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ASSESSMENT OF COASTAL WATER RESOURCES AND WATERSHED CONDITIONS AT PU'UHONUA O HONAUNAU NATIONAL HISTORICAL PARK, HAWAI'I

Dr. Daniel Hoover and Colette Gold

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Assessment of Coastal Water Resources and Watershed Conditions in Pu‘uhonua o Honaunau National Historical Park, Hawai‘i

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ACRONYMS AND ABBREVIATIONS

BMP	Best Management Practices
CESU	Cooperative Ecosystems Study Unit
chl-*a*	Chlorophyll-*a*
cm	Centimeter
CO_2	Carbon dioxide
CRAMP	Coral Reef Assessment and Monitoring Program
d	Day
DAR	Division of Aquatic Resources
DLNR	Division of Land and Natural Resources
DO	Dissolved Oxygen
DOH	Department of Health
DON	Dissolved Organic Nitrogen
DOP	Dissolved Organic Phosphorus
EH	Redox potential, usually measured in volts or millivolts
EPA	Environmental Protection Agency
FLIR	Forward Looking Infra-Red
FRA	Fish Replenishment Area
GPS	Global Positioning System
ha	Hectare
HAVO	Hawai‘i Volcanoes National Park
HI	Hawai‘i
HUC	Hydrologic Unit Code
I&M	Inventory & Monitoring Program (NPS)
in	Inch
JTU	Jackson Turbidity Units
KAHO	Kaloko-Honokohau National Historical Park
kph	Kilometers per hour
l	Liter
mg/l	Milligrams per liter
m	Meter
Mgal	Million gallons
NEC	North Equatorial Current
NH4	Ammonium
NO2	Nitrite
NO3	Nitrate
NO3+	Nitrate plus nitrite
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NTU	Nephelometric Turbidity Units
PACN	Pacific Island Network (NPS)
PCSU	Pacific Cooperative Studies Unit
pH	Unitless measurement of acidity/alkalinity, calculated as the negative logarithm of the hydrogen ion concentration in a solution

PICRP	Pacific Islands Coral Reef Program
PO4	Phosphate
PPB	Parts per billion
PPT	Parts per thousand
PSU	Practical Salinity Units
PUHE	Puukohola Heiau National Historic Site
PUHO	Puʻuhonua o Honaunau National Historical Park
S	Salinity
SCUBA	Self-Contained Underwater Breathing Apparatus
SiO2	Silicate
SRP	Soluble Reactive Phosphorus
STORET	STorage and RETrieval database (EPA water quality database)
T	Temperature
TDN	Total Dissolved Nitrogen
TDP	Total Dissolved Phosphorus
Temp	Temperature
Turb	Turbidity
UH	University of Hawaiʻi
USGS	U.S. Geological Survey
VOGNET	Volcanic Fog Monitoring Network
WHAP	West Hawaiʻi Aquarium Project
WQAOI	Water Quality Area Of Interest
WWTP	Waste Water Treatment Plant
y	Year
yd	Yard
% sat	Percent of saturation value
°C	Degrees Celsius
µg/kg	Micrograms per kilogram
µg/l	Micrograms per liter
µM	Micromoles per liter

EXECUTIVE SUMMARY

Puʻuhonua o Honaunau National Historical Park (PUHO) is a small park (73 ha/181 acres) located on the Kona (west) coast of the island of Hawaiʻi. The park currently consists of two parcels; a 72 ha/177 acre parcel situated along the coast, and a small (1.5 ha/3.7 acre) upland parcel. A recently authorized addition (96 ha/238 acre) abuts and extends inland from the southern part of the coastal parcel. The small upland parcel does not contain any significant water resources, and the authorized addition has not yet been acquired by the park, so these parcels are not addressed specifically in this report. The park was established primarily to preserve and protect native Hawaiian culture and cultural sites, but the park and adjacent marine waters (technically outside of park jurisdiction, but included here as they represent a significant resource for the park) also contain a diverse and unique array of water resources. The climate is arid, and aside from one intermittent stream, there are no freshwater resources in or near the park. Brackish groundwater flows seaward through the park and is exposed in subaerial anchialine pools, a prehistoric fishpond, and in associated wetlands. Brackish groundwater discharging along the park shoreline affects intertidal and coastal water quality. Brackish and marine waters in and adjacent to the park support a wide range of flora and fauna, including one of the best-developed shallow-water coral reef systems in West Hawaiʻi. The cultural and ecological value of these resources are significant, but park waters are vulnerable to impacts associated with upslope and adjacent development, which could affect groundwater supply and quality, to impacts associated with maintenance of cultural and archaeological resources in the park, and to degradation due to visitor activities. No point-source pollutant discharges are present in PUHO, but a number of non-point sources in and around the park have the potential to affect coastal water resources, particularly agricultural activity upslope of the park, residences and a small boat landing in Honaunau Bay adjacent to the park, and maintenance activities within the park.

Despite the value of water resources in and adjacent to the park, there are very few data available for quantitative assessment of water quality and associated biological resources. The National Park Service (NPS) ‘Horizon’ report (National Park Service 1999) and a new USGS water quality database (Wolff unpubl. 2005) include a number of sites in and near the park, but several are too distant to provide insight into the quality of park waters, and data from the remaining sites mostly are limited either to very short periods of measurement (one day to two months) or include measurements of only a few water quality parameters. As a result, existing data are inadequate to characterize water quality in the park.

Although biological assessments are more numerous than water quality measurements, biological assessments of park water resources have been sporadic, usually limited in scope, and often have not used quantitative methods, making it difficult to compare results across studies. Nonetheless, combining available data from the water quality databases with additional water quality and biological data from published reports does provide some insight into water quality and biological resource conditions in the park’s groundwater, anchialine pools, fishpond, intertidal areas, and coastal waters.

Overall, the available water quality data and the apparently good condition of most of the associated aquatic ecosystems suggest that park waters probably are in relatively good condition.

There are no data for pesticides, herbicides, solvents, heavy metals, or pharmaceuticals in the park, but there are relatively few sources in the area for these types of pollutants, and limited analyses from another Kona park (Hoover and Gold 2005) suggest that significant contamination is unlikely. However, herbicides have been used extensively in the park, and boat and vehicle traffic may result in some contaminant inputs, so investigation of these sources may be warranted. There are a few data that suggest that park coastal waters were relatively unaffected by nutrient contamination in 1969 and in 1977, despite the presence of two cesspools only 34 and 51 m from shore until 1971. The Royal Fishpond may have been affected by the cesspools, leading to algal overgrowth and the introduction of alien fish to control the algae, but no data are available to verify this and the deactivation of the cesspools in 1971 probably resulted in a rapid return to ‘normal’ nutrient loading conditions to the fishpond pools. A relatively recent (1992) dataset from the Royal Fishpond contains some elevated ammonia and phosphate values, but the data are sparse and may be affected by analytical errors, and fishpond water quality is unlikely to be representative of water quality in other areas of the park. Thus, the current status of park waters with respect to nutrient contamination is unknown, but the lack of significant nutrient loading sources in the watershed and in the park suggests that nutrient contamination probably is not a major issue. Groundwater flow through the park affects the salinity and thus water quality of mixohaline resources. Salinity data from the park and groundwater modeling in another Kona park study (Hoover and Gold 2005) suggest that groundwater flows in the park may have decreased significantly over the last 20 - 30 years, presumably due to upslope groundwater withdrawals. While development in the area to date has been less intense than in some other areas of the Kona coast, future development likely will result in additional reductions in groundwater flow, and increases in nutrient and other contaminant loading to park resources. Groundwater flows and quality thus will continue to be fundamental issues for all of the park’s water resources.

Biological resources in park waters mostly are poorly characterized. Available data indicate that while water quality and other impacts on biological resources mostly appear to be minor at this time, there are a number of existing and potential issues that warrant action or further study, and additional study is needed in virtually all areas to establish baseline data adequate for assessing current status and future trends. These issues and key biological features of each of the major coastal water resources are summarized briefly below.

Surface water

There are no perennial streams or other surface water bodies in the main park area. The lower portion of the Ki‘ilae Stream channel crosses the southern end of the main park parcel, but the stream is intermittent in its lower reaches, and no water quality or biological resource data are available for this area.

Groundwater

There is no data on groundwater in the park. Very limited water quality data are available from three groundwater wells north of and upslope of the park, but water quality in these wells may not be representative of groundwater transiting the park. Some information on groundwater quality can be inferred from brackish coastal water samples obtained in 1969 and 1977, but no recent data are available.

Anchialine pools

Anchialine pools are rare, and associated ecosystems are poorly understood. There are several pools in the park, but the number and locations of the pools are not well characterized, and no quantitative data are available to assess water quality or biological conditions. Information obtained from park personnel and observations made during a site visit suggest that at least one pool is impacted by stockpiling of plant waste and other pools may be impacted by sedimentation from road and trail fill material. Pool ecosystems also may be impacted by changes in groundwater flow due to upslope development, and by herbicides used for vegetation control in the park. While anchialine ecosystems in general appear to be relatively tolerant of variations in salinity, temperature, and nutrients, tolerance probably varies from pool to pool, and they may be vulnerable to toxic contaminants. Anchialine pools provide habitat for some rare and candidate endangered species, such as the orange-black damselfly (*Megalagrion xanthophelas*), which may be vulnerable to changes in habitat and to predation by alien species, such as orb-weaver spiders.

The Royal Fishpond

The Royal Fishpond was studied briefly in 1969, 1992 and in 1999. Water quality data are insufficient for a complete assessment, but do show significant nutrient uptake from groundwater inputs and large fluctuations in dissolved oxygen, both of which are consistent with the elevated productivity and respiration expected in large, shallow eutrophic pools. Biological observations show that the fishpond is impacted heavily by alien fish, particularly tilapia and mosquito fish.

Wetlands

PUHO’s wetlands primarily are associated with the Royal Fishpond pools, especially the southern pool and an associated extension that crosses into the pu‘uhonua grounds. Wetlands are rare in west Hawai‘i, so PUHO’s wetlands provide potentially important habitat for insects, plants, and transient birds. No water quality data are available, but there is no obvious indication of water quality impacts on PUHO’s wetland biota. Alien species that displace native species, and woody aliens that produce large quantities of leaf litter and encroach on open water areas (e.g., opiuma (*Pithecelobium dulce*), and Koa haole (*Leucena leucocephala*)) are significant issues.

Intertidal

Biological resources in PUHO’s intertidal have received only cursory study, but there is no indication that they are impacted significantly by water quality changes or by invasive species. A potentially invasive alien alga (*Acanthophora spicifera*) recently has been documented in the park, but does not appear to be a significant threat at this time. Recreational harvesting of intertidal organisms may be a significant issue, particularly of heavily exploited resources like endemic limpets (opihi). Intertidal zones provide significant habitat for green sea turtles

(*Chelonia mydas*), and potential habitat for threatened hawksbill turtles (*Eretmochelys imbricata*) and endangered Hawaiian monk seals (*Monachus schauislandi*), creating potential conflicts with visitor activities in these areas.

Coastal waters

Coastal waters include both pelagic and benthic habitats, from subtidal sands to extensive coral communities, that support a diverse community of resident and transient fish, reptiles, mammals, invertebrates, and other organisms, including turtles, monk seals, spinner dolphins, sharks, manta rays, and threatened humpback whales (*Megaptera novaeangliae*) offshore of the park. Studies that have addressed pelagic and benthic biological resources generally have concluded that they are in good condition, although several alien fish are established in park waters, and stressors such as sound and light pollution and behavioral impacts due to visitor activities (e.g. wading, swimming, snorkeling, SCUBA diving, and boating) have not been addressed. Water quality in Keone‘ele Cove may be negatively affected by sediment and contaminants from crushed coral fill used along the beach at the head of the cove, but no data are available to quantify possible impacts. Although coastal waters and associated biota probably are relatively tolerant of contaminant inputs due to the strong natural dilution characterizing Hawai‘i's coastal waters, contaminant inputs from adjacent residences and from the boat launch in Honaunau Bay are possible concerns. Other stressors that warrant additional study and monitoring include the potential for increased coral bleaching and disease with increasing ocean temperatures, and the continuing potential for alien species introductions, including pathogens that may result in disease in corals and other organisms.

Table i summarizes the above discussion in terms of the major stressors affecting park coastal water resources and our assessment of existing and potential impairments due to these stressors. Because so few data are available, most assessments were made using primarily professional judgement, and even areas with known impairments are considered to have insufficient data to adequately characterize the full extent of the associated impairment. Some of the stressors are associated with development around the park and with visitor impacts on the park, and thus present options for management that may include actions to reduce or eliminate the stressor. Others, such as sea level rise and increased temperature, are driven primarily by global processes and cannot be managed directly. Existing impairments in the park are well known only for invasive species in the Royal Fishpond pools and in wetlands around the pools, but invasive species also may be impacting other resources, and potential impairments exist in many other areas.

Recommendations for studies, monitoring, and actions to address existing and potential impairments are summarized in Table ii. Although a number of ongoing and planned studies will improve knowledge of the status of selected resources, major gaps still exist in the characterization of most resources and in understanding the potential for impacts due to the stressors identified above. The recommended studies will provide the baseline data needed to document current water quality and biological resource conditions in the park, and will allow for a more complete assessment of vulnerability to the stressors listed in Table i.

Table i. Existing and potential impairments in PUHO's coastal water resources.

Stressor	Ground-water	Anchialine Pools	Royal Fishpond	Wetlands	Intertidal	Coastal Waters
Water Quality						
Nutrients	OK	PP	PP	OK	OK	OK
Fecal bacteria	OK	OK	OK	OK	OK	PP
Dissolved oxygen	OK	PP	PP	OK	OK	OK
Metal contamination	OK	OK	OK	OK	OK	PP
Toxic compounds	PP	PP	PP	PP	OK	PP
Increased temperature	OK	OK	OK	OK	OK	PP
Water Quantity						
Changing GW flux	OK	PP	PP	PP	OK	OK
Population Effects						
Fish/shellfish harvest	na	OK	OK	OK	PP	PP
Invasive species	PP	PP	EP	EP	EP	PP
Physical impacts	na	PP	OK	OK	OK	OK
Behavioral impacts	na	OK	PP	OK	PP	OK
Habitat Disruption						
Sea level rise	OK	OK	PP	PP	PP	OK
Sound pollution	na	OK	OK	OK	OK	PP
Light pollution	na	OK	PP	OK	OK	PP

EP - existing problem, PP – potential problem, OK – not currently or expected to be a problem, shaded - limited data, na - not applicable.

Table ii. Recommendations for additional studies, monitoring, and actions to address existing and potential impairments.

Studies

1. Summarize pesticide and other toxic chemical use in the park and assess the potential for impacts on coastal water resources in and around the park.
2. Characterize groundwater flow through the park, and its sensitivity to existing and planned upslope and adjacent development (withdrawals and wastewater inputs).
3. Characterize groundwater quality in the park, possibly in conjunction with Study 2 above and/or Study 8 below.
4. Map, describe, and document the biological status of anchialine pools in the park. *
5. Characterize water quality and major biological processes affecting water quality (primary production, sediment respiration) in the Royal Fishpond. Include an assessment of the role of pond sediments in water quality, and the feasibility and benefits of removing sediments from the fishpond pools.
6. Characterize ecosystem structure and function in the Royal Fishpond to evaluate the impact of alien fish on ecosystem function. Include an assessment of the feasibility and benefits of removing alien fish.
7. Assess the feasibility and benefits of eradicating alien species in park wetlands.
8. Characterize the locations and intensity of groundwater inputs to coastal waters. Resampling at the sites used by Doty (1969) would provide insight into potential changes in groundwater discharge over time as well as into groundwater quality (Study 3 above).
9. Perform a quantitative survey of biological resources in rocky intertidal zones in the park.
10. Characterize water quality in Honaunau Bay and at an additional offshore site off of the southern portion of the park, possibly off of Ki‘ilae Stream. **
11. Characterize recreational fishing catch and effort in waters adjacent to the park.
12. Characterize recreational snorkeling and SCUBA activity in the park.
13. Characterize frequency and type of use of the small-boat launching ramp adjacent to the park and of boating activities in Honaunau Bay.
14. Perform a preliminary assessment of underwater noise pollution in coastal waters adjacent to the park and the potential for impacts to biological resources.

* May be addressed by recently funded PACN Inventory and Monitoring Program project.

