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MARINE FAUNA

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The National Park Service and the University of Hawaii signed the memorandum of agreement establishing this Cooperative National Park Resources Studies Unit (CPSU UH) on March 16, 1973. The CPSU UH provides a multidisciplinary approach to studies on the biological resources in the National Parks in Hawaii, that is, Hawaii Volcanoes National Park, Haleakala National Park, City of Refuge National Historical Park, and Puukohola Heiau National Historic Site. Through the Unit Director, projects are undertaken in areas identified by park management. These studies provide information for resource management programs. The involvement of University faculty and students in the resource management of the National Parks in Hawaii leads to a greater awareness of the problems and needs of the National Park Service. At the same time, research not directly or immediately applicable to management is also encouraged through the CPSU UH.

Contribution numbers are assigned as follows. CPSU UH identifies the Cooperative National Park Resources Studies Unit of the University of Hawaii. This is followed by a three-digit number assigned in sequence to each new project of this CPSU. The fourth digit indicates the report number for that particular project.

THE PHYSIOGRAPHY AND MARINE FAUNA OF INSHORE AND INTERTIDAL AREAS IN THE PUUKOHOLA HEIAU NATIONAL HISTORIC SITE

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ABSTRACT

This report describes the physiography and marine fauna of waters enclosed by the boundaries of the Puukohola Heiau National Historic Site from the high tide mark to approximately 150 m from shore. Line transect and qualitative methods were employed to sample the benthic and demersal macrofauna within biotopes ranging from brackish pools to coral patch reefs. Spot checks were also made outside the survey site for comparative purposes.

With few exceptions, the reef ecosystem within the site is depauperate. About half as many species of fish (63) were observed as were previously reported (111 species) in an area a few hundred meters seaward of the site. Grey reef, blacktip, and whitetip reef sharks were commonly seen breaking the surface near the presumed site of the Hale o Kapuni heiau. The sharks may have been attracted by the warm waters of the site and/or to the large schools of juvenile mullet seen within these waters.

Striking gradients in diversity and distribution of benthic invertebrates were typically correlated with substrate and water quality factors. Corals in the site were under moderate to heavy siltation stress and inshore areas were dominated by opportunistic species. Recommendations to stabilize and improve the reef ecosystem are given.

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INTRODUCTION

Puukohola Heiau National Historic Site was established on the sites of two major heiaus, the Pu'ukoholā Heiau and the Mailekini Heiau. There is historic evidence for a third structure, Hale o Kapuni, an underwater heiau for the feeding of sharks. These heiaus and associated home and farm sites comprise the principal historic features of the area.

The site encompasses an extensive dryland terrestrial biota (Macneil and Hemmes 1977) and is adjacent to a small section of shallow inshore reef. This report describes the biotopes and marine fauna of the reefs adjacent to the site and offers recommendations for the maintenance of the biota and shoreline development. The marine flora is described in a separate survey report (Ball 1977). The field work was conducted from April through June 1976, with the assistance of Mr. James Macneil, Mr. Loren Akaka, and Mr. Mike Severns.

Setting

The Puukohola Heiau National Historic Site is located on the northwest coast of the Island of Hawai'i on 77 acres of land (Fig. 1). It is bordered to the north by Kawaihae harbor and to the south by Sam Spencer Beach Park, a heavily used county facility. The northern boundary is bisected by Makeāhua Gulch, an old stream course which is dry except during periods of heavy rainfall.

The site is underlain by flows from Mauna Kea (Hāmākua series) and much of this basalt is exposed in the narrow intertidal region (Newman 1968). Makeāhua Gulch cuts into these flows, and alluvium from the stream has produced an outwash plain extending 100 m seaward. The beach berm at the mouth of the gulch encloses a series of small anchialine* pools which lead upstream. The Kawaihae harbor revetment

*Shoreline pools without surface connection to the sea, having waters of measurable salinity and showing tidal rhythms.

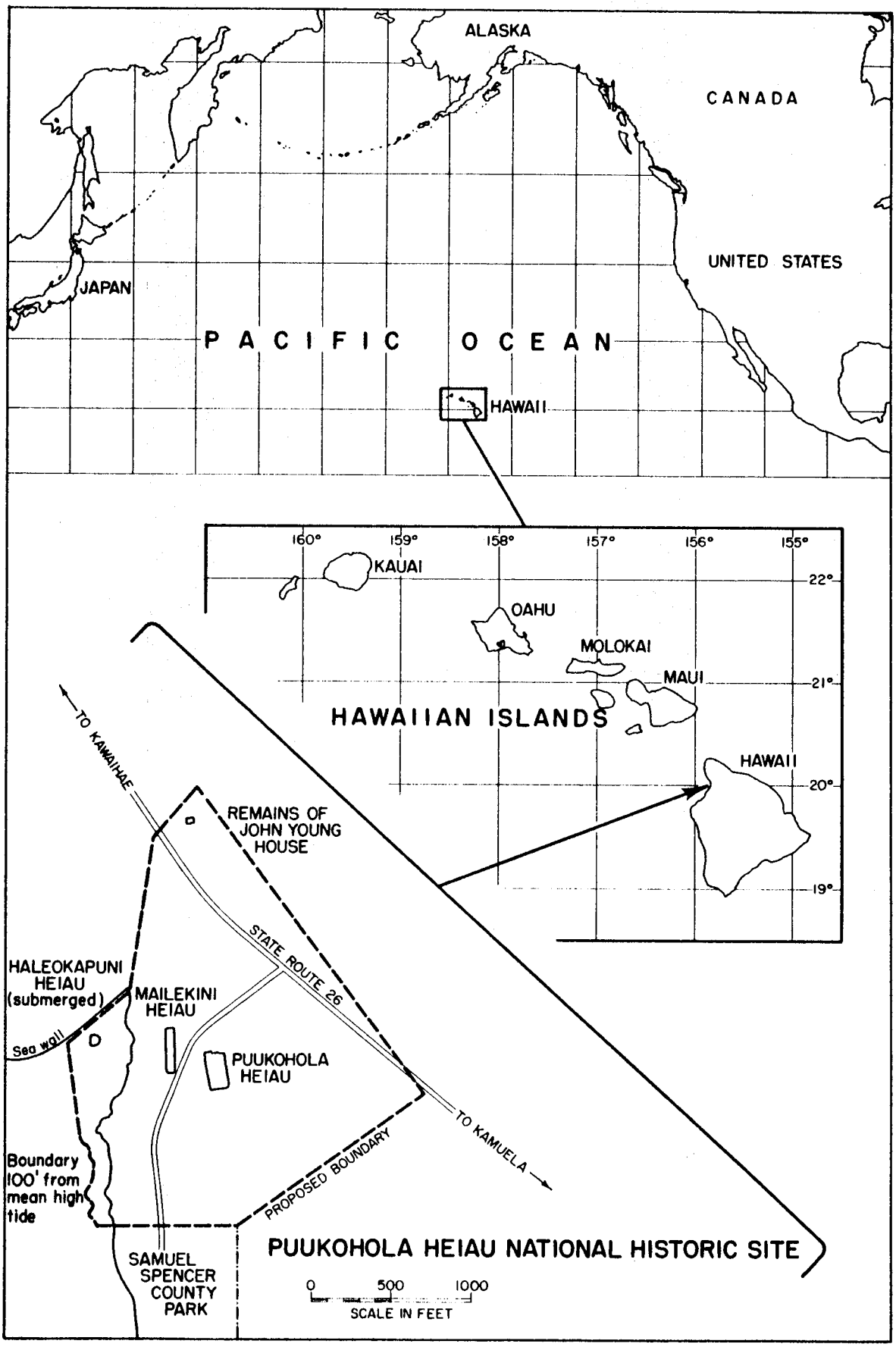

Figure 1. Map showing the location of the Puukohola Heiau National Historic Site on the Island of Hawaii.

