: 783-86, pl. 43.
- Sinoto, A.** 1976. A report on cultural resources survey at Barbers Point, Island of O'ahu. 90 p., 34 figs., 3 tables. Unpubl. rep. prepared for Dep. Army, Corps of Engineers, Pac. Ocean Div., Contract No. DACW84-76-C-0027, Dep. Anthropol., B.P. Bishop Museum, Ms. 122476.
- . 1978. Archaeological and paleontological salvage at Barbers Point, O'ahu. 72 p., 21 figs., 14 tables. Unpubl. rep. prepared for Dep. Army, Corps of Engineers, Pac. Ocean Div., Contract No. DACW84-77-C-0040, Dep. Anthropol., B.P. Bishop Museum, Ms. 030178.
- . 1979. Cultural resources survey of new dredged material disposal sites at Barbers Point, O'ahu, Hawai'i. 97 p., 4 + 50 figs., 6 tables. Unpubl. rep. prepared for U.S. Army Engineer Div., Pac. Ocean, Contract No. DACW84-77-C-0019, Dep. Anthropol., B.P. Bishop Museum, Ms. 050179.
- Sinoto, Y.H.** 1983. Archaeological excavations of the Vaito'otia and Fa'ahia sites on Huahine Island, French Polynesia. *Natl. Geogr. Soc. Res. Rep.* 15: 583-99.
- Solem, A.** 1976. Endodontoid land snails from Pacific Islands (Mollusca: Pulmonata: Sigmurethra). Part I: Family Endodontidae. *Field Museum of Natural History, Chicago.* xii + 508 p.
- Stejneger, L.** 1899. The land reptiles of the Hawaiian Islands. *Proc. U.S. Natl. Mus.* 21: 783-813.
- Taliaferro, W.J.** 1959. Rainfall of the Hawaiian Islands. Hawaiian Water Authority, Honolulu. 394 p.
- Tate, G.H.H.** 1951. The rodents of Australia and New Guinea. *Am. Mus. Nat. Hist. Bull.* 97: 189-430.
- Trotter, M.M. & B. McCulloch.** 1984. Moas, men, and middens. p. 708-27. In: P.S. Martin & R.G. Klein, eds., *Quaternary extinctions: A prehistoric revolution.* University of Arizona Press, Tucson.
- Whittaker, R.H.** 1952. A study of summer foliage insect communities in the Great Smoky Mountains. *Ecol. Monogr.* 22: 1-44.
- Zimmerman, E.C.** 1948. Introduction. *Insects of Hawaii.* Vol. 1. University of Hawaii Press, Honolulu. xx + 206 p.