** Coordinate with Hawaii DOH sampling in Honaunau Bay initiated in February 2006.

Monitoring*

1. Monitor groundwater levels and groundwater quality in the park.
2. Monitor the status of anchialine pools and associated biota, including rare and endangered species.
3. Monitor water quality and ecosystem status in the Royal Fishpond.
4. Monitor *A. spicifera* and other invasive alien algae in intertidal and shallow subtidal areas around the park.
5. Monitor nearshore water quality at the DOH site in Keone‘ele Cove, and at a site in Kapuwai cove. **
6. Monitor benthic ecosystem status for comparison to historical assessments and ongoing CRAMP monitoring at other Kona sites, including coral health and alien species. ***
7. Monitor fish populations in Honaunau Bay for comparison to recent and historical assessments and ongoing WHAP monitoring at other Kona sites, including alien species. ****
8. Monitor sea turtles in waters adjacent to the park in conjunction with monitoring being performed at KAHO. *****

* Coordinate with planned PACN Vital Signs monitoring.

** Coordinate with DOH monitoring in Honaunau Bay.

*** Coordinate with CRAMP program.

**** Coordinate with WHAP program.

***** Coordinate with KAHO and NMFS monitoring.

Actions

1. If determined to be feasible and beneficial, remove alien fish from one or both of the Royal Fishpond pools.
2. If justified by study, remove sediments from one or both pools of the Royal Fishpond.
3. If determined to be feasible and beneficial, eradicate invasive plants from park wetlands.

4. Consider working with the State of Hawai‘i to prohibit harvesting of endemic Hawaiian limpets (opihi) in intertidal areas around the park.
5. Work with the State of Hawai‘i to provide educational materials for park visitors and people using areas around the park regarding applicable fishing regulations and impacts on park resources.
6. Collaborate with researchers working in the park to maximize the relevance of ongoing and planned studies to park needs for basic, robust data on water quality and aquatic biological resources in the park.
7. Expand park interpretive materials to include information on park water resources and their vulnerability to development in and around the park.
8. Expand park interpretive materials to include information on culturally significant coastal water resources, such as brackish springs, the ‘Sun Stone’, Keawe-wai tidepool, Kekuai‘o tidepool, coastal bait cups, net-tanning tubs, and the submerged offshore formation reputed to be of Hawa‘e.
9. Collaborate with the State of Hawai‘i and others to enhance the level of resource protection and conservation of adjacent lands and coastal waters, including Honaunau Bay.

A. INTRODUCTION

This project was conducted to assess coastal water resources in Puʻuhonua o Honaunau National Historic Park (PUHO), on the west coast of the island of Hawaiʻi (Figure 1). The goal of the project was to identify both the state of knowledge regarding individual resources and the degree to which they are affected by natural and anthropogenic factors. As a result, this report summarizes the condition and state of knowledge for individual resources, identifies information gaps where data are insufficient to assess resource condition, and makes recommendations for future studies to fill information gaps and to facilitate resource management. While the focus of this effort was on coastal resources, watershed conditions and surface and groundwater in and around the watershed also were considered as they might affect coastal water quality and resources. Available sources were reviewed to obtain information on coastal water resources in and adjacent to the park. Sources cited in the text are listed in the Literature Cited section; other relevant but uncited sources are listed in Appendix A.

B. PARK DESCRIPTION

B.1. Background

B.1.a. Location, setting, and park holdings

Puʻuhonua o Honaunau National Historic Park (PUHO) is located on the western (Kona) shoreline of the island of Hawaiʻi at the base of the Mauna Loa volcano, roughly 35 km (22 miles) south of the town of Kailua-Kona (Figure 1). A small parcel situated upland of the main park parcel contains no significant water resources and is not considered in this report. A third parcel, proposed as an addition to the park, runs inland from the coast at the southern end of the main parcel, and covers about 96 ha (238 acres) and includes about 300 m (1000’) of coastline. The main parcel contains the visitor center, the Royal Grounds, and the puʻuhonua (place of refuge), and covers approximately 72 ha (177 acres), with roughly 1.6 km (1 mile) of shoreline. The park, whose legislated boundary ends at the high tide line, stretches along the coastline from Honaunau Bay to Kiʻilae Bay and includes coastal sections of three ahupuaʻa (Hawaiian land divisions): Honaunau, Keokea, and Kiʻilae (Greene 1993). To ancient Hawaiians, this area served both as a residence for Hawaiian royalty, and provided sanctuary for noncombatants and defeated warriors in times of war, and for kapu (taboo) violators. The proposed addition along the southern margin of the park includes the remains of much of the coastal village of Kiʻilae, which was inhabited until the 1930’s.

PUHO was formally established in 1961, with the primary purpose of preserving and providing interpretation of this major Hawaiian cultural site, including building structures, burial sites, prehistoric trails, Hawaiian slides (holua), and fishponds. A great rock wall (300 m/1,000’ long, 3 m/10’ high, and 5 m/17’ thick) separates grounds used by Hawaiian royalty from the grounds of the puʻuhonua. At the wall's north end is the Hale o Keawe heiau (Hawaiian temple), which was the repository for the bones of 23 Hawaiian chiefs and the center of religious activity in the puʻuhonua until the heiau was abandoned in the early 1800’s (Apple and Macdonald 1966). Due

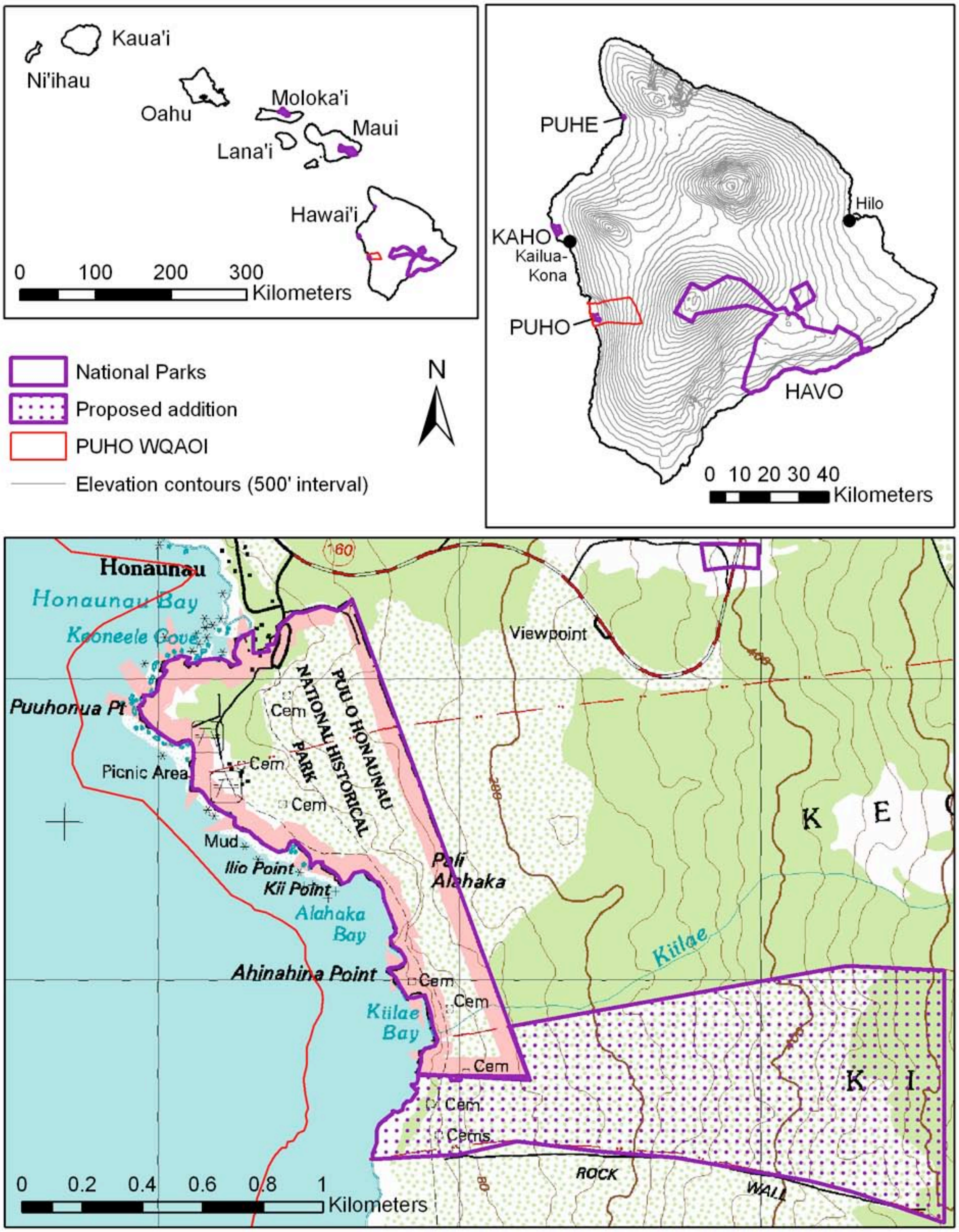

Figure 1. Pu‘uhonua o Honaunau National Historical Park (PUHO) and its associated Water Quality Area of Interest (WQAOI). Contour lines in the USGS topographic map background in the bottom panel are at 40’ (12.1 m) intervals.

to the archaeological importance of the site and its value in interpreting ancient Hawaiian religious, economic, social, and political life, the site is considered one of the most significant archaeological and historical complexes in the islands’ (Greene 1993).

Despite the fact that PUHO primarily is an archaeological/cultural park, park waters also are a significant resource. A handful of small anchialine pools are scattered throughout the park, and a pair of larger pools, used as fishponds by ancient Hawaiians, are located within the Royal Grounds, with another sizable pool complex on the puʻuhonua grounds. Other water-related resources located within the park include the lower reaches of the Kiʻilae Stream watercourse, brackish wetlands associated with the fishpond and puʻuhonua pools, and intertidal regions containing tidepools, rocky intertidal communities, and a sand beach at the head of Keoneʻele Cove. Marine waters technically are outside of the park boundaries, but are considered a significant resource due to their proximity to the park and the large number of visitors they attract to the park area. Threatened green sea turtles are regular visitors to Honaunau Bay and Keoneʻele Cove, and can frequently be found basking on intertidal benches adjacent to the puʻuhonua. Endangered Hawaiian monk seals and humpback whales also can be found in marine waters off the park. Rocky intertidal and subtidal habitats around the park contain rich biota, including an unusually well-developed shallow-water coral community in Honaunau Bay, and extensive reef complexes in deeper water that contain abundant and diverse biota. Processes affecting coastal water resources are varied, complex, and not thoroughly characterized (Basch et al. in prep.).

B.1.b. Land use

PUHO is located along a relatively undeveloped stretch of the Kona coast, with no major urban or suburban developments adjacent to or upslope of the park. There are a few residences along the shore of Honaunau Bay just north of the park, and some residential and other development on small agricultural lots along Mamalahoa Highway, about 3 km inland from the park, and along the access roads from the highway to the park and to Kealakekua Bay to the north (Figure 2). Residences in the area utilize on-site waste disposal systems. Development inside the park is limited to the park visitor center and parking lot and an array of buildings used for park operations. Coastal lands adjacent to the park are zoned for conservation, with another large conservation parcel (a forest reserve) located upslope of the park between 2,000 and 4,500’ (600 – 1,400 m) elevation (Figure 3). The remainder of the land upslope of the park is zoned for agriculture: most of the agricultural lands are suitable only for grazing, but there is some cultivation of coffee, fruit, and other crops on lands between 600 and 1,500’ (180 and 450 m) elevation (Figure 3). While development upslope of PUHO is dispersed and relatively low intensity, activities upslope of the park may affect the park as groundwater can carry contaminants downslope to the park, and development in the area likely will increase in coming years, with greater development of agricultural lots for residences and rezoning of agricultural lands for urban use.

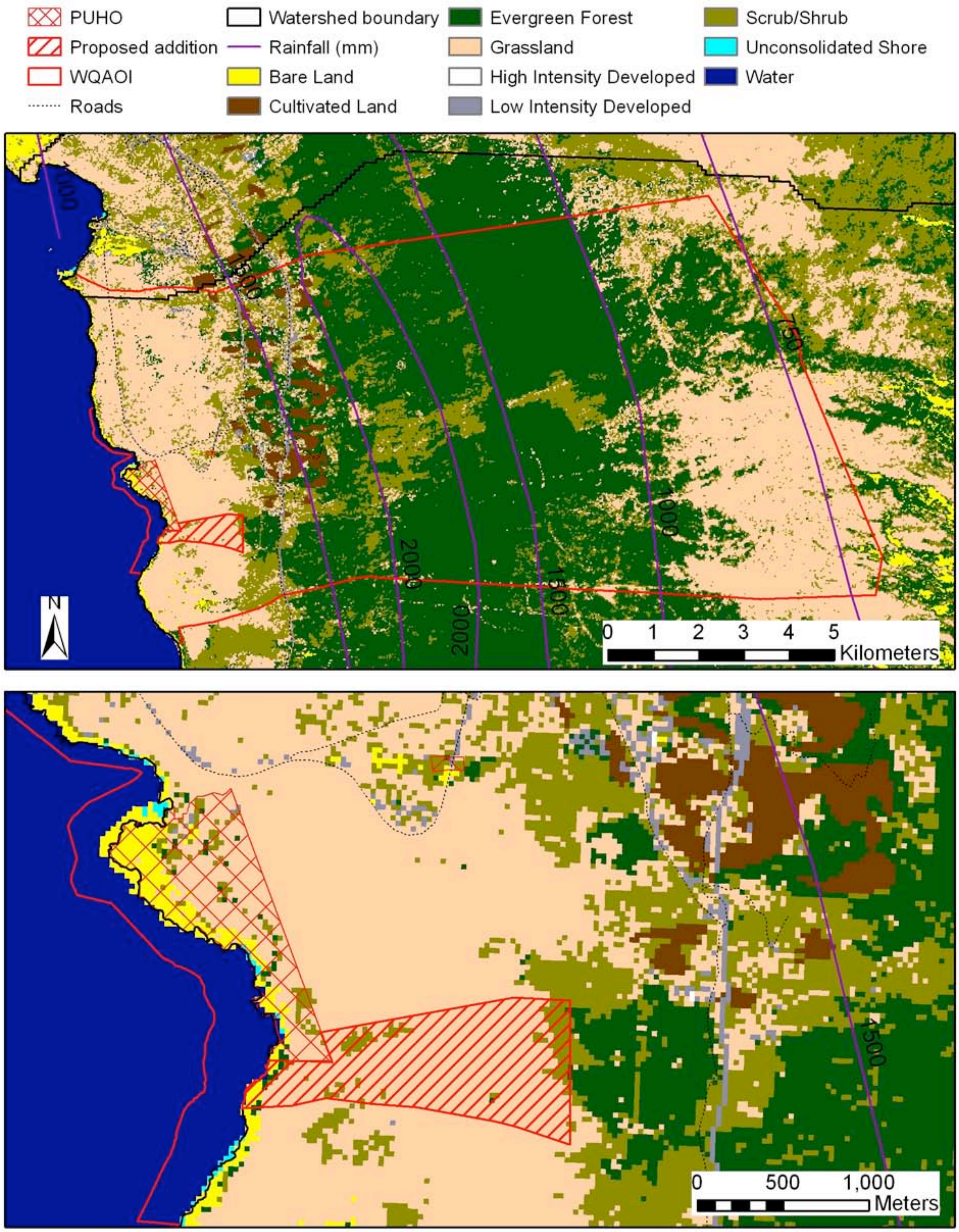

Figure 2. Land cover in the PUHO WQAOI. Cover data are from NOAA classification of Landsat images obtained in 2000 (http://www.csc.noaa.gov/crs/lca/hawaii.html).