extends out from the inside shore boundary of the site. This revetment is composed of basalt boulders with a coral fill and is part of an artificial facility completed in late 1959 by dredging a portion of the coral reef which extended offshore along the coast of Kawaihae. The fill and revetments of the harbor cover a significant portion of the reef north of Pu'ukoholā. Prior to construction of this facility, Kawaihae harbor consisted of a small boat harbor and wharf, both of which were a considerable distance from the present Historic Site.

Kawaihae harbor, however, was not designed for small boat moorage. Therefore, a small boat harbor was proposed in the late 1960's for placement on a site south and adjacent to the deep draft harbor and a few hundred meters seaward from Pu'ukoholā. The excavation for this harbor was completed during Project Tugboat in 1969-70. This project was conducted by the U.S. Army Engineers Nuclear Cratering Group to test excavation techniques using conventional explosives (ammonium nitrate gel) (U.S. Army Corps of Engineers 1975). The experiments included extensive environmental impact and fish-kill studies (Day et al. 1972). After the tests, an 850-foot breakwater was constructed and although the harbor is not yet completed, the area is now used as a more or less permanent anchorage for a small number of pleasure vessels.

MATERIALS AND METHODS

Study Site Description

The site for the marine survey was the area bounded by Pu'ukoholā, Kawaihae Breakwater, and Spencer Beach Park. It extended 150 m seaward from the southern boundary of the Historic Site and formed a rough rectangle 150 m by 300 m, enclosing approximately 45,000 m^2. An outline of the area is shown in Figure 2.

The site was initially evaluated from aerial color photographs to determine the gross underwater topography

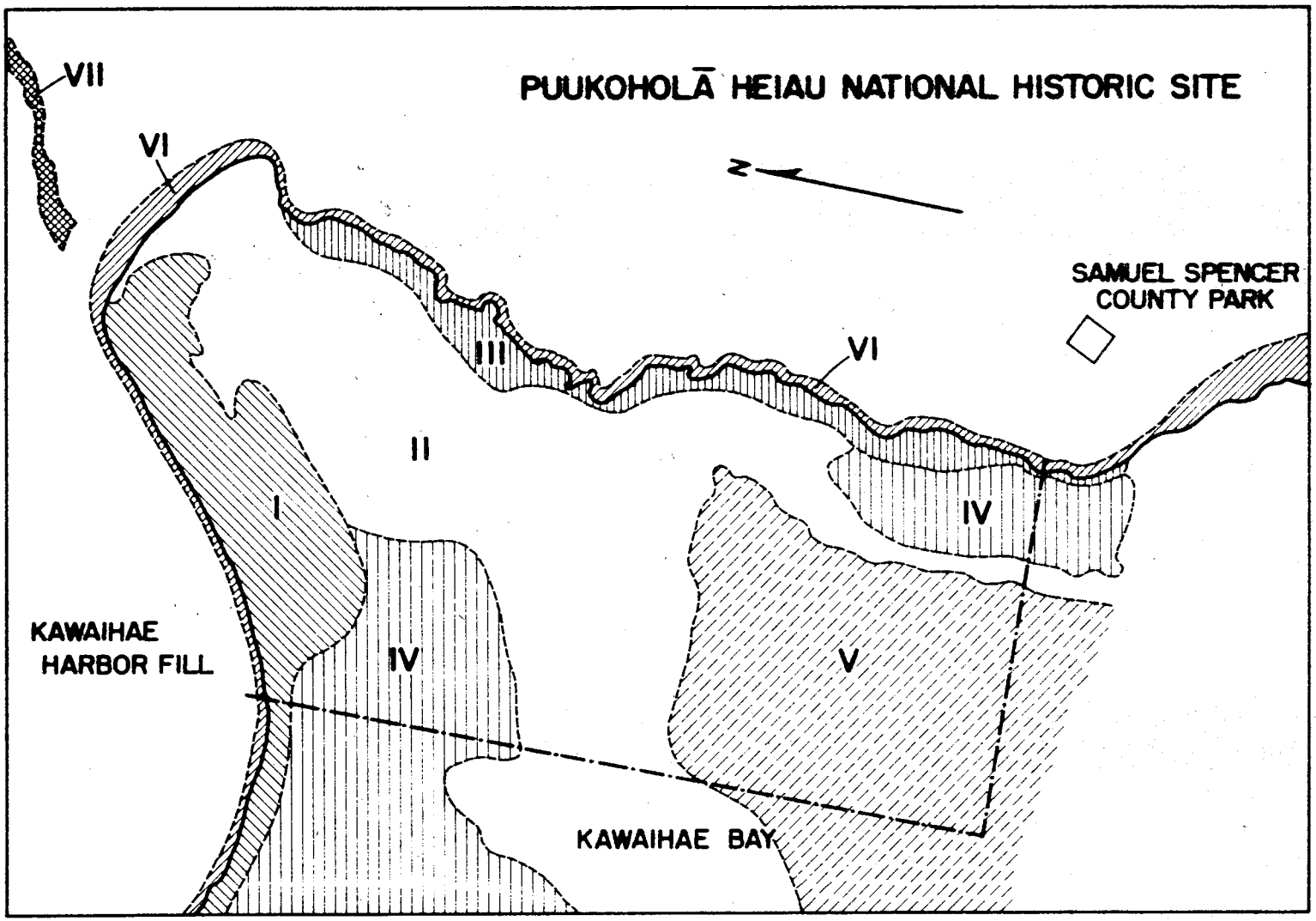

Figure 2. Biotopes and outline of the marine survey site at Pu'ukoholā. The biotope numbers correspond with those given in Table 1, p. 21. Scale is 1/2 inch to 100 feet (1.27 cm to 30.48 m).

and shoreline features. Biotopes were then mapped out by swimming and wading over the survey site and comparing subsurface features and water quality data (temperature, salinity, and turbidity) with the aerial photos. Seven biotopes were recognized as being distinct habitats for the fish and invertebrate communities.

Survey Methods

Fish

SCUBA was used to survey the fish fauna of the site. The species list was compiled from six hours of underwater observations throughout the biotope types of the bay. Silt and rubble areas had very limited populations of fishes; therefore no quantitative assessments were made in those regions. At the southern limits of the Historic Site boundary there is a rich region of living coral in the form of patch reefs separated by sand plains. In this area two 50-m transect lines were installed at a depth of 4 to 5 m. The inner line (#1) was set 50 m out from shore with an east-west orientation. The outer line (#2) lay seaward of, and adjacent to, line #1 and ran northwest to southeast.

Three replicate censuses were performed on each transect (2 April, 1000 hours; 10 April, 1000 hours; and 10 April, 1400 hours). Fish were counted 5 m on each side of the line and data recorded in 5-m^2 quadrats on underwater Ascot paper. All fishes were counted and juvenile stages were noted. Details, advantages, and pitfalls of this technique are reported in Nolan (1975) and Nolan and Taylor (1977). In addition to offshore observations, intertidal, brackish water, and pond fishes were captured for identification with small hand nets and mini spears.

Benthic invertebrates

Quadrats of 100 m^2 were sampled qualitatively within each biotope by recording or collecting the benthic epi- and infauna. When possible, relative abundance estimates were made for the dominant taxa. Additional identification of macroinvertebrates

was made from samples of living and dead coral heads, coralline and fleshy algae, and basalt or limestone rubble. These samples were taken on shore, subsampled, fixed in 10% seawater Formalin for identification in the laboratory, and held for deposit in NPS collections. The infauna in sand and mud was collected by removing surface samples of 0.5 to 1 m^2 to a depth of 2 to 10 cm with a bucket dredge and filtering the whole sample through a large 2 mm square mesh larval net.

The line transects employed for the fish censuses were used to enumerate corals and other benthic invertebrates in the coral-rich fringe zone of the site. The biota and substrate type were recorded in one-meter increments along the line, and samples were taken at points where an immediate identification could not be made.

Most of the information concerning mollusks within the site was obtained by a random sampling of patch reefs and sand deposits within the offshore portion of the site and by a detailed search along the intertidal zone. Transects or quadrats were not used on the reef area because of the limited visibility within the site. Snorkeling and SCUBA surveys of offshore areas were conducted during early morning hours, while shoreline surveys were completed during both day and night.

RESULTS

Surveys conducted at Pu'ukoholā provide a relatively complete picture of the marine macrofauna of the area as it now exists. The area enclosed by the survey site is not large but does include a wide range of environmental parameters. A map with outlines of the biotopes is shown in Figure 2, and the physical and environmental characteristics of each biotope are listed in Table 1.

The temperature rise in biotopes I, III, VI, and VII was primarily due to the influence of warm (up to 29.5°C) freshwater

springs although solar radiation in biotope I was an important heating factor. The intrusion of fresh water also depressed salinities in parts of biotopes III, VI, and VII. The surface layer of fresh water had an additional adverse effect on surface visibility but this was not as severe as the reduction in visibility throughout the site due to the suspension of particulate matter.

The species compositions of benthic invertebrates and fishes in the survey area are shown in Tables 2 and 3. The relative abundance estimates are based on the frequency of encounters during survey dives and provide a subjective measure of population density within phylogenetic groups. The quantitative observations along the straight-line transects are shown in Table 4 for fish and Table 5 for corals.

Description of Biotopes and Invertebrate Fauna

Biotope I--Mixed rubble and silt bottom

This area borders the Kawaihae breakwater revetment and consists of a band 25 to 50 m in width. It is characterized by a coarse, coral-rich sand near the seaward boundary of the survey area, grading to fine or silty terrigenous deposits near the inside of the breakwater. Small to medium-sized rocks ranging from 5 to 10 cm in diameter are scattered throughout the area. These rocks are for the most part old broken coral heads, but some basaltic rocks can be found near the beach.

The rubble area close to the breakwater shows distinctly different biological characteristics near the beach versus on the outer edge of the survey site. Inshore, the larger macroinvertebrates were scattered portunid and box crabs. The substrate is silty and perforated with shrimp burrows. The undersides of rocks are covered with masses of sand tubes of sabellariid worms, while the upper surfaces are usually bare. The inshore infauna consists of isopods (Tanioidea, Apseudidae) with scattered stomatopods (i.e. *Squilla alba*), ghost shrimp (callianassid), small holothurians, and snapping

(alpheid) shrimp. There are numerous unidentified micromollusks (shell length less than 5 mm) and debris made up of detrital material and skeletal components from urchins and coral.

Macroinvertebrates become more common near the outer seaward edge of the biotope. Living corals, which are not present inshore, are represented by *Pocillopora damicornis*. Twenty colonies 5 to 20 cm in diameter were counted in a 50 m^2 area and many more colonies less than 5 cm in diameter were seen. *Cyphastrea ocellina* also occurs but other coral species are not represented. Echinoderms are represented by *Echinometra mathaei* living in the coral rubble and a few individuals of *Tripneustes gratilla*. Sand deposits contain a small infauna of macroinvertebrates made up of alpheid shrimp and annelids (i.e., sabellids). The undersurfaces of rocks were encrusted with coralline algae, serpulids, and sabellariids. The upper surfaces were colonized by vermetids, filamentous algae, and an occasional colony of the hydroid, *Pennaria tiarella*.

Biotope II--Sand and silt bottom

These are sand/mud channels which are continuous from the outwash plain near Makeāhua Gulch to deep offshore sand deposits. A branch runs parallel to the Spencer Beach shore. Mud becomes the major bottom element inshore and numerous shrimp burrows and tracks from *Terebra crenulata* are present along with scattered coral colonies. The infauna from a single sample was made up completely of annelids (nereids).

Biotope III--Basalt pavement with rubble

This is a band of solid pavement 5 to 30 m in width leading north from Spencer Beach Park to the beach at Makeāhua Gulch. Inshore surface waters have widely varying salinity, with a freshwater lens about 0.3 m thick extending up to 30 m from shore. *Pocillopora damicornis* is the dominant coral in shallow water throughout the biotope; in deeper water near the southern edge of the biotope,

colonies of *Porites compressa*, *Montipora verrucosa*, and *Pocillopora meandrina* are found. Encrusting vertical faces of rocks in the central portions of the biotope are the corals *Leptastrea bottae* and *Cyphastrea ocellina*, zooanthids, the soft coral *Athelia edmondsoni*, and the sponge *Terpios*. Toward the breakwater most live coral disappears, visibility decreases to 1 to 2 m, and a thick brown silt covers most of the substrate. *Echinothrix diadema* is the most common echinoderm on bare pavement although *Tripneustes gratilla* was also often seen. *Echinometra mathaei* is usually found in the cracks and old coral heads. The contents of a single coral head 15 cm in diameter included six *Echinometra mathaei* of 1 to 2 cm diameter, five brittle starfish (*Ophiocoma brevipes*), five small colonies of *Pocillopora damicornis* and *Porites* sp., two tunicates, and many small syllids and serpulids.

Biotope IV--Coral in mixed rubble

This is not a clearly defined biotope but is dominated by larger (to 4 m diameter) dead and living coral heads or clumps of colonies with 0.25 to 1 m vertical relief surrounded by a light and loose silt substrate. Smaller coral heads and coral rubble are interspersed in the mud and silt between the larger masses. Many of the coral heads are silted over, particularly those near the breakwater side of the biotope, and there is some evidence of recent death or stress, i.e., bleached but not silted coral heads. Living corals near the breakwater side are predominantly *Pocillopora damicornis* and *P. meandrina*, with *Porites compressa*, *P. lobata*, and *Montipora verrucosa* seen less frequently. Other species are noted in Table 2.