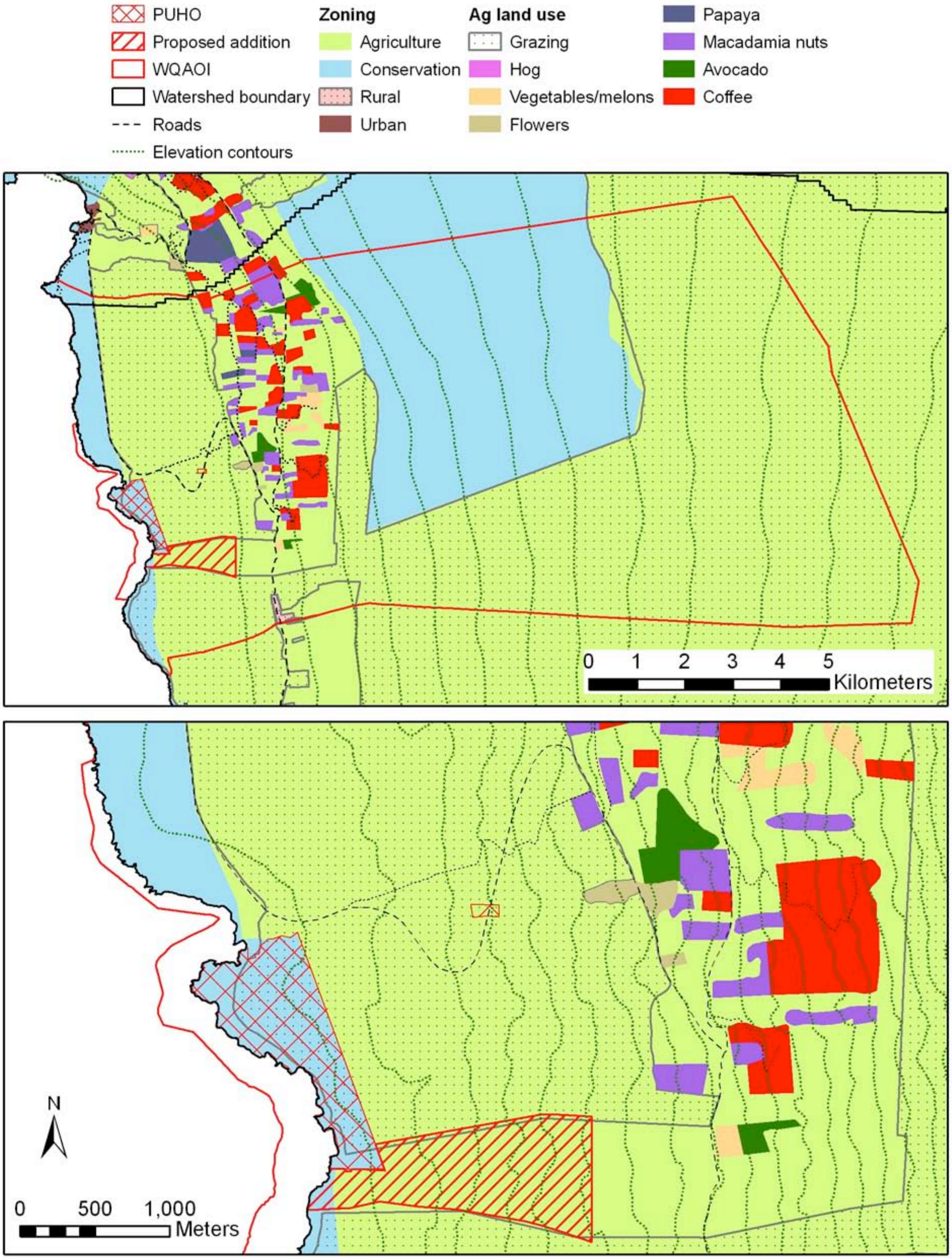

Figure 3. Land use zoning and actual agricultural land use in the PUHO WQAOI. Zoning data are from 2004, land use data are from 1976. Elevation contours in upper panel are at 500’ (152 m) intervals, contours in lower panel are at 100’ (30 m) intervals.

B.1.c. Human utilization: historic and current

Human utilization of resources in and around PUHO probably extends back more than 1000 years (Greene 1993). The calm waters of Honaunau Bay provided easy access to Kona's rich fishing grounds and other marine resources, and Keoneʻele Cove, with a sandy beach to park canoes, was a favorite of royalty (Greene 1993). Numerous springs containing potable water were located in the area, soils in surrounding and upland areas were suitable for growing coconuts, taro, bananas, sweet potatoes, sugarcane, awa, kukui, pili grass, pandanus, kou, and breadfruit (Greenwell 1986; Greene 1993). Brackish pools made suitable holding pens for fish destined for royal consumption and supported growth of makaloa reed for construction of fine woven mats. Trees were found in nearby areas that could be crafted into canoes and lumber for homes and religious structures (Greene 1993). As a result, the inland portion of Puʻuhonua Point ultimately became the residence of the ali'i (royalty) of Kona, while the seaward portion of the point, behind a great stone wall (constructed around 1550), was maintained as a puʻuhonua, or place of refuge. The refuge provided a safe haven where *kapu*-breakers, defeated warriors and other criminals could find absolution (Greene 1993).

By the time of Captain Cook's initial contact with Hawaiians in 1778, the Hawaiian population is believed to have grown to a significant size. Estimates of the actual number vary, but it is has been argued that the extensive agricultural developments characterizing that time, and the cultivation of many areas of marginal agricultural value, reflect a population approaching or exceeding the carrying capacity of the available resources (Cuddihy and Stone 1990). Historical records and archaeological evidence show that a substantial and well-organized community flourished in the area surrounding Honaunau, including extensive cultivation of upland areas (Cuddihy and Stone 1990), and the importance of the area as the center of political life suggests that population and development were at least as significant in Honaunau as in other areas. As a result, early Hawaiians had significant impacts on coastal and inland areas in the Honaunau area, including deforestation of coastal and inland forests to elevations greater than 760 m (2500'), and widespread changes to terrestrial ecosystems due to deliberate and accidental introductions of alien plants (Cuddihy and Stone 1990).

The population of native Hawaiians declined rapidly after Cook's arrival, due primarily to disease introduced by western visitors, and political and cultural change precipitated by Western contact also affected the Honaunau area. Although there was still a significant native population in Honaunau in 1823 (147 houses were counted in Honaunau village, and the population of Honaunau and the ~40 villages along the coast to the north was estimated at 20,000 (Bryan et al. 1986), the king no longer resided in Honaunau, and all of the heiau except for Hale o Keawe had been destroyed following Kamehameha II's abolition of traditional religious practices in 1819. In 1825, the carved wooden figures (kiʻi) in the main heiau (Hale o Keawe) of the puʻuhonua were removed by western collectors; in 1829 the remains of the chiefs that had been kept in the heiau for at least 300 years were relocated to a burial cave and Hale o Keawe was destroyed. By the mid 1800s, the village of Honaunau had declined to about 40 houses containing roughly 100 residents (Emory 1986).

Significant changes also were occurring in land use upslope of Honaunau; traditional agriculture, which had been practiced in the upland Kona field system for a thousand years or more (Cuddihy and Stone 1990), largely was abandoned within a few decades after western contact due to the decline in native Hawaiian population and the shift to a cash economy. Sandalwood harvesting virtually eliminated sandalwood from lowland and mid-elevation forests by the early 1800's, while wild cattle, introduced by Captain Vancouver at Kealakekua in 1793 and 1794, had increased in numbers to where they were causing significant damage to vegetation and watersheds. By the mid-1800s, most of the wild cattle had been captured and were being maintained on large ranches as part of the growing cattle ranching industry, but significant numbers still were present in 1900, and a few still survive today. After the Great Mahele (land division) of 1848, ranch lands expanded and new forms of agricultural development increased as lands became available to foreigners. Upslope of Honaunau, coffee was planted on lands that previously were cultivated as part of the Kona field system; by 1898, more than 2340 ha (6000 acres) of coffee were being cultivated in Kona. Other crops grown in upland areas include macadamia nuts, avocados, vegetables, and flowers. Most of the intensive agricultural development has been restricted to elevations between about 700 and 1500', with the majority of the remaining agricultural land in the watershed utilized for grazing (Figure 3). Cattle in lower portions of the watershed occasionally were watered at springs in the puʻuhonua area; in 1978 a fence was erected along PUHO's mauka border to keep cattle out (Pratt and Abbott 1996).

While upslope development in the 1900's focused on ranching and agriculture at mid elevations, coastal communities in the Honaunau area declined until the last permanent residents left the village of Kiʻilae in the 1920's – 1930's. However, a number of individuals recognized the cultural and historical significance of the archaeological features in the puʻuhonua area and began working to restore and preserve them. As a result, the lands now included in PUHO were leased to the County of Hawaiʻi in 1921 for a county park, and ultimately were transferred to the federal government in 1961 to form the City of Refuge National Historical Park, later renamed Puʻuhonua o Honaunau National Historical Park. Today, the park hosts close to a million visitors a year, with a significant number also visiting Honaunau Bay, adjacent to the park's northern boundary, for snorkeling, scuba diving, and other recreational activities. Area residents also use waters and coastal areas in this area for recreation, including boat launching from a small ramp in Honaunau Bay. Park visitation has increased significantly in recent years, from around 251,000 in 1968 (Doty 1969), to 375,000 in fiscal year 2002 and 791,000 in fiscal year 2004 (http://www.nps.gov/puho/pphtml/facts.html). Visitation is expected to continue to increase as development and visitation to the Kona region increase.

B.2. Hydrologic information

B.2.a. Oceanographic setting

Oceanographic features of park waters are not well characterized, although some work by the National Park Service (NPS), University of Hawaiʻi (UH) and the U.S. Geological Survey (USGS) is in progress (Gibbs et al. 2004; Glenn et al. 2006; Grossman et al. 2006; Street et al. 2006). Some general features can be inferred from the location of the island relative to large-scale oceanographic features, from the position of the park on the island's west coast, and from local topography and limited nearshore oceanographic data. However, nearshore oceanography likely is complex due to the varied topography in nearshore park waters, and the effects of alongshore and subtidal brackish groundwater discharges and occasional stream water discharges on circulation and stratification.

The island of Hawaiʻi is situated between 19 and 20 degrees north latitude, near the southern margin of the North Pacific gyre. Relatively high surface water temperatures, strong stratification, and low biological productivity are typical of coastal and offshore waters in this region (Bidigare et al. 2003). Coastal biological communities are adapted to the prevailing oligotrophic (low nutrient) conditions, especially in areas not subject to significant inputs of terrestrial nutrients or to upwelling of deep, higher-nutrient, waters. Hawaiʻi Island is the southernmost island in the Hawaiian archipelago, and is located to the north of the main axis of the westward-flowing North Equatorial Current (NEC), but the northern edge of the NEC impinges on the island, resulting in the deflection of a portion to the northwest. The interaction between the island and the NEC, and surface wind variations associated with the prevailing tradewinds and the positions and topography of Hawaiʻi and Maui islands, result in the formation of large eddies to the west of the island (Chavanne et al. 2002). These eddies may play a role in enhancing biological productivity in the waters west of the island, and in the transport of planktonic larvae in the area (Bidigare et al. 2003), but their importance to PUHO park resources is not known. Coastal currents offshore of the park probably vary significantly with tides (Armstrong 1983) and with the presence and location of the eddies noted above (Seki et al. 2002). A study conducted in 1968 observed a strong (0.3 mph/0.5 km/hr) southerly current outside of Honaunau bay and to roughly one mile (1.6 km) offshore, but observed fishing boats further offshore drifting north (Doty 1969). Local fishermen stated that the nearshore (to 1 mile/1.6 km offshore) current generally flowed northwestward from April to October, while a stronger southerly current generally was found in winter months (Doty 1969). Tides along the west Hawaiʻi Island coast are mixed diurnal, with a tidal range normally less than 1 m (3') (Juvik and Juvik 1998). Sea level rise and island subsidence have resulted in significant inundation of coastal areas around the island on geologic time scales (Apple and MacDonald 1966); present-day rates probably vary, but appear to be on the order of 0.34 cm (0.13 inch) per year (Hapke et al. 2005).

The location of the park on the west coast of the island of Hawaiʻi causes park waters to be sheltered from wave action associated with the prevailing northeast tradewinds, and reduces significantly the intensity of the wave energy associated with northerly and southerly swells. Northerly swells can be particularly large, but some protection from these swells is provided by 'shadowing' by the other islands in the Hawaiian archipelago (Figure 1) and by Pehehoni Point to the north of the park (Figure 4). Southerly swell effects on the waters of Honaunau, Alahaka and Kiʻilae bays are similarly attenuated by the sheltering effect of Puʻuhonua Point and by Loa Point south of the park (Figure 4).

Details of PUHO's nearshore oceanography are not well known, but local topography probably plays a significant role in controlling nearshore circulation. Topography varies significantly from Honaunau Bay in the north to Kiʻilae Bay in the south. In Honaunau Bay, a deep trench runs from west to east at the base of the northern shore of the Bay, while the southern portion of the Bay is relatively shallow and slopes gently offshore (Figure 5). Seaward of Puʻuhonua Point and in southern areas of the park, water depths increase relatively rapidly with distance from shore, and in many areas the coastline is composed of steep cliffs. Tidal fluctuations in Honaunau Bay

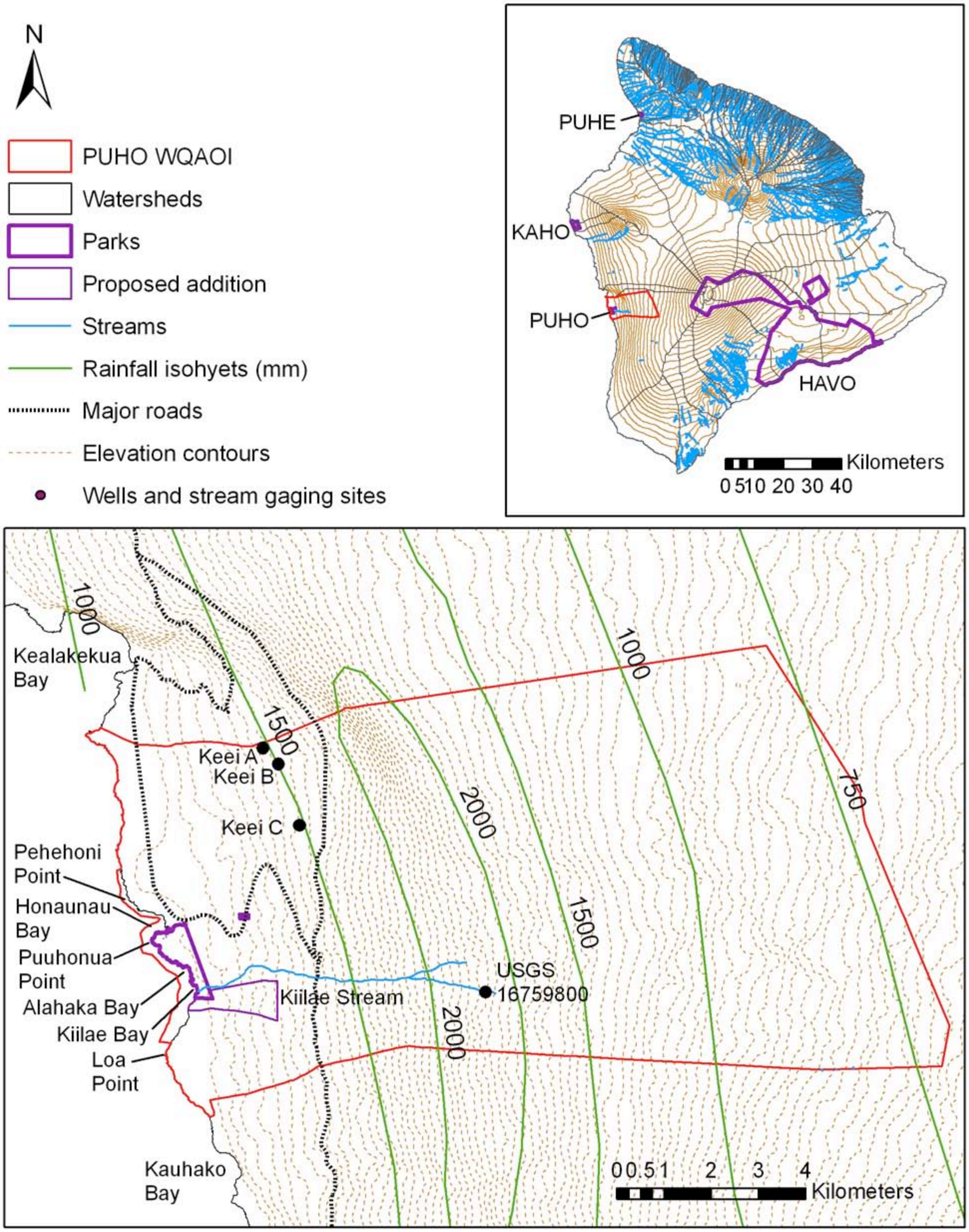

Figure 4. PUHO topography and hydrologic features. Elevation contours are at 100’ (30 m) intervals in detail map, 500’ (152 m) in island map. PUHO and its associated Water Quality Area of Interest (WQAOI) lie within USGS HUC 20010000, which covers the entire island of Hawai‘i. Nearby wells and the USGS gaging site on Ki‘ilae Stream are shown in their approximate positions.

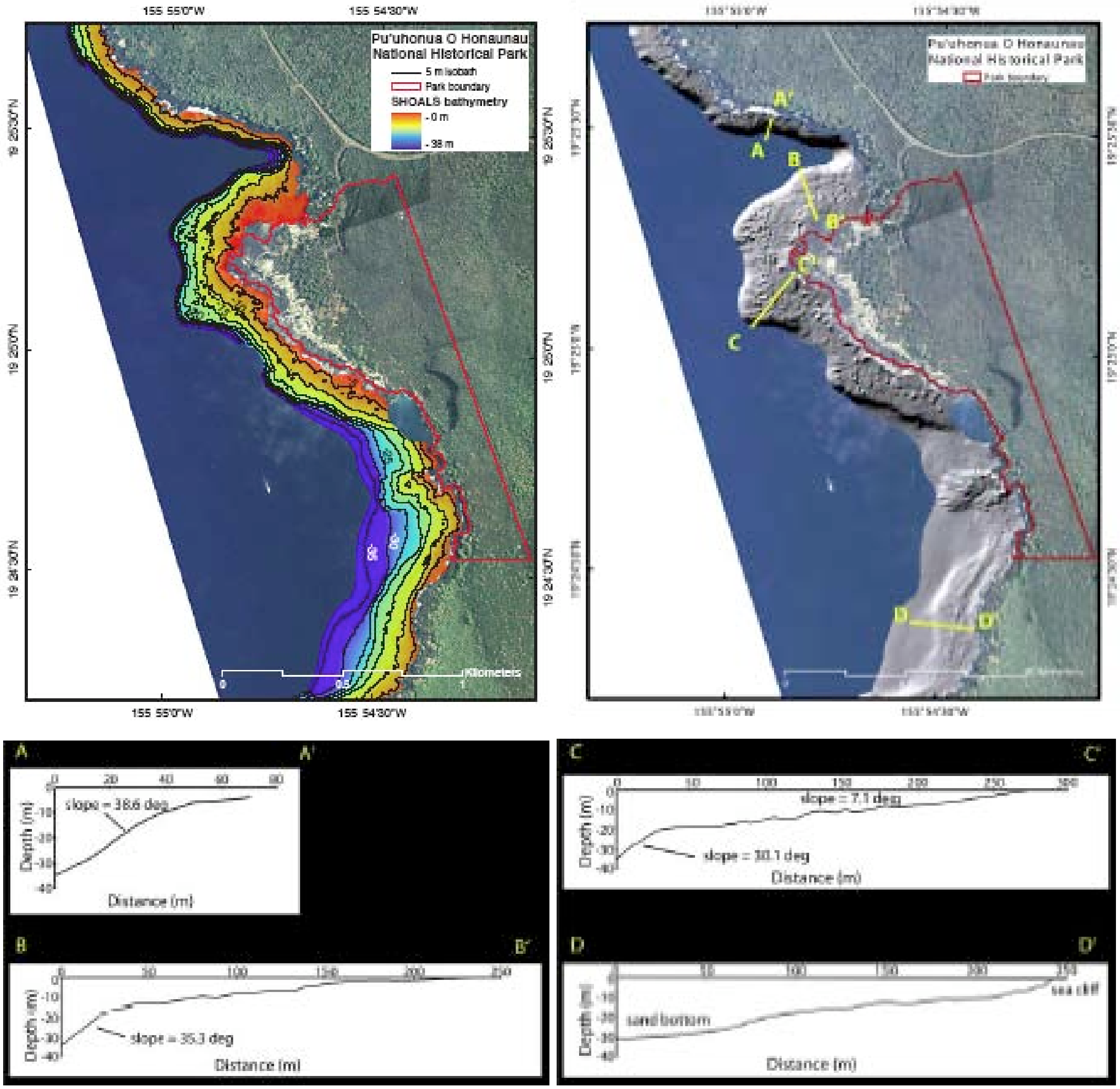

Figure 5. PUHO bathymetry derived from SHOALS data. Open area in Alahaka Bay is missing data. Figures from Cochran et al. (in press).

are relatively small, with a mean range of 0.64 m (2.1') between mean-lower-low-water (MLLW) and mean-higher-high- water (MHHW) (Okahara 1982). Doty (1969) noted that surface currents quickened and circular patterns became evident as the tide rose (Figure 6). Neighbor Island Consultants (1972) observed that the natural topography of Honaunau Bay aids water circulation, and that currents created by waves enhance mixing and exchange in coves.

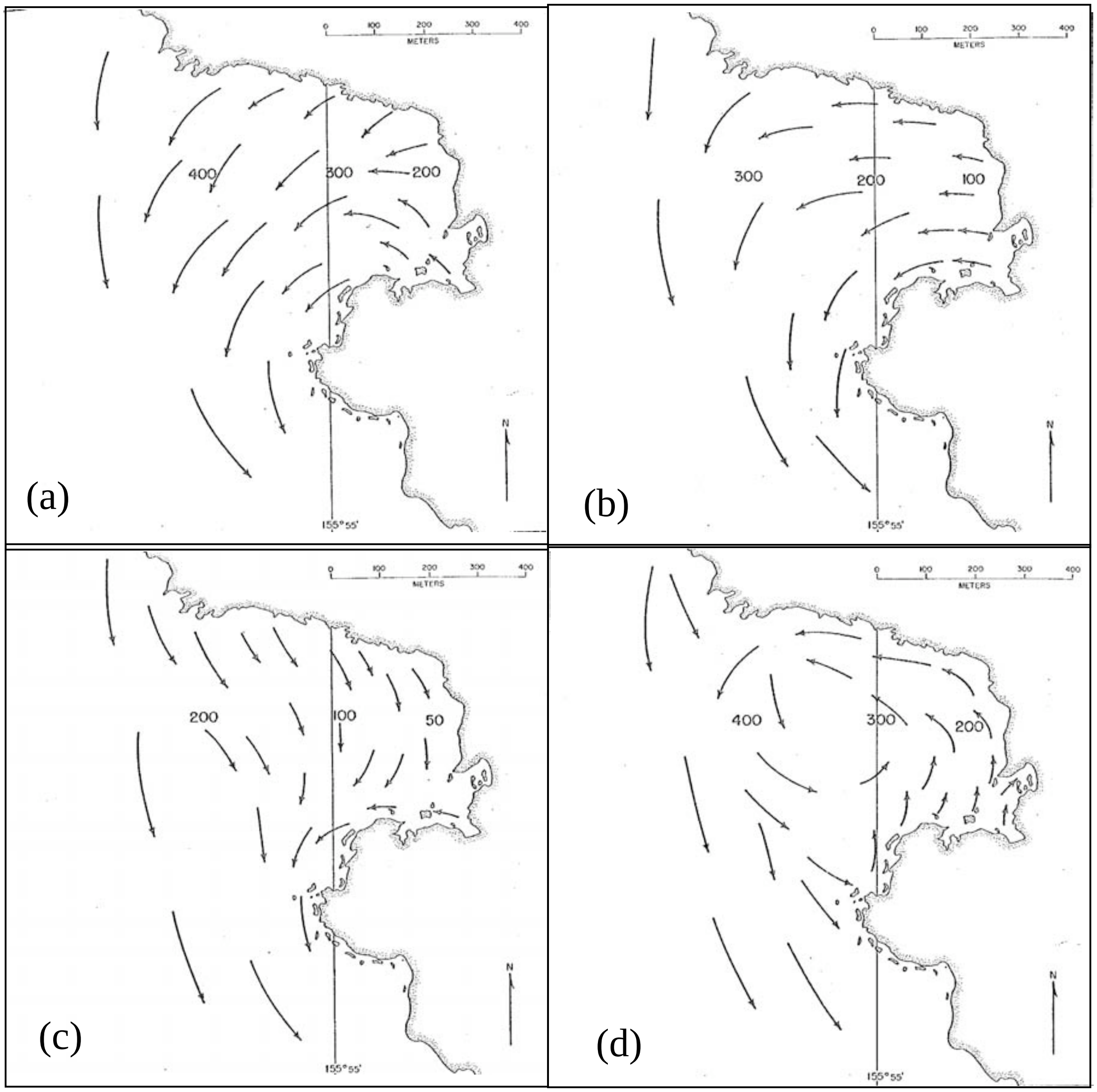

Figure 6. Surface (upper 1 m) circulation in Honaunau Bay on March 6, 1969. Numbers show current speeds in m/h. (a) High tide. (b) Falling tide. (c) Low tide. (d) Rising tide. Plots from Doty (1969).

B.2.b. Hydrology affecting the park

The climate along the Kona coast typically is cool and calm in the mornings, with breezes blowing onshore by mid-morning and dissipating in the evening. There is little seasonal variation in temperature, with a mean high temperature of 31°C (88°F), and a mean low of 18°C (65°F) (Doty 1969). The mountains of Mauna Loa, Mauna Kea, and Hualalai block most tradewind showers (Leishmann 1986), resulting in relatively dry conditions on leeward slopes: the mean annual rainfall along the coast at Honaunau is a little over 1000 mm (39”), increasing upslope of the park to a maximum of over 2000 mm (78”) at an elevation of about 700 m (2300’) (Figure 4). At higher elevations, rainfall declines steadily, reaching 750 mm/y (30”/y) at the upper boundary of PUHO's WQAOI (~2,000 m/6,500' elevation) and declining further to less than 500 mm (20") at the summit of Mauna Loa (4,168 m/13,677'). Slightly more rain falls in summer than winter (Juvik and Juvik 1998), but storms are more frequent in the winter months and can result in strong winds and intense rains (Doty 1969). No perennial streams flow in the park, but one intermittent stream (Kiʻilae) occasionally flows through the southern portion of the park after extended periods of heavy rainfall (Davis and Yamanaga 1968). Recharge in the higher rainfall areas maintains subsurface groundwater that flows downslope toward the park. Fresh groundwater that reaches sea level floats on and mixes with underlying salt water. Because mixing begins well inland of the park, groundwater flowing through the park is brackish, with salinity increasing as it approaches the coast (Oki et al. 1999).

B.2.c. Water bodies and other water resources

PUHO has a number of significant water resources. Fresh water normally is not found in the main park parcel, although as noted above rare large runoff events can result in flow in the lower portions of Kiʻilae Stream. Groundwater is a significant resource as it was a critical source of drinking water for early inhabitants and because it passes through the park and affects water quality in the park's anchialine pools, fishpond, and wetland areas. Groundwater discharges also affect nearshore water quality. Marine resources include rocky and sandy intertidal areas around the park and coastal waters and benthic habitats offshore of the park.

B.2.c.i. Groundwater

Groundwater in the park has not been studied directly, but in geologically and hydrologically similar areas, groundwater consists of a relatively thin brackish layer floating on underlying seawater. Based on similar areas along the Kona coast, maximum groundwater heads in the park probably are less than 0.6 m (2') (Oki et al. 1999). Because so little rain falls in the park, groundwater flow through the park primarily is maintained by recharge upslope of the park in higher rainfall areas. Groundwater intersects the land surface in the park's anchialine pools, and groundwater flow through the park results in a significant number of groundwater intrusions or springs along the park coastline and from submarine discharges offshore (Fischer et al. 1966; Adams 1969; Oki et al. 1999). Although groundwater head gradients in the park likely are quite low, significant groundwater flows still can occur because of the highly permeable nature of the lavas making up the Kona coast (Oki et al. 1999). Groundwater discharges alter the salinity and temperature of receiving waters, and add nutrients and other dissolved constituents derived from upland portions of the watershed. Groundwater flow through the park may be impacted significantly by upslope land use, which can affect rainfall and recharge, and by withdrawals and artificial recharge associated with irrigation and wastewater disposal. Upslope activities also may affect groundwater quality via the direct introduction of wastewater, or contamination of runoff by non-point sources.

B.2.c.ii. Anchialine pools

PUHO is one of only three legally protected sites in the state of Hawaiʻi with anchialine pools. Anchialine pools contain water that is a mixture of seaward-flowing brackish groundwater and more saline seawater (Brock et al. 1987; Brock and Kam 1997). Although anchialine resources in

PUHO are less common than in some other areas of the Kona coast (Kikuchi and Belshe 1971; Maciolek and Brock 1974), there are a number of pools in the park, including at least one within the pu'uhonua enclosure (Figure 7). Several are noted on old archaeological maps as springs or wells, but some of these may now be filled with rubble or sediment. The few pools that have been identified inland and south of the pu'uhonua are cryptic and poorly documented (M. Laber pers. comm. 2005). One relatively well-known pool was used as a well by early inhabitants and is located just south of the main park parcel boundary in the village of Ki'ilae (Greene 1993, D. Hoover pers. obs. 2004). Despite their relative scarcity in PUHO, anchialine pools in the park are important culturally and may be important biogeographically, as anchialine habitat is scarce between Kailua-Kona to the north, and Milolii to the south (Oceanic Institute et al. 1992). Because anchialine pools are surface expressions of the local groundwater table, and groundwater quality varies both with the degree of mixing between freshwater and seawater, and with local factors affecting water quality, water in anchialine pools naturally displays a wide range of physical and chemical conditions (Brock and Kam 1997).

Figure 7. Anchialine pool inside the pu'uhonua grounds, near the Ka'ahumanu stone. Photo D. Hoover, 2004.

B.2.c.iii. Fishpond

PUHO contains a pond complex (Heleipalala, or the Royal Fishpond) that historically was used to hold fish for consumption by the ali‘i (royalty) (Pratt 1998). The pond complex consists of separate northern and southern pools; the northern and more seaward (makai) pool (Figure 8) has been modified with a rock wall along the western and southern margins and is on the park's List of Classified Structures due to its value as a cultural resource. The pool is separated from the ocean waters of Keone‘ele Cove by beach sands, making the complex a ‘puuone hakuone'-type fishpond.

Figure 8. North pool of the Royal Fishpond. View is looking north from the causeway between the pools. Photo D. Hoover, 2004.