Near the sand channels the biotope is characterized by mixed colonies of *Porites*, usually clumped into masses up to 4 m in diameter. Most of the colonies are dead and fragile and are infiltrated with sponges, algae, and a rich infauna like that seen in coral rubble from other biotopes. The Spencer Beach Park portion of the biotope has a lush growth

of *Porites compressa* and *P. lobata* with colonies up to 1 m in diameter, and smaller colonies of *Pocillopora meandrina*, *P. damicornis*, *Montipora verrucosa*, and *M. patula*. Both species of *Echinometra* are abundant in the *P. compressa* heads, but *E. oblonga* is more common in shallow water. *Echinothrix diadema* is fairly common around the bases of coral heads, and the slate pencil urchin, *Heterocentrotus mammilatus*, is frequently seen.

Biotope V--Patch reefs

This is a uniform biotope with individual colonies and patch reefs ranging from less than 0.5 m to 20 m in width with 0.25 to 3 m of vertical relief. The surfaces of the colonies may break the surface at low tide. Straight-line transects were established on the seaward fringe of this biotope, and the living coral coverage from these transects is summarized in Table 5. There is an apparent deterioration of coral cover and diversity and an increase in silt deposits toward the breakwater side of the biotope which is more or less similar to biotope IV. A large colony of the coral *Porites* (*Synaraea*) sp. was found near the outer edge of the inside transect site (line #1), and two possibly "tumorous" colonies of *Montipora verrucosa* were observed and marked near the center of the biotope.

Dead coral heads within the transect area are encrusted with coralline and filamentous algae, bryozoans, hoof shells (*Hipponix pilosus* and *H. barbatus*), and serpulid worms. Boring sponge is common, and scattered bivalves, vermetids, and zoanthids also occur.

Biotope VI--Intertidal

The biotope includes a narrow ledge, 1 to 5 m in width, along the Pu'ukoholā shoreline; a sand beach 50 m in length in Makeāhua Gulch; and a basalt block revetment on the Kawaihae breakwater. Large movable rocks along the natural basaltic shoreline exhibit very little surface fauna or flora except coralline algae and vermetids. The bottom surfaces hold a rich epifauna consisting mainly of small

Echinometra mathaei, *E. oblonga*, and serpulids (spirorbinae). Sea cucumbers are quite common in the subintertidal region, more so than in other biotopes. The tidepools contain a euryhaline* fauna, and mussels and nerites (live and crabbed) are very common. The bottoms of smaller pools and protected pavement are sometimes encrusted with zoanthids and algae forming a crust or mat 1 to 3 cm in thickness. Echiuroids and crabs are often found beneath or within these layers. The loose gravel in the upper intertidal zone contains sipunculoids (about 2 per 0.25 m^2).

The beach portion of the biotope contains ghost crab (*Ocypode ceratophthalmus*) burrows and a typical onshore strand vegetation. Schools of juvenile mullet (*Mugil cephalus*) and āholehole (*Kuhlia sandvicensis*) can be seen feeding near the surface in calm waters around clumps of *Enteromorpha* and beneath the overhanging kiawe (*Prosopis pallida*) trees near the southern edge of the beach. The water in this area is clearer than in the nearby rubble of biotope I and did not appear to become as turbid with increasing onshore winds.

The rocks along the Kawaihae breakwater hold a narrow band of nerites, littorines, and *Siphonaria*. Grapsid crabs (*Grapsus grapsus* and *Metapograpsus messor*) are common on all rocky portions of the biotope.

Biotope VII--Brackish pool

This biotope consists of a series of small anchialine ponds inside Makeāhua Gulch set off from the bay by a narrow berm. These ponds have variable but low salinity (see also Maciolek and Brock 1974), and are 1 to 3 m in width and no more than 1 m in depth. They contain much organic debris, and have very soft muddy bottoms. *Palemon debilis* (glass shrimp) and *Tilapia* were seen in these ponds although none of the *Tilapia* appeared to be greater than 20 cm in length.

*Able to live in waters of a wide range of salinity.

The Fishes on Transects

Thirty-six fish species were found on the transects, with weke, *Mulloidichthys samoensis*, most numerous. Following the weke in order of abundance were *Chromis ovalis*, *Thalassoma duperreyi* (hīnālea), *Abudefduf abdominalis* (maomao), and *Scarus sordidus* (parrotfish). Juveniles of each of the latter four species were also common. Several species were found on every replicate of both transects: *Gomphosus varius*, *Chaetodon trifasciatus*, *Scarus sordidus*, *Ctenochaetus strigosus* *Thalassoma duperreyi*, *Pomacentrus jenkinsi*, *Abudefduf abdominalis*, and *Chromis ovalis*. These data are fully listed in Table 4.

DISCUSSION AND CONCLUSIONS

The waters adjacent to the Puukohola Heiau National Historic Site contain a fauna which is nowhere as diverse as that found in similar areas along the coast of the island of Hawai'i (Brock and Brock 1974, Kimmerer and Durbin 1975). Nevertheless, the area is an important resource and supports a significant population of juvenile fish and a large benthic biomass.

Physical Characteristics

The dominant factors affecting the distribution of organisms within the sutdy site are substrate and water quality characteristics. Wave activity is, except during periods of strong southwesterly swells, limited to localized wind-driven waves less than 0.5 m high. It is usually minimal in the morning and reaches a peak in mid-afternoon. Turbidity generally correlates with increased onshore wind speed and wave height. It is greatest near the inner portions of the site, and the waters on the outer margin of the survey site also have a relatively high turbidity when compared with offshore waters. Visibility is greatest in the morning but was never

greater than 3 to 10 m anywhere within the site. Near shore, the water is extremely turbid (visibility less than 1 m) and any activity results in a fine suspension.

Salinity and temperature are influenced by warm (to 29.5°C) subsurface freshwater springs, intermittent surface runoff, prevailing exchange rates, and incident solar radiation. The freshwater springs are most noticeable in the rocky intertidal areas between Spencer Beach Park and the breakwater.

These springs produce a distinct surface layer of warm water which overlies the cooler subsurface water over most of the site. In shallow waters the zone of freshwater influence extends through the water column and results in a more or less estuarine environment in these areas.

The outer edge of the site has salinities and temperatures approximating oceanic seawater.

The Fish Fauna

Although the Kawaihae reef system at one time must have had one of the best developed reefs in the Hawaiian Islands, today its fish fauna is depauperate, due perhaps to a combination of environmental disturbances associated with harbor construction and unrestricted resource use. Nowhere is this more evident than near shore at the Pu'ukoholā site. Dredge tailings in biotope I and parts of biotope IV have enveloped much of the reef and siltation from these tailings has spread throughout the survey area. The occurrence of reef fishes is highly dependent upon proper habitat in the form of shelter and feeding sites (Nolan 1975), and at Pu'ukoholā the normal habitat has been drastically altered. As expected, the coral-rich area had more individuals and a higher diversity than any other biotope in the site.