Both northern and southern pools are relatively small. The northern pool covers an area of about 300 – 360 m^2 (0.07 – 0.09 acres) (Oceanic Institute et al. 1992; National Park Service 2002), but the area of the southern pool appears to vary significantly, possibly due to changes in groundwater flow associated with seasonal and longer-term changes in rainfall in the upslope watershed (Figure 9). Oceanic Institute et al. (1992) noted that the southern pool (Figure 9c) was significantly smaller in 1992 than was shown on archaeological maps from the 1960's, which showed the pool extending under the Great Wall and into the pu‘uhonua grounds (cf., Figure 9b), and suggested that the reduction in area may have been due to infilling by sediments. At least one earlier map from 1957 also shows the southern pool covering more area than was observed in 1992 (Figure 9a), and notes made by park staff in 1979 refer to the southern pool being contiguous with a pool inside the refuge area (National Park Service 1979), but more recent maps (1998 and 2002; Figures 9d and 9e), and personal observations (D. Hoover 2004) also show the southern pool extending through the Great Wall and into the pu‘uhonua complex on at least 3 occasions since 1992, suggesting that natural variability may be a significant factor. In 1992, the southern pool covered about 350 m^2 (0.09 acre) (Oceanic Institute et al. 1992); in 2002, the area of the contiguous portion of the southern pool was 920 m^2 (0.23 acre), with another 50 m^2 (0.01 acre) in a small satellite pool to the south and 785 m^2 (0.19 acre) in the extension of the southern pool that was located inside the pu‘uhonua grounds (Figure 9e). Data collected in 1992 showed that both pools were shallow (~40 – 50 cm/16 – 20”) and contained 13 – 28 cm (5 – 11”)

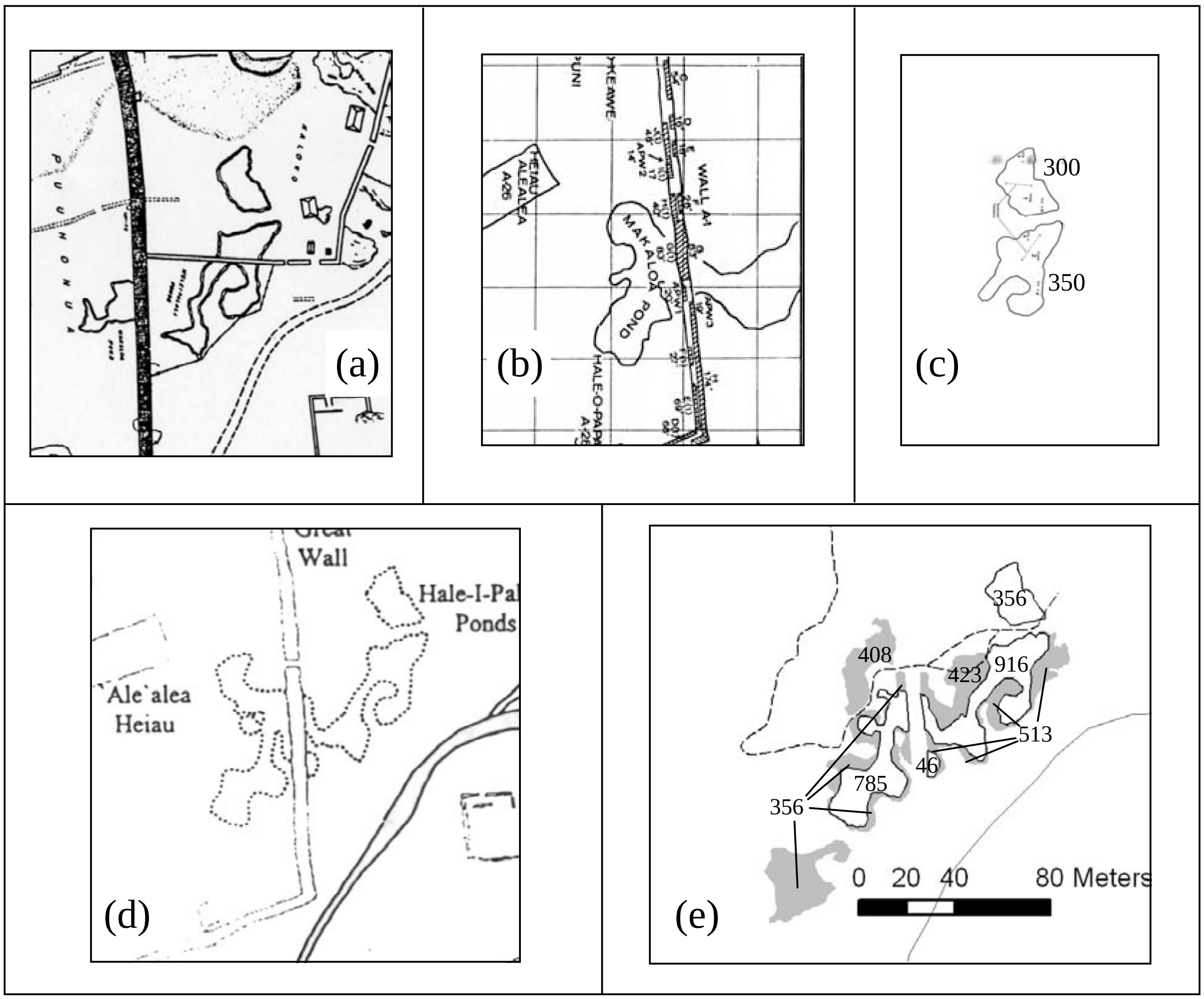

Figure 9. Maps of Royal Fishpond from various time periods showing variations in the size of the south pool and the portion inside the pu‘uhonua grounds. (a) 1957 (Emory 1986 in Greene 1993) (b) 1963 (Greene 1993) (c) 1992 (pond areas in m^2; Oceanic Institute et al. 1992) (d) ~1997 (Pratt 1998) (e) 2002 (pond and marsh (gray) areas in m^2; http://nrdata.nps.gov/puho/puhodata/puho_veg_1986.xml). Figures are reproduced roughly at the same scale.

of predominantly biogenic sediments overlying pahoehoe basalt (Oceanic et al. 1992). These conditions appear rather similar to those encountered in 1976 – 1980 ("…about 4" of mud. Deepest spot about 12".") when restoration work (manual removal of marsh grass and loose stones followed by mud removal using a pump system) was performed on the south pool by members of the Youth Conservation Corps under the supervision of park staff (National Park service 1976; 1977; 1979; 1980). Because of the pools' proximity to the ocean, they occasionally have been subject to disturbance by large storms, high surf, and tidal waves. These types of events probably are responsible for the introduction of species more commonly found in open coastal environments, and for the introduction of larger rocks and other debris (Emory 1986). For instance, a major storm in January of 1980 was responsible for introducing "lots of fist-sized stone" into the south pool (National Park Service 1980), presumably due primarily to the unusually high surf associated with the storm (Rosendal 1980). Prior to ~1971, the pools also may have been affected by nutrient inputs from two nearby cesspools - park employees have indicated that alien fish currently found in the pools were introduced to control excessive algal growth, possibly due to sewage nutrients, and as noted above, pond sediments were removed from 1976 – 1980 in an effort to preserve the cultural scene (National Park Service 1976; 1977; 1979; 1980). The pools currently are subject to overgrowth by vegetation encroaching from surrounding wetland areas, and both pools currently require periodic removal of alien woody vegetation and spot removal of native plants to maintain open water areas (Pratt 1998).

B.2.c.iv. Wetlands

PUHO's wetlands are restricted to marshy areas associated with the fishpond pools, two areas inside the puʻuhonua grounds, and potentially with anchialine pools. A recent map of the wetland areas around the Royal Fishpond shows wetlands covering an area of about 2500 m^2 (0.62 acre) (Figure 9e). Although the areal extent of PUHO's wetlands is small, they contain unique flora and fauna, including a number of native species and species introduced by early Polynesians that are important both biogeographically and culturally (Pratt 1998). PUHO's wetlands currently do not provide significant habitat for native or transient waterbirds due to their small size, the presence of non-native predators, and visitor disturbance (Morin 1998). Wetlands are dynamic communities that undergo progressive changes due to natural processes, but they also are vulnerable to changes due to other factors, including sediment inputs and invasion by alien species (Pratt 1998).

B.2.c.v. Rocky and sandy intertidal

PUHO's shoreline consists primarily of intact pahoehoe lava, with a small sand beach at the head of Keoneʻele Cove in Honaunau Bay (Kimmerer and Woodrow 1975), and a perched beach/sand berm south of the puʻuhonua area (Pratt 1998; Hapke and Richmond 2004). The rocky intertidal zone is an area of active water exchange and contains tide pools and associated flora and fauna, as well as flora and fauna associated with rocky substrates that are subject to cyclic submergence by tides and wave action, or receive intermittent moisture in the form of splash and spray. The rocky intertidal also contains a number of water-related cultural resources, including bait cups and net tanning tubs, culturally significant springs and tidepools (e.g. Keawe-wai, where the bones of Keawe are reputed to have been washed, the Kekuaiʻo pool, where fish were caught using a natural sedative derived from the ʻauhuhu plant, and the tidepool containing the ʻSun

Stone' (Pohaku Nana La), which variously was described by early informants as having been used for astronomical observations or as a natural feature that produced an underwater image of the sun (Stokes 1986)). Rocky intertidal areas in the park occur in two distinct zones: the peninsula area and the area south of the peninsula. The peninsula was formed by one or a few conterminous low-lying pahoehoe flows that extended offshore. The northern and southern edges of the peninsula make up the southern shore of Honaunau Bay and the northern shore of Alahaka Bay, respectively. South of the peninsula, the coastline becomes morphologically more diverse as the Pali Alahaka reaches the coast, with sheer basalt cliffs and platforms along the shore. The only significant sandy intertidal area in the park is found at the head of Keone'ele Cove. The beach at this site currently is eroding, and park personnel are attempting to minimize sand losses to prevent damage to culturally significant palm trees and rock walls around the cove (Figure 10). The perched beach/sand berm south of the pu'uhonua also is subject to erosion by high waves and storms, resulting in damage to associated archaeological sites and burials (Pratt 1998).

B.2.c.vi. Coastal waters

PUHO's legislated boundaries end at the shoreline, but adjacent coastal waters represent an important resource, both for their relevance to the cultural history of the park, and their biological and recreational values. A variety of coastal environments are found adjacent to the park, from the relatively sheltered waters of Honaunau, Alahaka and Ki'ilae Bays to the exposed areas off Pu'uhonua Point. Coastal environments are structured primarily by the morphology of the coastline and underwater topography, which are controlled by the distribution and modification of the recent (750 – 1,500 year old, Lockwood and Lippmann 1987 in Pratt and Abbott 1996) lava flows forming the coastline (Figure 5). The peninsula containing the pu'uhonua probably was formed by one or a few contemporaneous pahoehoe flows that extended out into the ocean, resulting in a gently sloping shelf extending from relatively shallow waters to depths of 15 - 20 m (50 – 70'), where the slope steepens. On the north side of the peninsula, the deeper slope ends in a sand deposit at depths of about 25 - 35 m (80 – 120'), with a similar sand deposit on the south side in Alahaka Bay at slightly shallower depths. South of Alahaka Bay, the coastline is composed of a series of cliffs where the Keanae'e pali fault scarp reaches the coast, resulting in relatively deep waters (~ 5 m/15') at the shoreline. The basalt substrate at the base of the cliffs slopes gently offshore to depths of ~ 20 m (70'), where the slope steepens and intersects sand deposits at depths of ~20 – 25 m (70 – 80'). Fine scale structure in the basalt substrate is the result of weathering and wave action. Exposed areas such as those off Pu'uhonua Point have rocks and boulders scattered on the bottom that have been displaced from shallower areas by wave action, while the basalt substrate along the sheltered north side of the point more closely matches the original contours of the constituent flows. Although there are no known archaeological features offshore of the park, there is at least one potentially noteworthy cultural feature, an unusually shaped rock in an underwater cave that was reputed to be a representation of the god Hawa'e. Human sacrifices purportedly were performed at this site by drowning victims (Greene 1993).

Consolidated coral reefs do not form extensive substrate in PUHO, although corals are a significant component of the benthic biota in Honaunau Bay (Figure 11) and along deep (15 - 25 m/50 – 80') slopes, and corals have colonized much of the basalt substrate to varying degrees (Figure 12). Significant changes in the overall morphology of PUHO's benthic substrate are

Figure 10. Erosion control fabric exposed along the head of Keoneʻele Cove in December 2004. (a) View looking southwest from the east side of the cove. (b) Closeup of southeast corner of cove. Photos D. Hoover, 2004.

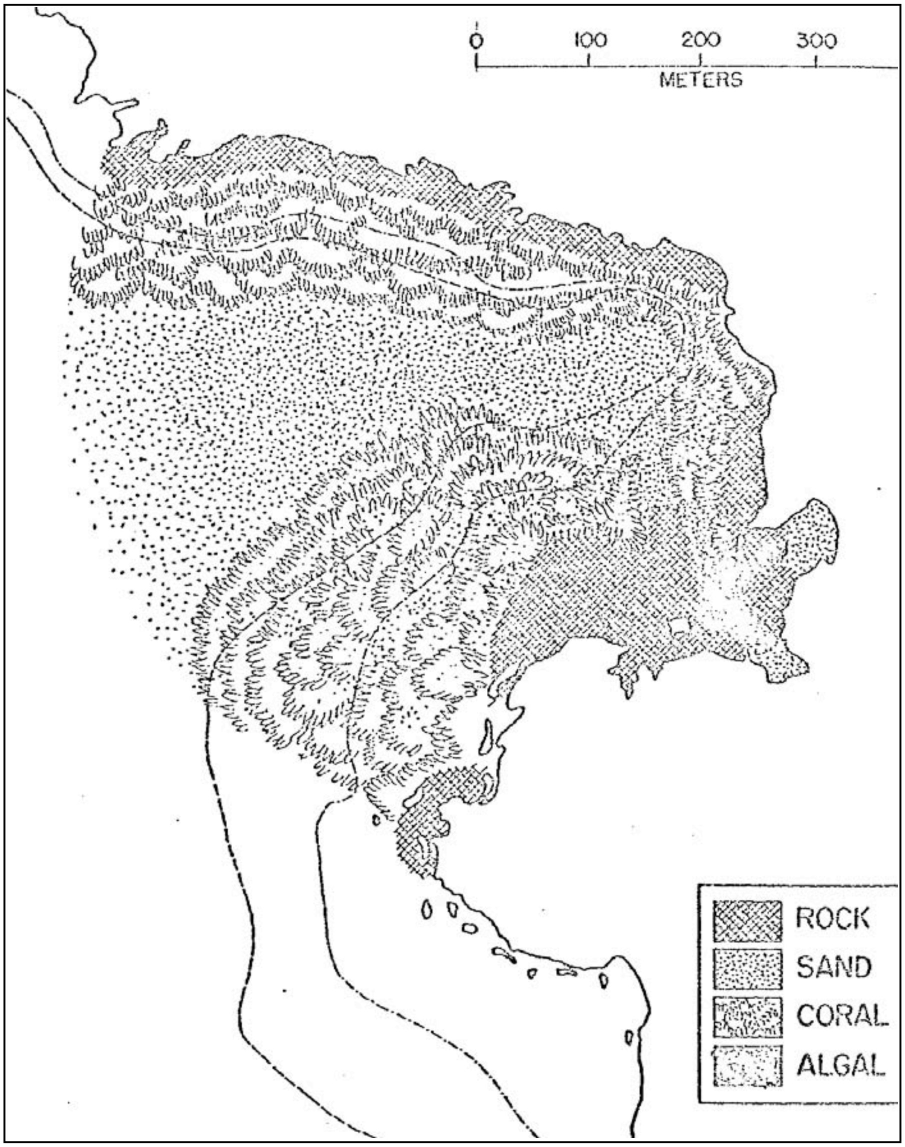

Figure 11. Benthic habitat in Honaunau Bay circa 1969. Depth contours are at 5 fathom (30'/9 m) intervals. Figure from Doty (1969).

unlikely due to the robust nature of the lava substrate, but occasional changes probably occur in the deep coral slope due to slumping, which may be triggered by severe storms (cf., Parrish et al. 1990; Larry Basch pers. comm. 2005) and possibly by boat anchors, and changes probably occur in the presence and extent of subtidal sand deposits.