The reef ecosystem only a few hundred meters seaward of the study site near the proposed site of the small boat harbor was not so extensively altered. The richness of this reef as documented in pre- and post-detonation surveys during Project Tugboat by the State Division of Fish and Game

(Day et al. 1972) contrasts markedly with that of the study site. Fish and Game biologists observed or collected 111 different species of fishes in 34 families while only about half as many species were seen in the study site (63 total--of which two occurred in brackish pools and five were restricted to tidepools). Common species observed during Project Tugboat were *Thalassoma duperreyi*, *Chromis ovalis*, and *Mulloidichthys samoensis*. These were also among the most common individual species found on the study transects. The most abundant fish seen during Project Tugboat, *Scarus dubius*, had a low level of abundance during the Pu'ukoholā survey.

Sharks are characteristic inhabitants of the study site. Grey reef sharks (*Carcharhinus menisorrah*), black-tip sharks (*C. melanopterus*), and whitetip reef sharks (*Triaenodon obesus*) were seen at most high tides during calm, still air conditions. These sharks are currently under study to determine their range of activities and attraction to the area (Nolan 1977). Feeding bouts on mullet have been observed and it may be that the sharks have a predatory advantage over prey in the murky, turbid water. Local fishermen report that the sharks enter the bay to mate and give birth to young. Prior to the survey a female grey reef shark was taken and found to be bearing fetuses. An additional attractant may be the elevated water temperature and/or reduced salinity of the inner part of the survey site.

The Invertebrates--Excluding Mollusks

The distribution of invertebrate species and particularly corals and crustaceans is distinct from that of fishes and is indicative of the prevailing conditions of the area. The general characteristics of these distributions may be seen in Table 4. Living corals are absent in silt-laden rubble areas of biotope I or limited to only a few species where silt and freshwater intrusion predominate, such as in the

northern portions of biotope III. Many coral colonies are in what appears to be stress-state and exhibit extensive dead zones, usually in basal areas, or reduced pigmentation. A considerable fraction of the coral-based substrate (i.e., not a sand or silt bottom) is made up of dead and moribund colonies. This is more obvious in the coral rubble areas of biotope IV than on the patch reefs which normally show good living coral coverage (Table 5). In the more heavily silted sections of biotopes III and IV diversity is low, although the abundance of small colonies of *Pocillopora damicornis* and *Porites* sp. is relatively high.

Crustaceans are especially numerous in and under the dead coral heads of biotopes I, III, and IV and beneath algal crusts and zooanthid mats in the intertidal zone. These habitats support large and diverse populations of xanthid crabs, with at least 12 species, and alpheid shrimp. The large isopod and alpheid shrimp populations of parts of biotope I seem to be correlated to the intrusion of warm and possibly nutrient-enriched fresh water from basal springs. The available habitat suitable for xanthids is also extensive within the rubble-filled areas of the survey site and probably represents an optimal environment for these organisms.

Bryozoans (Entoprocta and Ectoprocta) are common throughout the survey site. Turbidity and sedimentation do not appear to be a problem for survival of these animals. Most are found attached to the undersurfaces of rocks and coral colonies where they would not be affected by sediments.

Polychaete annelids, which were not identified to the genus level, were an important group of invertebrates in all biotopes except those areas with a high percentage of live coral or bare pavement. The extensive porous coral rubble combined with minimal water movement offer favorable conditions for the development of large populations of serpulids, especially in intertidal regions; sabellariids, in the silted rubble of biotope I; and sabellids. The

polychaetes are a major infauna in living and dead coral heads and occupy small habitats in association with sponges, bryozoans, crustaceans, gastropods, and echinoderms. These microsystems are fertile territory for the definition of the structure and dynamics of small animal communities.

The Mollusks

There appears to be a remarkably smaller population of macromollusks in the highly silted portion of the Historic Site than in the clearer waters further offshore and to the north and south of the site (personal observation). Cowrie species such as *Cypraea caputserpentis* Linn., *C. isabella* Linn., and *C. helvola* Linn. were not seen after extensive searches under rocks and coral rubble in the area. Early morning searches of sand pockets turned up some *Conus quercinus* Solander, *C. pulicarius* Hwass, and *Terebra crenulata* Linn. on the Spencer Beach side of the Historic Site, but nothing comparable to the wide variety of species of sand dwellers which can be observed in sand pockets several hundred meters seaward of the site at approximately 5 to 10 m depth (e.g., *Terebra maculata* Linn., *T. guttata* Roeding, *T. strigilata* Chem., *T. areolata* Link, *T. affinis* Gray, *Hastula lanceata* Linn., and *H. lauta* Pease).

The intertidal zone was dominated by *Nerita picea* Recluz and *Littorina scabra* Linn., the latter being found in abundance on kiawe (*Prosopis pallida*) branches hanging in the ocean. Only small populations of crabbed mollusks were observed along the coastline from Spencer Beach Park to the beach near Makeāhua Gulch during the night or day. The beach and the shoreline along the artificial breakwater bordering the northern end of the marine portion of the Historic Site were not surveyed for crabbed specimens because of the large number of empty shells available in the breakwater rubble which could become crabbed and not be representative of the living mollusks of this region.

Man-related Site Features

Sharks, Hale o Kapuni, and toxic organisms

Sharks are common in the site; nevertheless, local fishermen report that they have never been molested by these large carnivores and they are rarely seen swimming inside the bathing area of Spencer Beach Park (which should attract the attention of the swimmers!). Because the presence of these animals reinforces the historical significance of the shark heiau, Hale o Kapuni, they should be protected, or at least not disturbed.

With the exception of the concentration of sharks within the apparent site of Hale o Kapuni, positive evidence for the existence of the structure is lacking. The area is presently heavily silted and no rock outcroppings or artificial structures are visible. The site is identified (though not clearly) on Jackson's map of 1870 (Soehren 1964), where it appears to rest about 30 m offshore in line with Pu'ukoholā and Mailekini heiaus. Soehren (1964) writes of an informant speaking of a channel leading into a structure ("heiau") where bodies were placed for sharks. Whether the bodies were human or animal was not stated. The same site is mentioned in the story of Lono-i-ka-makahiki (an ancient Hawaiian chief) as a place of encampment (Daws 1968). An old Kawaihae resident, Eddie Laau, Sr., reported that the site was covered many years ago by silt washed down from the river in Makeāhua Gulch and more recently from the coral fill (Barrera and Kelly 1974). A recent archaeological survey of the site (Carol Link, personal communication) failed to reveal the presence of any subsurface structure. Thus the true significance of Hale o Kapuni remains unclear and it cannot be stated if it was an actual heiau or merely a site of concentrated shark activity.

Except for the sharks, few other toxic or dangerous organisms are present at Pu'ukoholā. The toxic echinoids, *Echinothrix calamaris* and *E. diadema* (wana), are very common in shallow waters facing the rocky natural shoreline (biotope III) and could be a hazard to swimmers or waders

in the area. A few small (0.3- to 1-m long) moray eels are present inshore among the coral heads and boulders.

Human waste

An abundance of litter in the form of car bodies, boats, engine blocks, tires, bottles, cans, and wire may be seen on the bottom and along the shoreline. Much could be done to improve the aesthetic qualities of the site both in the water and on the land by removing the litter and educating the public as to the nature of the Historic Site in an effort to maintain a relatively natural and litter-free environment.

The Kawaihae breakwater and fill is a major visual obtrusion but cannot be easily modified. Vegetation compatible with the Historic Site should be placed along the breakwater facing the site to improve the visual setting, at least from sea level. An additional benefit of the plantings might be a reduction in sand and silt erosion into the water from the fill area.