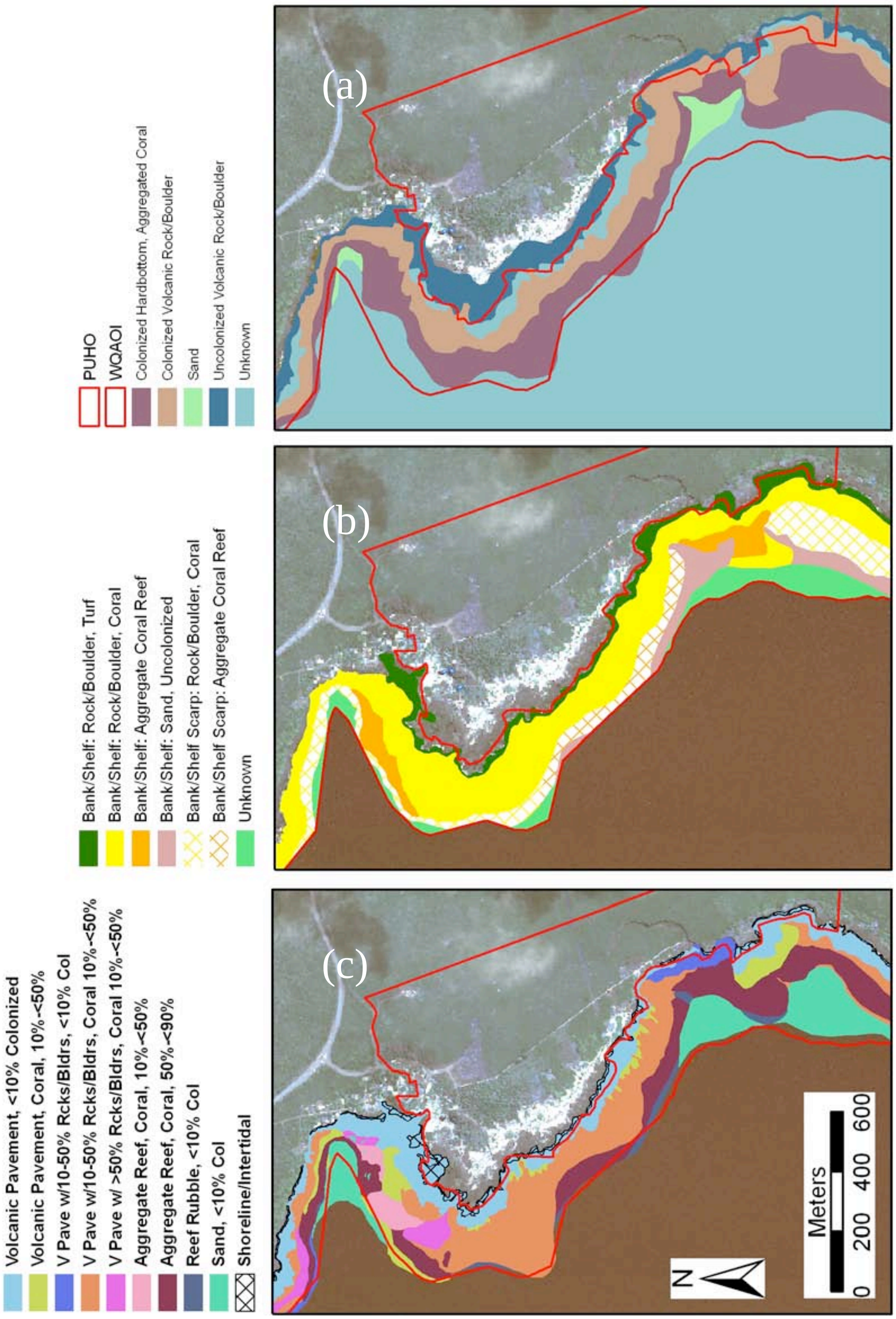

Figure 12. Benthic habitat around PUHO. (a) Benthic structure and cover from aerial photographs and satellite imagery obtained in 2000 (http://ccma.nos.noaa.gov/about/biogeography/). (b) Structure and cover from aerial photographs and satellite imagery obtained in 2005 (ibid). (c) Structure and cover from airborne hyperspectral images obtained in 2000 (Cochran et al. in press).

B.3. Biological resources

B.3.a. Freshwater

Freshwater habitat in PUHO occurs only in association with Ki‘ilae Stream. The headwaters of the stream are perennial, but because the lower reaches are intermittent, stream waters seem unlikely to contain fauna (e.g., native gobies), that also are associated with coastal habitats. Biological resources thus are not considered for Ki‘ilae Stream.

B.3.b. Groundwater

Groundwater typically is not considered to contain biological resources. However, the mixohaline fauna found in Kona’s anchialine pools and fishponds includes hypogeal fauna that can live in brackish groundwater. Their distribution in groundwaters is not quantitatively known, but shrimp commonly found in anchialine pools also have been observed in groundwater samples collected from a well in Kaloko-Honokohau National Historical Park (KAHO), north of PUHO (Brock and Kam 1997). Their presence in widely separated anchialine habitats along the Kona coast suggests that groundwater may provide an important pathway for dispersal and colonization of mixohaline flora and fauna, including endemic and threatened and endangered species.

B.3.c. Anchialine pools

Anchialine pools in Hawai‘i harbor a distinct assemblage of organisms, including crustaceans (shrimps and amphipods), fishes, mollusks, a hydroid, sponges, polychaetes, tunicates, aquatic insects, algae, aquatic macrophytes, and a unique cyanobacterial mat community (Brock and Kam 1997; Foote 2005). Species of concern and species being considered for listing under the U.S. Endangered Species Act include the shrimp *Metabetaeus lohena* and a native damselfly (*Megalagrion xanthophelas*) (Pratt 1998; Else 2004). Anchialine shrimp and amphipods have been observed in park pools (M. Laber pers. comm. 2004, D. Hoover pers. obs. 2004), but no quantitative data are available on the number and type of organisms present. However, anchialine fauna in PUHO seems likely to be reduced compared to other areas due to the relative scarcity of pools, their small size, and the degraded condition of some pools. A biological survey of park pools was performed recently, but results are not yet available (Tango et al. submitted 2005).

B.3.d. Royal Fishpond

Early observations of the Royal Fishpond noted that the fishpond pools were used to hold fish for consumption by the ali‘i, but no details of biological resources are given. In 1969, Doty (1969) observed that the fishpond was polluted and ‘an embarassment to … park personnel’ due to its proximity to 2 cesspools. Anecdotal information from a retired park employee suggests that the pond probably was eutrophic and overgrown by macroalgae around that time, leading to the introduction of alien fish to control the algae (M. Laber pers. comm. 2006). Doty (1969) did note that the fishpond provided habitat for the humped gray-black nerite *Theodoxus cariosus*. Qualitative and semi-quantitative surveys of the fishpond pools in 1992 found that pond waters were characterized by daily blooms of phytoplankton, consisting mostly of diatoms but also including chlorophytes. Macrofauna consisted of abundant alien and invasive species with relatively few of the organisms normally found in pristine anchialine and fishpond habitats (Table 1). Oceanic Institute et al. (1992) noted that many of the organisms commonly found in anchialine habitats, particularly the crustaceans *Halocaridina rubra*, *Metabetaeus lohena*, and *Palaemon debilis*, and several species of amphipods were “conspicuously absent”. They concluded that the fishpond no longer was suitable for aquaculture as historically practiced due to poor water quality and ecological conditions, including displacement of native species by invasives, particularly tilapia and guppies. In addition, they observed spontaneous die-offs of several tilapia, mullet, and aholehole on two separate days. While they were unable to determine the cause, they suggested that poor water quality was “a probable contributing factor”. Chai (1999) inventoried biological resources in the fishpond pools in the summer of 1999 and observed that native species appeared to have been displaced by invasives, particularly tilapia (*Sarotherodon melantheron*) and mosquito fish (*Gambusia affinis*), although he did observe some endemic fish (mullet, milkfish, aholehole, and mamo), a native goby (oʻopu) and an anchialine shrimp (*Palaemon debilis*) (Table 1).

Table 1. Fauna observed in Royal Fishpond in 1992 and 1999. Common or Hawaiian name is given in parentheses. Pond 1 is the northern pool, pond 2 is the southern pool. Data from Oceanic Institute et al. (1992) and Chai (1999).

	1992		1999
	Pond 1	Pond 2	Not specified
Crustaceans			
Metapograpsus thukuhar (crab)	Several	Several	
unidentified grapsid crab	Few/one	-	
Ligia sp. (supralittoral isopod)	-	Abundant	
Palaemon debilis			Noted
Mollusks			
Theodoxus cariosus (neritid shell)	Several	Abundant	Noted
Thiara granifera (spiral shell)	Abundant	Abundant	(Thiaridae)
Littoraria pintado (pipipi kolea)			Noted
Fish			
Mugil cephalus (mullet)	Few/one	Few/one	Noted
Kuhlia sandvicensis (aholehole)	Few/one	Few/one	Noted
**Oreochromis mossambicus* (tilapia)	Abundant	Abundant	
**Sarotheradon melantheron* (tilapia)			Noted
**Gambusia affinis* (guppy/mosquito fish)	Abundant	Abundant	Noted
Parapeneus multifaciatus (moano)	-	Few/one	
Acanthuras triostegas (manini)	-	Few/one	
Abudefdef abdominalus (mamo)	-	Few/one	Noted
Chanos chanos (milkfish)			Noted
Unidentified goby (o’opu)			Noted

* = alien species

B.3.e. Wetlands

PUHO's wetland areas are relatively small and likely have been impacted heavily by human use of ponds and pools for aquaculture and by goats and cattle that ranged in the area until 1978. There is little historical data on the extent and status of wetlands and associated flora and fauna in the park, although the park currently does manage the vegetation in wetlands around the Royal Fishpond to some degree. No data exist on the extent of any wetlands associated with anchialine pools in the park, or on any associated flora or fauna.

Early reports noted that an area inside of the puʻuhonua grounds supported the growth of makaloa reed (*Cyperus laevigatus*), a wetland plant used for weaving fine mats (Greene 1993). Greenwell (1986) discussed Honaunau flora from surveys conducted in 1957, but did not mention wetlands, and none of the species listed in the report are found exclusively in wetlands. Maps documenting stabilization work on the Great Wall in 1963 show a portion of the south Royal Fishpond pool extending into the puʻuhonua grounds with the label "Makaloa Pond" (Greene 1993). Doty (1969) surveyed the shoreline vegetation around Honaunau Bay and Puʻuhonua Point, but did not discuss wetland areas specifically. His shoreline vegetation map did not include any wetland species except for *C. laevigatus* inside the puʻuhonua grounds and at one site near the visitor center (Figure 13, Table 2). Field notes from restoration work performed from 1976 – 1980 in and around the south pool include references to the removal of "marsh grass" "weeds", and "Maninia" (National park Service 1976; 1977; 1979; 1980). A comprehensive survey of vascular plants conducted from 1983 - 1985 documented 126 species in the park, but only four were noted as being found in association with brackish ponds in the park (Table 3), while a vegetation map prepared in 1986 shows the general location of the fishpond pools but does not include any wetland areas or plant associations that would be associated with wetlands (Leishmann 1986). A second vascular plant survey conducted in 1992-1993 focused primarily on undeveloped inland areas of the park, but also addressed indigenous plants around the Royal Fishpond pools and the adjacent brackish pond inside the puʻuhonua (Pratt and Abbott 1996). They identified a number of indigenous species that were associated either with wetlands or were found exclusively around the ponds (Table 4). They also found an invasive pickleweed (*Batis maritima*), in a single patch on the margin of the fishpond just east of the Great Wall. They noted that it was not present in the 1986 survey, and suggested that it be removed "to prevent its spread to adjacent pools that support native sedges and herbs". The pickleweed subsequently was removed by park staff and appears to have been successfully eradicated (Pratt 1998; M. Laber pers. comm. 2006). Pratt (1998) noted that the areas around brackish pools were one of the few areas in the park where native plants persisted, primarily due to alien plant management in those areas, and provided a description of the pools comprising the Royal Fishpond and the associated vegetation:

> "Several ponds persist within the area of the original Royal Grounds; collectively called Hele'ipalala Ponds, they were apparently used as fish ponds to supply the king …. The northernmost of these has been highly modified and supports virtually no vegetation. To the south is a large irregular pond complex adjacent to the Great Wall, which separates the outer pond from the Makaloa Pond within the Pu'uhonua enclosure …. The vegetation of the southern pool is composed primarily of native or Polynesian plants. A dense stand of indigenous milo persists on the southern edge of the pond, and low growing 'akulikuli (*Sesuvium portulacastrum*) and beach morning glory or pohuehue (*Ipomoea pes-caprae* subsp. *brasiliensis*), as well as the sedges makaloa and 'ahu'awa (*Mariscus javanicus*) are

common in and around the pond. Scattered coconut palms, noni, and ki plants grow in the area between the ponds and the Great Wall. The only conspicuous alien plants persisting near the ponds are Bermuda grass and scattered young 'opiuma trees (*Pithecellobium dulce*). Similar vegetation surrounds the Makaloa pond within the Pu'uhonua, and as the name implies, makaloa sedge is abundant within the pond and in an adjacent depression. The depression may represent a filled-in former pool."

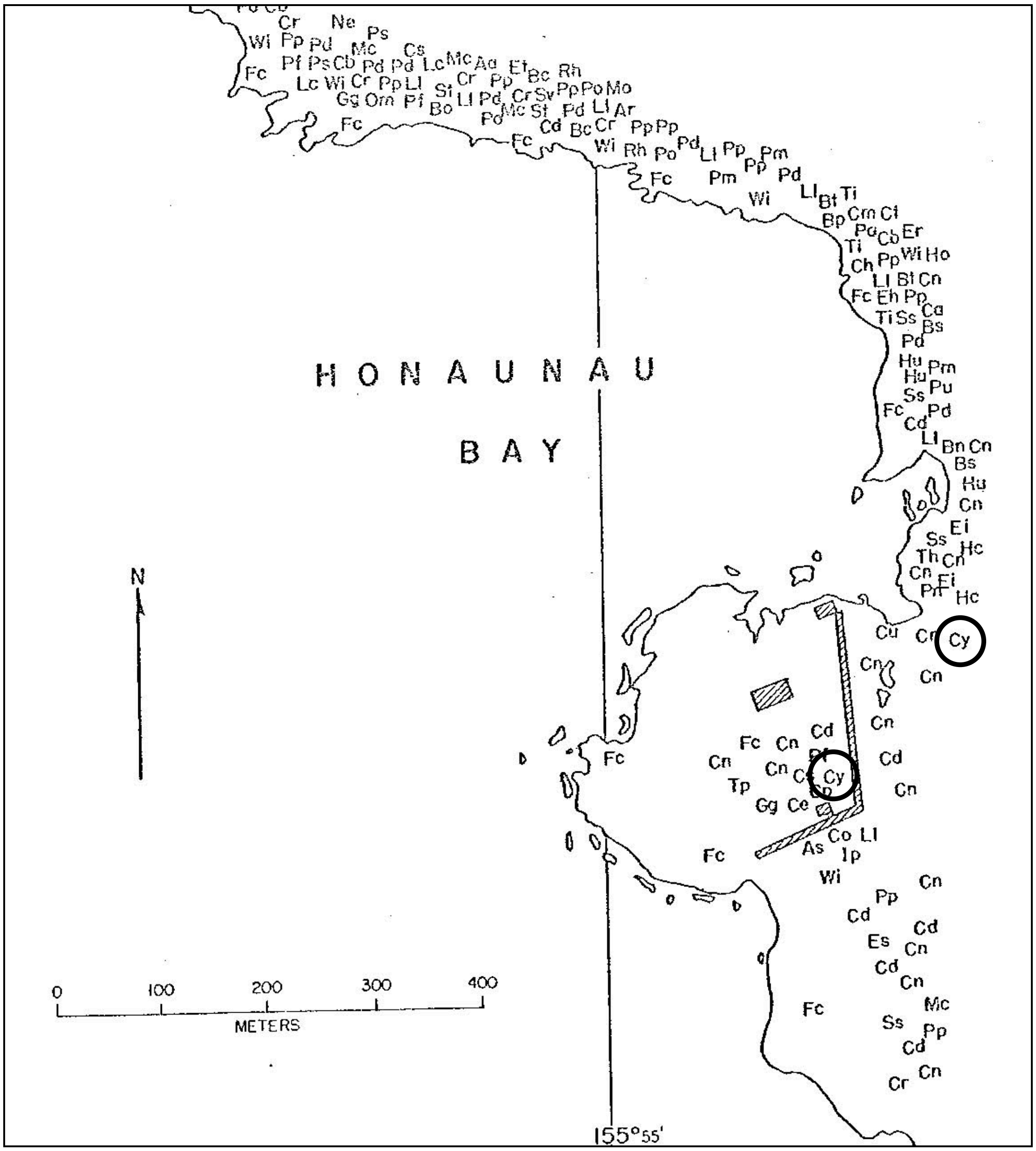

Figure 13. Shoreline vegetation around Honaunau Bay and Pu‘uhonua Point circa 1969. Occurrences of *Cyperus* sp. indicative of marsh habitats are circled. Vegetation codes are in Table 2. Figure from Doty (1969).

Table 2. Shoreline vegetation around Honaunau Bay circa 1969. Codes are plotted on Figure 13. Unless otherwise noted species are historical (>1778) introductions. From Doty (1969).