Recreational impact

Public use of the Historic Site can be expected to increase once access and aesthetic improvements are made. Presently gill nets are set in the northern portions of the survey site (biotopes I and II), and hook-and-line fishermen sometimes work through the kiawe trees to fish from the shoreline. The fish species taken most frequently by these fishermen are pāpio (young of several species of ulua or jacks), mullet, and moano (*Parupeneus multifasciatus*). Spear fishermen are common but their catch rates appear to be very low compared with the catch in areas north or south of the site.

Greater use of the intertidal zone is expected with increased public awareness of the Historic Site and heavier use of the neighboring county park. The organisms in this zone and subtidal areas are relatively resistant to non-consumptive use and should be protected to the limits of the survey site, although some fishing could be permitted.

Present and future development

The greatest impact on the water quality and marine biota of Pu'ukoholā will come from the construction and maintenance of the proposed Kawaihae small boat harbor and industrial developments in and around Kawaihae harbor. For example, turbidity resulting from dredging operations can extend into adjacent areas and possibly affect the type and rate of colonization of marine organisms (Sullivan and Gerritsen 1972). Secondary impacts of these and other developments will be the release of pollutants from boats, industrial sources, and cesspools.

The influence of future development on the Pu'ukoholā marine fauna will probably be overshadowed by the ongoing impact of the Kawaihae breakwater. This structure undoubtedly effectively blocks longshore currents and facilitates the deposition and resuspension of detrital and organic sediments. Unless the nearshore circulation can be reestablished, the marine fauna of Pu'ukoholā will continue to undergo change to silt-tolerant species.

SUMMARY

This report describes the physiography and marine fauna of waters enclosed by the boundaries of the Puukohola Heiau National Historic Site in biotopes ranging from brackish pools to coral patch reefs.

Approximately one-third of the site is covered by silt, small coral heads, coral rubble and fragments; one-third by sand and silt or basaltic pavement; and one-third by patch reefs surrounded by sand or silt.

The greatest proliferation and diversity of active coral colonies occurs on the extreme margins of the survey site. Corals in other areas are often heavily silted and/or replaced by more silt-tolerant species.

Polychaetes, bryozoans, and crustaceans are most abundant in the heavily silted portions of the site with widely varying salinity, and dominate the macroinvertebrate fauna of these regions.

The subtidal areas of the site support only a small population of macromollusks compared with similar regions north and south of Kawaihae. The population density and species composition of intertidal mollusks are not so depressed and are similar to other coastal areas.

The number of individuals and species of fish is considerably lower in the survey site as compared with adjacent seaward reefs, although the species composition is similar. Many of the species present are represented by both juveniles and adults.

Striking concentrations of sharks occur, and while they are not apparently a human safety hazard, their presence does tend to support the historical evidence for the shark heiau, Hale o Kapuni. The attraction of sharks to the site appears to be related to feeding, breeding, and water quality factors.

The water quality and aesthetic attributes of the survey site are not favorable for the maintenance of a coral-rich environment or for providing an attractive background for the historical features of the site. Planned development outside the Historic Site is likely to accelerate the deterioration of the area.

TABLE 1. Physical characteristics of the marine biotopes within the Pu'ukoholā survey area. Visibility is defined as low (0.2 to 1 m), medium (1 to 2 m) or high (2 to 6 m). Depth is the approximate range in meters at mean low water.

Biotope Number	Biotope	Temperature (°C)	Salinity (°/₀₀)	Visibility	Water Depth (m)
I	Mixed rubble and silt bottom	29.5	31.4	Low	0.1 to 1
II	Sand and silt bottom	24.0	32.5	Medium	1 to 5
III	Basalt pavement with rubble	25.5	25.7	Medium	0.1 to 2
IV	Coral in mixed rubble	24.0	32.5	Medium to high	1 to 5
V	Patch reefs	24.0	32.5	High	0.1 to 5
VI	Intertidal	25.0 to 28.5	3.0 to 25.0	Medium to high	. . .
VII	Brackish pool	27.0	2.0 to 8.0	Medium	0.1 to 1

TABLE 2. The marine macroinvertebrates within the waters adjacent to Puukohola Heiau National Historic Site, Hawaii. The fauna are listed as:
A = Abundant; always seen, many individuals encountered;
C = Common; localized populations, species in which more than two individuals were observed;
R = Rare; one or two sporadic specimens observed;
S = Seen, but no relative abundance measure applied.

Species	Biotopes					
	Rubble /silt I	Sand /mud II	Pave-ment/ rubble III	Coral/ rubble IV	Patch reef V	Inter-tidal VI
Phylum Porifera (sponges)						
Cliona vastifica	S		S	S	S	
Terpios sp.			S			
Leucetta sp.			S			
various encrusting forms	S		S	S	S	S
Phylum Cnidaria (corals and hydroids)						
Pennaria tiarella	R		R	R		
Athelia edmondsoni	R		A	C	C	
Zoanthids			S	S	S	S
Montipora verrucosa		R	A	A	A	
M. patula			R	C	C	
M. verrilli					R	
Pavona varians				R	R	
P. explanulata					R	
Leptastrea bottae			C	R	R	
L. purpurea				R	R	
Cyphastrea ocellina	R		R	R	R	
Porites compressa	R	R	C	A	A	
P. lobata		R	C	A	A	
P. (*Synaraea*) sp.					R	
Pocillopora damicornis	A	R	A	C	C	R
P. meandrina		R	A	A	A	
Psammocora verrilli					R	

TABLE 2. Marine macroinvertebrates (continued).

Species	Biotopes					
	Rubble /silt I	Sand /mud II	Pave- ment/ rubble III	Coral/ rubble IV	Patch reef V	Inter- tidal VI
Phylum Platyhelminthes (flatworms)						
Polycladida (unidentified)						S
Phylum Sipunculoidea (peanut worms)						
Sipunculus sp.						S
Phylum Echiuroidea (peanut worms) (unidentified)	S			S		S
Phyla Ectoprocta and Entoprocta (moss animals)						
encrusting forms			S	S	S	
erect forms	S			S		
Phylum Annelida (segmented worms)						
Nereidae (large crawling worms)	S	S	S			
Sabellariidae (sand grain tube worms)	S		S	S	S	
Terebellidae (spaghetti worms)			S	S		
Sabellidae (fan worms)	S	S	S	S	S	
Serpulidae (calcareous tube worms)	S	S	S	S	S	S
Syllidae (small crawling worms)	S		S	S		
Phylum Arthropoda						
Insecta						
Halobates sp.	S		S			
Crustacea						
Amphipoda (unidentified)	S		S	S	S	S
Isopoda						
Apseudidae	S					

TABLE 2. Marine macroinvertebrates (continued).