Code	Scientific name	Common and/or Hawaiian name	Code	Scientific name	Common and/or Hawaiian name
Aa	*Alternanthera amoena*		Hc **	*Heteropogon contortus*	Pili grass
As	*Amaranthus spinosus*		Hu	*Hylocereus undatus*	Night-blooming cereus
Ar *	*Artocarpus altilis*	Breadfruit, ‘ulu	Ii **	*Ipomoea indica*	Morning glory, keali ‘awahia
Bc	*Bidens cynapiifolia*		Ip **	*Ipomoea pes-caprae*	Beach morning glory, pohuehue
Bs	*Bougainvillea spectabi1is*	Bouganvillea	Lc	*Lantana camara*	Lantana
Bn	*Breynia nivosa*	Snow bush	Ll	*Leucaena leucocephala*	Koa haole, ekoa
Bp	*Bryophyllum pinnatum*	Air plant	Mo	*Momordica charantia*	
Bt	*Bryophyllum tubiflorum*	Bryophyllum	Mc *	*Morinda citrifolia*	Noni
Cp	*Carica papaya*	Papaya	Ne **	*Nephrolepis exaltata*	Swordfern, ni ‘ani‘au
Cr	*Catharanthus roseus*	Madagascar periwinkle	Om	*Opuntia magacantha*	
Ce	*Cenchrus echinatus*		Pn *	*Pandanus sp.*	Hala
Ch	*Chenopodium sp.*		Pm	*Panicum maximum*	
Cb	*Chloris barbata*		Pf	*Passiflora foetida*	Passion flower
Cu	*Coccoloba uvifera*		Ps	*Pennisetum setaceum*	
Cn *	*Cocos nucifera*	Coconut, niu	Pd	*Pithecelobium dulce*	Opiuma
Cm	*Commelina benghalensis*		Pu	*Pluchea odorata*	
Co *	*Cordia subcordata*	Kou	Pa	*Plumeria acutifolia*	Plumeria
Ct	*Cordyline terminalis*		Po	*Portulaca oleracea*	
Cs	*Cucumis dipsaceus*		Pp	*Prosopis pallida*	Kiawe
Cd	*Cynodon dactylon*	Bermuda grass	Rh	*Rivina humilis*	
Cy	*Cyperus sp.*	Sedge, ‘ahu‘awa	Ss	*Samanea saman*	Monkeypod
Ei	*Eleusine indica*		St	*Schinus terebinthifolius*	Christmas berry
Es	*Emilia sonchifo1ia*		Sv	*Setaria verticillata*	
Et	*Eragrostis tenella*		Ti	*Tamarindus indicus*	Tamarind
Er	*Erythrina sp.*		Tp *	*Tephrosia purpurea*	‘auhuhu
Eh	*Euphorbia hirta*	Garden spurge	Th *	*Thespesia populnea*	Milo
Fc **	*Fimbristylis cymosa*	Sedge, manu aki‘ala	Wi **	*Waltheria indica*	hi’aloa
Gg	*Gynandropsis gynandra*				

* Polynesian introduction
** Native

Table 3. Vascular plants noted in association with PUHO brackish ponds in 1983-1985 (Smith et al. 1986).

Species	Common/ Hawaiian name	Occurrence	Indigenous/ Introduced
Cyperus javanicus	Marsh cyperus, ‘ahu‘awa, ‘ehu‘awa	Common by inland brackish ponds.	Indigenous
Cyperus laevigatus	Makaloa, ‘ehu‘awa	Common by inland brackish ponds.	Indigenous
Sesuvium portulacastrum	Sea purslane, ‘akulikuli	Common along brackish ponds	Indigenous
Eclipta alba	False daisy	Occasional in lawn and adjacent to brackish ponds	Introduced after 1778

Table 4. Indigenous vascular plants associated with brackish ponds in 1992-1993 (Pratt and Abbott 1996). List includes both wetland plants and those found near brackish ponds. Results from 1957 survey also are shown for comparison.

Species	Common/ Hawaiian name	Occurrence	1986 survey (Smith et al. 1986)	1957 survey (Greenwell 1986)
Mariscus javanicus	Sedge, ‘ahu‘awa	Throughout pu’uhonua and near fishpond E of Great Wall, with a few individuals at other inland and coastal sites	Common near brackish ponds (listed as *C. javanicus*)	Not noted
Cyperus laevigatus	Sedge, makaloa	Only near brackish pools east and west of Great Wall	Same areas	Not noted
Ipomoe pes-caprae subsp. *brasiliensis*	Morning glory, pohuehue	Low numbers near margins of brackish ponds, within Great Wall, one coastal site	Occasional along strand	Noted
Sesuvium portulacastrum	Sea purslane, akulikuli	Only on edges of ponds near Great Wall	Same areas	Not noted
Pandanus tectorius	Hala	Several near brackish ponds, also visitor center, park roads, possibly planted	Occasionally around visitor center	Noted
Thespesia populnea	Milo	Dense stand > 50 trees on S side of S pond near Great Wall. Others near visitor center possibly planted	Noted near visitor center	Noted

The only quantitative documentation of the extent of PUHO’s wetlands is found in a recent digitized version of Leishmann’s 1986 vegetation map, which was modified in 2002 by NPS to include areas for the major park pools and associated wetlands (Figure 9e). The areas shown in the 2002 map generally appear to be very similar to those observed during a site visit in December 2004 (D. Hoover pers. obs.)

No data are available on wetland fauna, but Morin (1996) noted that the fishpond pools (and presumably associated wetlands) potentially could provide habitat for migratory shorebirds, waterbirds, and seabirds. However, a number of factors reduced their suitability for bird use, including their small size, the presence of non-native predators and mosquitoes, and visitor disturbance. Bird surveys in 1992 and 1993 noted only two species that might be considered to be particularly associated with wetland habitats, the Wandering Tattler (*Heteroscelus incanus*) and the Ruddy Turnstone (*Arenaria interpres*), but other waterbirds occasionally are seen in the park, including the endemic endangered Hawaiian Stilt (*Himantopus mexicanus knudseni*) (Morin 1996). New data on birds using aquatic resources in the park will be available from an upcoming inventory of shorebirds, seabirds, and waterbirds in the park (F. Klasner pers. comm. 2006).

B.3.f. Rocky and Sandy Intertidal

Portions of PUHO's intertidal area were surveyed in 1957 by Kay (1986), in 1968 by Doty (1969), and in 1969 by Kimura (1969). None of these historical surveys were comprehensive or quantitative, but they do provide some data on mollusks, algae, and echinoderms, primarily in PUHO's rocky intertidal. Some recent work has been performed on the reproductive status of opihi in the park (Kay et al. 2005), and an ongoing "rapid assessment" survey of algae in the park in intertidal and shallow subtidal areas around the park will include data collected in November and December of 2005, with additional data to be collected in summer 2006 (C. Squair, pers. comm. 2006). No significant surveys have been conducted in sandy intertidal areas in the park. Kay (1986) did note that in 1957 sand patches in a large tidepool (Keawewai) "form[ed] a feeding ground for several species of carnivorous mollusks", and listed seven species that either were particularly numerous or noteworthy, and observed that the sandy substrate in Keoneʻele Cove had "little to offer in the way of either animal life or algae".

The 1957 survey by Kay (1986) was conducted on five days in January and three days in August "to present a generalized picture of the marine biota of the Honaunau Bay region". Intertidal survey results were separated by the type of habitat surveyed: tidepools, protected habitat, and rocky shoreline (Figure 14), and included observations of corals, sponges, annelids, mollusks, sea stars, sea urchins, sea cucumbers, brittle stars, crustaceans, a bryozoan, fish, and algae (Appendix B). Tidepools were found to contain a rich biota that varied significantly with pool distance from shore and the associated frequency with which pools were renewed by inputs of ocean water. Mauka (landward) tidepools were relatively barren with only a few mollusk species and crabs, while more seaward pools contained dense mats of algae and associated fauna. Tidepool biota also varied with salinity in pools containing brackish water. Rocky intertidal areas in protected waters around Keoneʻele Cove contained a relatively sparse biota consisting of dark colored species of algae, annelids, and mollusks. Biota on exposed rocky shoreline also were sparse compared to tidepools, and included mostly species suited to high-energy environments, such as coralline alga, rock-boring urchins, the opihi *Helcioniscus exaratus*, and barnacles.

Doty (1969) conducted a somewhat more thorough survey of mollusks and algae in PUHO's intertidal than was performed in 1957. The mollusk survey was conducted over three days in April 1969 by Dr. Allison Kay, who added her new observations to those she had previously made in 1957, resulting in a total of "approximately 120" marine and brackish species from habitats from the high shoreline/supralittoral spray zone to shallow subtidal areas (Figure 15, Appendix C). She noted two unusual mollusk populations, both on basalt substrate in Kapuwai cove; a colony of two species of marine pulmonates (*Melampus* sp. and *Laemondonta bronni*) that were found in association with littorines and the nerite *Nerita picea*, which usually occur in different habitats, and a very small colony of *Littorina undulata*, which previously had been recorded in Hawaiʻi only from three specimens on Oahu and from a single colony on Maui. She also made detailed observations of the distribution of species in Keawe-wai tidepool and in two more seaward pools (Figure 15, Appendix C). The mollusk fauna overall was relatively similar to that found at Kealakekua Bay to the north, and at another rocky site on Kauaʻi island, with differences attributable primarily to minor differences in habitat. One notable difference was the

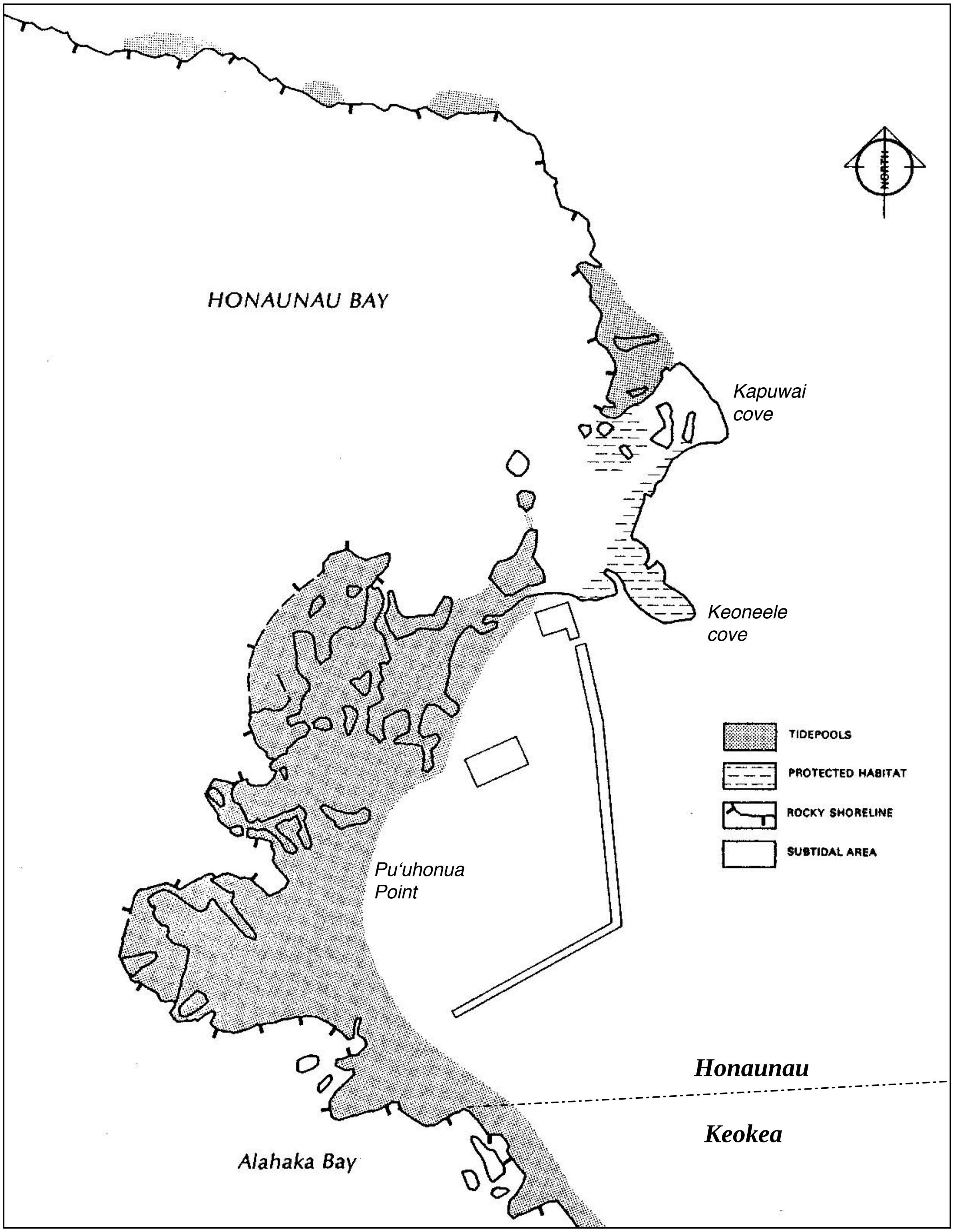

Figure 14. Intertidal and shallow subtidal marine habitats surveyed around Honaunau Bay and Pu‘uhonua Point in 1957. Figure modified from Kay (1986).

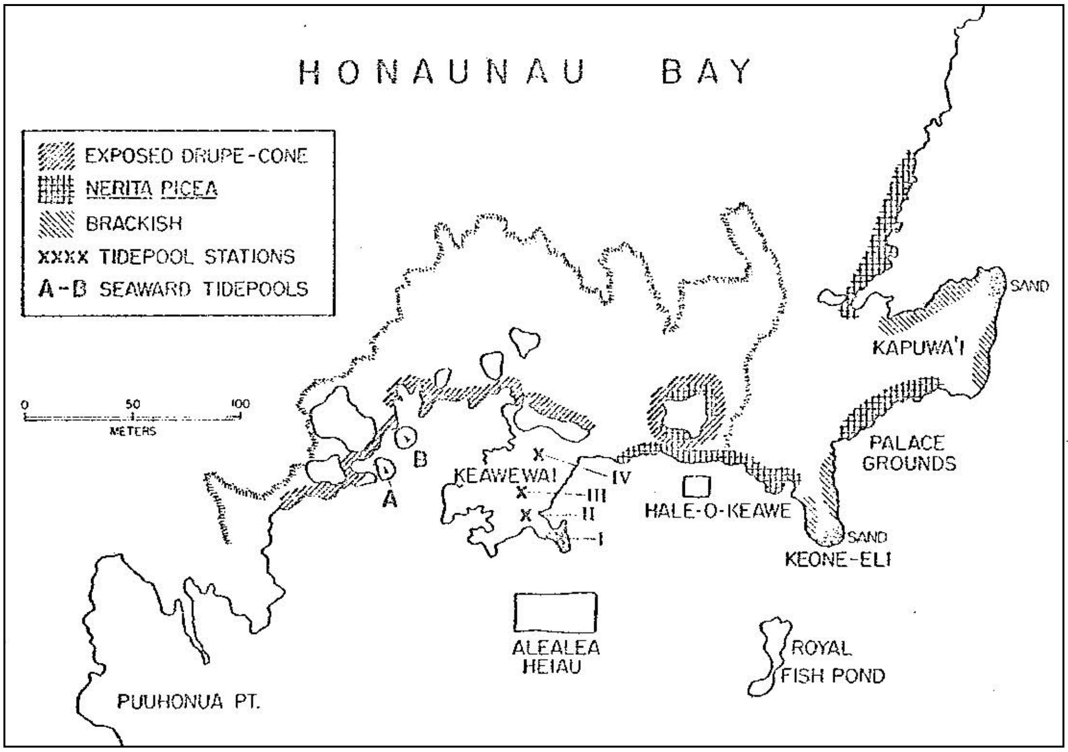

Figure 15. PUHO shoreline/intertidal habitats surveyed in ~1969. Data from Doty (1969).

scarcity of opihi (*Cellanus exarata* and *C. sandwichensis*) in PUHO compared to Kealakekua Bay, likely due to heavy harvesting pressure in the PUHO area.

Algae were surveyed in March 1969 (Doty 1969). Surveys included both shoreline and offshore subtidal observations, although little ‘seaweed’ was observed below the low tide line. Shoreline observations were separated by habitat type (exposed, partially sheltered, protected). A total of 55 species were recorded from intertidal and subtidal habitats (Table 5), with thirteen (including one planktonic species) from “offshore” habitats, leaving at least 42 species from intertidal areas. Algae in and around Keoneʻele Cove were noted to be unusually abundant and dominated by species found in association with, or tolerant of, high nutrient concentrations. Their presence was interpreted as evidence of cesspool leachate impacting the area.

Kimura (1969) assessed the distribution of algae in the littoral zone along PUHO’s shoreline between Kapuwai cove and the boundary between the ahupuaʻa of Honaunau and Keokea (cf., Figure 14). Twelve species were discussed with respect to their appearance, use by native Hawaiians, their distribution, and factors likely to control their distribution (Table 6). Observations were made primarily during the summer of 1968 and were not quantitative.