Species	Biotopes					
	Rubble /silt I	Sand /mud II	Pave-ment/ rubble III	Coral/ rubble IV	Patch reef V	Inter-tidal VI
Phylum Arthropoda						
Crustacea						
Decapoda						
Macrura--Natantia (shrimp, 'ōpae-kai)						
*Palaemon debilis** (glass shrimp, 'ōpae-huna)						
Alpheus spp. (snapping shrimp)	S		S	S		
Callianassa sp. (mud shrimp)	S	S				
Anomura (hermit crabs, pāpa'i-iwi-pūpū)						
Calcinus laevimanus	S					
C. elegans	S					
Clibanarus zebra			S			S
Brachyura (crabs)						
Hapalocarcinus marsupialus	S	S	S	S	S	S
Calappa hepatica (box crab)	S					
Portunus sanguinolentus	S					
Thalamita edwardsi	S					
Trapezia intermedia	S					
Phymodius ungulatus	S					
Zoozymodes biunguis	S					
Xanthodius biunguis	S					
Xantho crassimanus				S		S
Pseudozius caystrus						S
Chlorodopsis niger				S	S	
Carpilodes sp.					S	
Xanthid (misc. sp.)	S		S	S	S	S

*found in brackish ponds (biotope VII) only.

TABLE 2. Marine macroinvertebrates (continued).

Species	Biotopes					
	Rubble /silt	Sand /mud	Pave-ment/ rubble	Coral/ rubble	Patch reef	Inter-tidal
Phylum Arthropoda						
Crustacea						
Decapoda						
Brachyura (crabs)						
Grapsus grapsus (Rock crab, 'a'ama)						S
Metapograpsus messor	S					S
Perinea tumida	S					
Ocypode ceratoph-thalmus (ghost crab)						S
Stomatopoda (mantis shrimp)						
Squilla sp.	S					
Phylum Echinodermata						
Asteroidea (starfish)						
Asterope carinifera					S	
Ophiuroidea (brittle stars)						
Ophicoma erinaceus			S	S		S
O. brevipes			S			
Echinoidea (sea urchins)						
Echinothrix calamaris (wana)			R	C	C	
E. diadema (wana)	R		A	A	C	
Tripneustes gratilla (hāwa'e)	R	R	C	C	C	
Astropyga radiata	S					
Echinometra mathaei ('ina-uli)	C		A	A	A	C
E. oblonga ('ina-uli)			C	R	R	A
Heterocentrotus mammilatus ('ina-'ula, slate pencil urchin)			R	C	R	
Holothuroidea (sea cucumbers, loli)						
Actinopyga mauritiana or *obesa*			S			S

TABLE 2. Marine macroinvertebrates (continued).

Species	Biotopes					
	Rubble /silt I	Sand /mud II	Pave-ment/ rubble III	Coral/ rubble IV	Patch reef V	Inter-tidal VI
Phylum Echinodermata						
Holothuroidea (loli, sea cucumbers)						
Holothuria atra	S	S	S	S	S	
H. arenicola	S					S
H. impatiens						S
Phylum Chordata						
Tunicata (sea squirts) (unidentified forms)			S	S	S	S

Species	Biotopes	
	Littoral I,III,VI	Offshore II,IV,V
Phylum Mollusca		
Amphineura (chitons)		
Ischnochiton petaloides	R	R
Gastropoda (snails)		
Littorina scabra (periwinkle)	A	
L. pintado (periwinkle)	C	
Nerita polita (kupe'e, polished nerite)	R	
N. picea (pipipi, neglected nerite)	A	
Cellana sandwichensis ('opihi, limpet)	C	
Purpura harpa (dye harp)	C	
Siphonaria normalis (normal siphon)	C	
Morula uva	C	
Conus abbreviatus (abbreviated cone)	R	
C. ebraeus (Hebrew cone)	C	
C. flavidus (golden-yellow cone)		C
C. pulicarius (flea cone)		C
C. quercinus (oak cone)		R
C. sponsalis (Ceylon cone)	C	
Strombus maculatus (spotted stromb, pūpū-mamāiki)	crabbed	
Trochus intextus (top shell, pūpū-o-Hā'upu)	C	

TABLE 2. Marine macroinvertebrates (continued).

Species	Biotopes	
	Littoral I,III,VI	Offshore II,IV,V
Phylum Mollusca		
Gastropoda (snails)		
Cypraea maculifera (reticulated cowry, leho-kōlea)	R	
Maculotriton serriale	crabbed	
Nassarius reeveanus	crabbed	
Peristernia chlorostoma	crabbed	
Peristernia sp.	crabbed	
Terebra crenulata (crenulated auger)	R	
Hipponix pilosus (hoof shell)	A	C
H. foliatus (hoof shell)	S	
Notarchus lineolatus (sea hare)	S	
Nudibranch spp. (sea slugs)	S	S
Vermetid spp. (calcareous tube snails)	A	A
Bivalvia (clams and mussels)		
Brachidontes cerebristriatus (mussel)	A	A
Isognomon incisum (mussel)	C	
I. costellatum (mussel)	S	
Quidnipagus palatum (tellin)	C	
Periglypta reticulata (cockle)	C	

TABLE 3. Species list of fish within the waters adjacent to Puukohola Heiau National Historic Site, Hawaii.
The relative abundance index is shown as:
R = Rare; one or two sporadic individuals seen during surveys;
C = Common; more than two individuals were observed; and
A = Abundant; many individuals were encountered.
+ = Adults;
- = Juveniles; and
± = Adults and juveniles.
The biotopes numbers correspond with those listed in Table 1.

Species	Biotopes				
	Littoral		Offshore		
	I, III	VI	II	IV, V	Pond VII
Carcharhinidae (requiem sharks, manō)					
Carcharhinus menisorrah (grey reef shark)	C+		C+		
C. melanopterus (blacktip shark)	C+		C+		
Triakidae (leopard sharks, manō)					
Triaenodon obesus (whitetip shark)	C+		C+	C+	
Myliobatidae (eagle rays)					
Aetobatus narinari	R+				
Muraenidae (moray eels, pūhi)					
Gymnothorax eurostus		R+			
Echidna nebulosa		R+			
Gobiidae (gobies, 'o'opu)					
Bathygobius fuscus		C±			
Blenniidae (blennies)					
Istiblennius zebra (pāo'o)		A±			
Exallias brevis (pāo'o kauila)				C+	
Eleotridae ('o'opu)					
Asterropteryx semipunctatus	C+	C+			
Kuhliidae (āholehole)					
Kuhlia sandvicensis		A±			
Mugilidae (mullets, 'ama'ama)					
Mugil cephalus	A±	A-	A+		
Holocentridae (squirrelfishes)					
Adioryx lacteoguttatus ('ala'ihi)		R-			
Cichlidae					
Tilapia mossambica					A±
T. macrochir					A±

TABLE 3. Species list of fish (continued).

Species	Biotopes			
	Littoral		Offshore	
	I, III	VI	II	IV, V
Mullidae (goatfishes)				
Mulloidichthys auriflamma (weke-'ula)			A+	R+
Parupeneus porphyreus (kūmū)			R+	
P. pleurostigma (malu)			C+	
P. multifasciatus (moano)			A±	
Lutjanidae (snappers)				
Lutianus vaigiensis			C+	
Labridae (wrasses, hīnālea)				
Thalassoma lutescens				R+
T. duperreyi (hīnālea lau-wili)				A±
Gomphosus varius ('aki-lolo)				A±
Coris gaimardi (hīnālea-lolo)				C+
Labroides phthirophagus (cleaner wrasse)				C±
Halichoeres sp.				R-
H. ornatissimus (lā'ō)				R±
Stethojulis balteatus ('ōmaka)				R+
Cheilinus rhodochrous (pō'ou)				C+
Scaridae (parrotfishes, uhu)				
Scarus dubius				A±
S. sordidus				A±
Calotomus sandvicensis				C±
Pomacentridae (damselfishes)				
Abudefduf abdominalis (maomao)		A-		A+
Dascyllus trimaculatus	R±			
D. albisella				C±
Pomacentrus jenkinsi				A±
Chromis ovalis				A±
C. vanderbilti				C±
Plectroglyphidodon johnstonianus				C±
Chromis hanui				C±

TABLE 3. Species list of fish (continued).

Species	Biotopes			
	Littoral		Offshore	
	I, III	VI	II	IV, V
Zanclidae (moorish idol, kihikihi)				
Zanclus canescens (kihikihi)				R+
Acanthuridae (surgeonfishes)				
Acanthurus triostegus (manini)				A±
A. mata (pualu)				A±
A. nigrofuscus				A±
A. nigroris (maiko)				A±
A. olivaceus (na'ena'e)				C±
Ctenochaetus strigosus (kole)				A±
Zebrasoma veliferum				R+
Chaetodontidae (butterfly fishes)				
Chaetodon trifasciatus				A±
C. unimaculatus (one-spot butterfly fish)				A+
C. miliaris (lemon butterfly fish)				R+
C. ornatissimus (ornated butterfly fish)				C+
C. auriga				C+
Monacanthidae (filefishes)				
Pervagor spilosoma ('ō'ili-'uwī'uwī)				R+
Canthigasteridae (sharpbacked puffers)				
Canthigaster jactator				R+
Tetraodontidae (puffers, balloonfishes)				
Arothron meleagris				R+
A. hispidus ('o'opu-hue)				R+
Diodontidae (porcupine fishes, spiny puffers)				
Diodon hystrix ('o'opu-kawa)				R+
Ostraciontidae (boxfishes)				
Ostracion lentiginosus (moa)				R+

TABLE 4. Pu'ukoholā fish transect data (see also pp. 5, 12). Replicates on individual transects are designated by:
A = 2 April morning;
B = 10 April morning;
C = 10 April afternoon.

Species	Inner Transect (Line #1)				Outer Transect (Line #2)				Lines #1 & #2
	A	B	C	Mean	A	B	C	Mean	Mean
Mulloidichthys samoensis	0	0	0	0	97	84	4	62	32
Chromis ovalis	14	21	37	21	20	42	42	35	28
Thalassoma duperreyi	15	13	14	14	20	13	11	15	16
Abudefduf abdominalis	22	9	16	16	2	10	11	8	12
Scarus sordidus	2	11	5	7	44	20	6	23	10
Pomacentrus jenkinsi	9	14	8	10	12	5	5	8	9
Ctenochaetus strigosus	4	1	5	2	9	9	11	10	6
Acanthurus nigrofuscus	0	0	0	0	9	3	9	7	4
Gomphosus varius	2	2	2	2	3	3	7	4	3
Chaetodon trifasciatus	3	4	2	3	1	1	1	1	2
Scarus dubius	0	0	2	1	2	3	1	2	2
Chaetodon unimaculatus	0	0	0	0	4	1	0	2	1
Parupeneus multifasciatus	1	2	1	1	1	0	0	1	1
Thalassoma ballieui	1	0	0	1	3	1	0	1	1
Arothron meleagris	0	0	0	0	0	2	2	1	1
Chaetodon miliaris	0	0	0	0	0	3	0	1	1
Lutianus vaigiensis	0	0	0	0	1	2	0	1	1
Acanthurus mata	0	0	0	0	1	1	0	1	1
Acanthurus nigroris	0	0	0	0	0	0	2	1	1
Calotomus sandvicensis	0	0	0	0	2	0	0	1	1

TABLE 4. Fish transect data (continued).

Species	Inner Transect (Line #1)				Outer Transect (Line #2)				Lines #1 & #2
	A	B	C	Mean	A	B	C	Mean	Mean
Stethojulis balteatus	0	0	0	0	1	1	0	1	1
Acanthurus triostegus	0	0	1	1	0	0	0	0	1
Canthigaster jactator	0	0	0	0	1	0	0	1	1
Chaetodon multicinctus	0	0	0	0	1	0	0	1	1
Chaetodon ornatissimus	1	0	0	1	0	0	0	0	1
Chaetodon quadrimaculatus	0	0	0	0	1	0	0	1	1
Labrid sp.	0	0	0	0	0	0	1	1	1
Labroides phthirophagus	0	0	0	0	0	0	1	1	1
Naso lituratus	0	0	1	1	0	0	0	0	1
Ostracion lentiginosus	0	0	1	1	0	0	0	0	1
Paracirrhites arcatus	0	1	0	1	0	0	0	0	1
Pervagor spilosoma	0	0	0	0	1	0	0	1	1
Plectroglyphidodon johnstonianus	1	0	0	1	0	0	0	0	1
Scarus sp.	0	0	0	0	0	1	0	1	1
Zanclus canescens	0	0	0	0	1	0	0	1	1
Zebrasoma veliferum	0	0	1	1	0	0	0	0	1

TABLE 5. Coral coverage and composition of species intersecting 50-m transects set on patch reefs (biotope V) in waters adjacent to Puukohola Heiau National Historic Site.

	INNER TRANSECT (Line #1)		OUTER TRANSECT (Line #2)		AVERAGE	
Coral Coverage	Length (m)	%	Length (m)	%	Length (m)	%
Coral substrate	27	54	32	64	29.5	59
Mud/sand substrate	23	46	18	36	20.5	41
Living coral--total	23	46	21	42	22	44
Living coral--coral substrate only	23	85	21	66	22	77
Species Composition	**Number inter-sects**	**%**	**Number inter-sects**	**%**	**Number inter-sects**	**%**
Porites compressa	21	50	13	21	17	32
Porites lobata	8	19	20	32	14	27
Porites (Synaraea) sp.	3	8	0	0	1.5	3
Pocillopora meandrina	2	5	7	11	4.5	9
Pocillopora damicornis	0	0	1	2	0.5	1
Montipora verrucosa	5	12	13	21	9	17
Montipora patula	0	0	6	9	3	6
Pavona varians	1	2	1	2	1	2
Leptastrea bottae	1	2	0	0	0.5	1
Cyphastrea ocellina	1	2	1	2	1	2
TOTALS:	42	100	62	100	52	100

TABLE 6. Summary of counts of identified species of invertebrates and fish for biotopes in the Pu'ukoholā survey site.

Species	Biotopes						
	Littoral			Offshore			
	Rubble /silt I	Pave-ment/ rubble III	Inter-tidal VI	Sand /mud II	Coral/ rubble IV	Patch reef V	Pond VII
Invertebrates excluding Mollusks	27	26	16	9	24	28	1
	I and III				IV and V		
Fish	7		9	9	40		2
Invertebrates excluding Mollusks	40		16	9	30		1
	I, III, and VI			II, IV, and V			
Mollusks	23			6			
Fish	14			47			
Invertebrates excluding Mollusks	47			31			

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