Kay et al. (1969) included PUHO in a study evaluating opihi population genetics and reproduction and growth rates at sites throughout the Hawaiian islands. PUHO data were collected from May 2004 to March 2005 at a site close to the southern boundary of the park, in habitat consisting of “low-lying cliffs and outcroppings, and boulder shore”. Three species were observed in the study – *Cellana exarata*, *C. sandwicensis*, and *C. talcosa*. *C. melanostoma* was

Table 5. Algal species recorded from Honaunau Bay and environs in March 1969. From Doty (1969).

Cyanophyta	Chrysophyta (cont.)	Rhodophyta (cont.)
Calothrix sp. *	*Cocconeis* sp.	*Champia parvula*
Lyngbya sp.	*Melosira* sp.	*Erythrotrichia* sp. *
Trichodesmium sp. **	Phaeophyta	*Galaxaura* sp.
Chlorophyta	*Chnoospora pacifica*	*Gelidiella acerosa*
Acetabularia moebii	*Colpomenia sinuosa*	*Gelidium* sp.
Boodlea sp.	*Ectocarpus breviarticulatus*	*Gelidiopsis scoparia*
Chaetomorpha antennina	*Ectocarpus* sp.	*Griffithsia* sp.
Chaetomorpha sp.	*Padina japonica*	*Hemitrema* sp.
Cladophora sp.	*Lobophore variegata*	*Herposiphonia* sp. *
Cladophoropsis adhaerens	*Sargassum echinocarpum*	*Hypnea* sp.
Dictyosphaeria cavernosa	*Sargassum polyphyllum*	*Jania* sp.
Enteromorpha spp.	*Sphacelaria tribuloides* *	*Laurencia subsimplex*
Halimeda discoidea *	*Turbinaria ornata* *	*Laurencia* spp. *
Microdictyon setchellianum	Rhodophyta	Melobesioid sp. (unidentified) *
Pseudobryopis (?) sp. *	*Acrochaetium* sp. *	*Polysiphonia* sp.
Ulva fasciata	*Ahnfeltia concinna*	*Porolithon onkodes*
Valonia aegagropila	*Alsidium* sp.	*Pterocladia capillacea*
Chrysophyta	*Centroceras clavulatum*	*Tolypiocladia glomerata* *
Amphiprora sp.	*Centroceras minutum*	*Wurdemannia miniata*
Amphora sp.	*Ceramium* sp.	

* Species noted from "offshore habitats". *Pseudobryopis* (?) (sic) was not listed in the original table in Doty (1969) but is discussed in text.
** Planktonic species noted as often distributed offshore as a dark yellow surface scum.

found to be "synonymous with *C. exarata* and *C. sandwicensis*", presumably based on genetic data, but no details are provided in the report. No population density data were collected in PUHO, but a significant number of individuals apparently were collected based on the study design (14 individuals of each species for reproductive analysis and 5-15 individuals in each of five size classes for the growth study collected every ~6 weeks). No growth rate data were obtained due to major tag retention and/or harvesting problems, but reproductive cycling was inferred from gonad development, with significant spawning in May-July 2004 and November 2004-January 2005, and possibly in September-October 2004. Reproductive and size data showed that the current minimum size for harvesting (31 mm; applicable to all *Cellana* spp.) is appropriate for *C. sanwicensis* but is too low for *C. talcosa*, which matures at roughly 35 – 40 mm, and thus probably should not be harvested until at least 40 – 45 mm to allow time for reproduction.

No quantitative data are available from the ongoing algal survey, but 2005 data include observations of one alien alga (*Acanthophora spicifera*) at two locations on tidal benches south of Puʻuhonua Point, and it seems likely that it also is present at other sites around the park (C. Squair, pers. comm. 2006). While *A. spicifera* does not appear to be a significant threat at this time, it can be an aggressive competitor and thus may represent a future threat. An interim report from this project should be available in July 2006 (C. Squair, pers. comm. 2006).

Threatened green sea turtles (*Chelonia mydas*) often can be found grazing algae on shallow subtidal benches around Honaunau Bay, and frequently can be found basking or resting on the rocky shelf off of Hale o Keawe (Doty 1969, D. Hoover pers. obs. 2004), but no quantitative data are available on turtle activity in intertidal areas. Comprehensive intertidal habitat, resources, and threats characterization, and inventory and mapping of intertidal geomorphology and biota by the NPS Pacific Islands Coral Reef Program (PICRP) is scheduled for PUHO and other National Parks in Hawaiʻi in 2007 (Larry Basch pers. comm. 2005).

Table 6. Algae observed in PUHO's littoral zone by Kimura (1969).

Species	Hawaiian name	Occurrence/notes
Asparagopsis sanfordiana	Limu kohu, limu koko	Only in rocky areas exposed to heavy surf. Most abundant at Lae limu koko (point just SW of Keawewai), sparse along coast south towards Keokea
Dictyota spp.	Alani	Grows in clusters in exposed areas, accessible at low-tide
Ahnfeltia concinna	Limu ʻakiʻaki	Abundant along high tide line in relatively protected areas, crevices in more exposed areas. Dominates where present. Preferred food of turtles
Gymogongrus spp.	Koʻele, Koʻeleʻele	Along edges of exposed shelves or in pockets/cracks in high energy areas at low-tide depths. Dominates where present
Sargassum spp.	Limu kala	Grows profusely in areas exposed to surf/tides. Dominates where present
?	Hinakea	On exposed shelves away from other algae. May actually be two closely associated species
Ulva spp.	Limu palahalaha, Pakaiea	Mostly in protected habitats, often associated with inputs of nutrient-rich groundwater. Dominates where present. Favorite food of turtles.
Enteromorpha spp.	Limuʻeleʻele	Only in protected areas of Kapuwai cove where salinity reduced by brackish groundwater. Thrives in "sandy-rocky" areas along beach
Laurencia spp.	Lipeʻepeʻe	On shelves exposed to surf and tidal action.
Valonia utricularis	Lipuʻupuʻu, limu opihi	On shelves exposed to surf and tidal action, often along top edge of vertical surface. Occasionally on shells of large opihi.
Dictyosphaeria versluysii	Limu paheʻe	In protected areas during winter (November – February). Exposed at low tide, grows densely on flat surfaces similar to those favored by *Ulva* spp.
Codium edule	Wawaeʻiola, ʻaʻala ʻula	In protected areas, only exposed at very low tides. Dominates where present

B.3.g. Coastal Waters

B.3.g.i. Planktonic and pelagic biological resources

Coastal waters off of PUHO provide habitat for phytoplankton and a wide variety of planktonic and pelagic animals. Plankton studies are relatively uncommon in Hawaiian coastal waters, so it is not surprising that few plankton data are available. Some data are available from Doty (1969), which includes data from plankton tows at three sites in Honaunau Bay and at one site in Alahaka Bay. Pelagic resources around the park have received more attention – Kay (1986) included some observations of fish in Honaunau Bay from surveys performed in 1957, Doty (1969) conducted fish surveys along two transects in Honaunau Bay and also discussed sharks, porpoises, turtles, and whales in the area, Kimmerer and Durbin (1975) surveyed fish populations along 36 transects in Honaunau Bay, (Ludwig et al. 1980) surveyed fish populations on two transects in Honaunau Bay and one in Alahaka Bay, Madden (1980) performed a reconnaisance survey of fish abundance along one transect in Honaunau Bay, and Ostman-Lind et al. (2004) discussed dolphin distributions along the Kona coast, including Honaunau Bay. In addition, in 2005 waters off of PUHO were surveyed for marine vertebrates (primarily reef fish) with stratification by habitat type and depth using the NPS Inventory and Monitoring criterion of 90% species identification (Beets and Friedlander in prep; Larry Basch pers. comm. 2005). These studies provide insight into the population status and taxonomic composition primarily of fishes over time, although methodological differences between earlier and more recent studies preclude complete quantitative analysis of trends.

- *Plankton*

No detailed studies have been performed on phytoplankton in waters around PUHO. Doty (1969) did note that *Trichodesmium* sp., a planktonic alga, frequently was observed forming “a dark yellow surface scum” offshore of the park.

Doty (1969) performed zooplankton tows in Honaunau and Alahaka Bays (Figure 16). Tows were conducted using a 45-cm (18”) diameter conical net with a 300 micron mesh size. Tows were performed at a depth of approximately one meter (3’) by towing the net in a figure-eight pattern at a speed of approximately 5 mph (8 kph). Data are reported as the volume and wet weight of plankton per cubic meter sampled (Table 7). One tow at Station 19 was conducted on October 31, 1968, with an additional four tows at this station and single tows at Stations 20 – 22 conducted between March 3rd and March 12th, 1969. Doty (1969) also conducted tows at 7 sites in the Kealakekua bay area north of the park and at one site midway between Kealakekua Bay and Honaunau Bay, and concluded that Station 19 at the head of Honaunau Bay was the most productive site sampled, with an average of 187 mg/m^3, compared to 146 mg/m^3 at the next most productive site, which was in Kealakekua Bay. Samples from more exposed sites north of

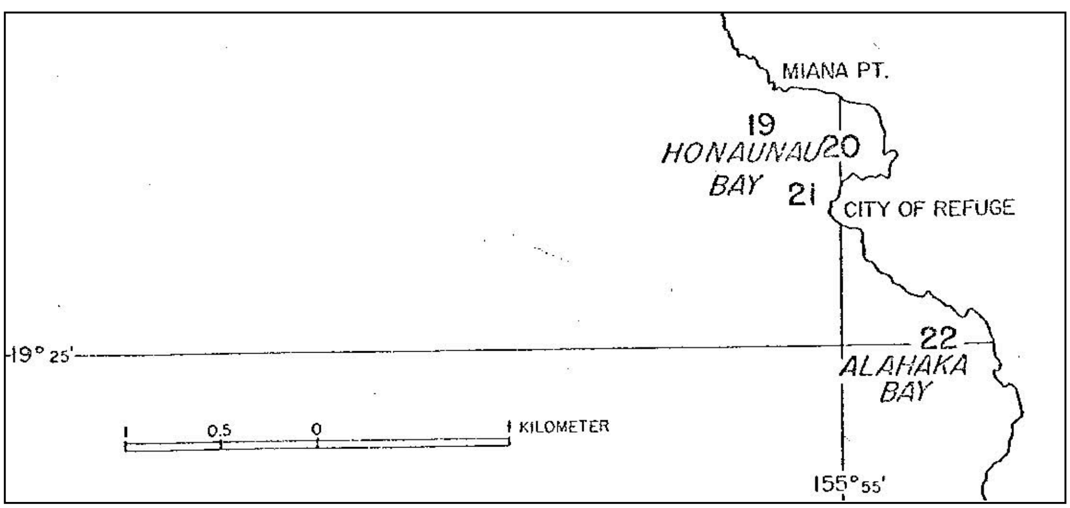

Figure 16. Sites of zooplankton tows conducted ~1969 in the PUHO area. From Doty (1969).

Table 7. Zooplankton (> 300 μm) volume and wet weight in surface (1 m depth) tows around PUHO. See Figure 16 for station locations. From Doty (1969).

		Tide		Volume	Zooplankton	
Station	Date/time	Height (feet)	State	sampled (m^3)	Volume (ml/m^3)	Wet weight (mg/m^3)
19a	10/31/68 10:00	1.1	rising	41.4	0.23	81
19b	3/6/69 13:05	0.1	rising	17.1	0.74	127
19c	3/11/69 9:45	0.4	rising	18.9	0.76	133
19d	3/11/69 14:40	0.1	ebb	21.5	2.37	403
19e	3/12/69 14:05	0.3	falling	16.6	1.2	192
19-mean		**0.4**		**23.1**	**1.06**	**187**
20	**3/6/69 8:15**	**0.7**	**n/a**	**16.3**	**0.9**	**150**
21	**3/6/69 10:15**	**0.0**	**falling**	**15.5**	**0.64**	**110**
22	**3/11/69 13:10**	**0.2**	**falling**	**23.9**	**0.88**	**141**

Honaunau Bay contained considerably less zooplankton, with offshore surface water at the mouth of Kealakekua Bay containing only 2 mg/m^3, and the open coastal site midway between the bays having only 10 mg/m^3.

- Pelagic fauna

Kay's 1957 survey focused primarily on intertidal areas and did not include extensive assessments of subtidal areas (Figure 14, Kay 1986). However, a few observations of subtidal fauna were made from shore, and some additional fish species were noted from interviews with local fishermen and included in a species list provided with the report (Appendix B).

Doty (1969) included extensive fish data from four surveys performed by the State of Hawai'i Department of Fish and Game along two 250-yard (230 m) transects in Honaunau Bay (Figure 17). Surveys were conducted in June, August and October of 1968 and in February 1969 by recording data (species, abundance and size) on all fish within 20 feet (6 m) of the transect line. (Appendix D). Results were used to estimate fish biomass in pounds per acre. Results from the Honaunau transects were compared to results from five similar transects in Kealakekua Bay. The number of species observed at each station varied between surveys, but averages over the four surveys were similar across stations (mean 48, range 39 – 57). A total of 98 species were observed in Honaunau Bay, compared to 110 in Kealakekua Bay, with yellow tangs (*Zebrasoma flavescens*) and kole (*Ctenochaetus strigosus*) "the commonest and most numerous species in both bays'. Fish were most abundant overall along transect 7 in Honaunau Bay (average 1,833 per survey), but abundance on transect 6 (1,604/survey) and at a nearshore transect adjacent to the Captain Cook monument in Kealakekua Bay (Station 2; 1,740/survey) were only slightly lower. Biomass was greatest on transect 6, averaging 438 lb/acre, followed by transect 2 in Kealakekua Bay at 325 lb/acre. Biomass on transect 7 in Honaunau Bay averaged 289 lb/acre.

In addition to quantitative survey data, Doty (1969) also included incidental observations on sharks, porpoises, turtles, and whales in the area. Sharks were rarely seen in Honaunau Bay, but "more often frequent[ed] the exposed bays to the south, Alahaka and Kiilae, and … were also sporadically observed offshore between Honaunau Bay and Alahaka Bay" (Doty 1969). In contrast, the shark population in Kealakekua Bay was judged to be "moderate", based on a catch of six sharks on a line stretched overnight across the mouth of the bay. Porpoises (*Stenella* sp.)

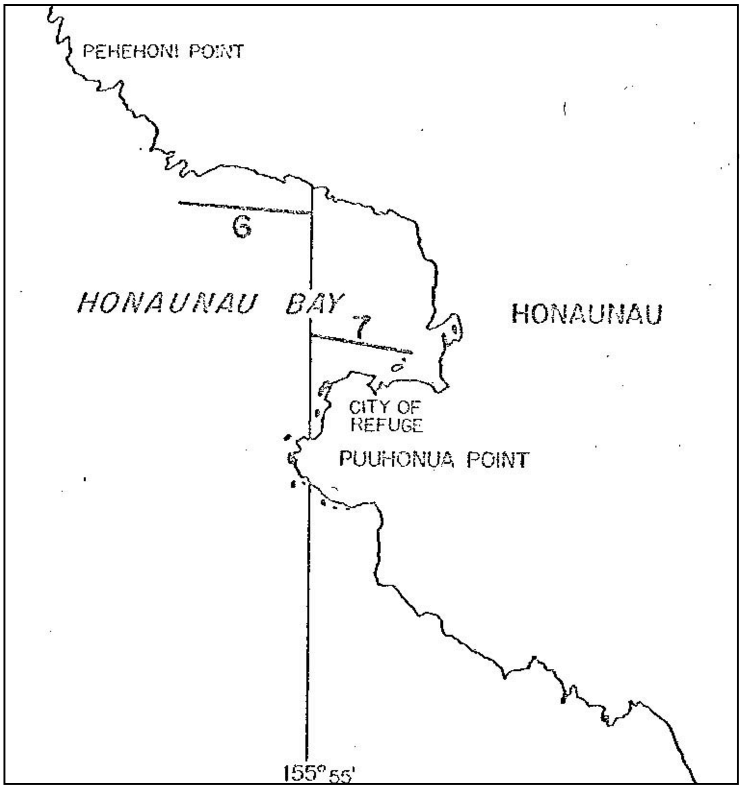

Figure 17. Transects used for fish surveys in Honaunau Bay in 1968 – 1969. From Doty (1969).

were observed on one occasion in Honaunau Bay, and area residents commented that the school, which normally resided at Kealakekua Bay, commonly visited the Bay in the early morning. Turtles were observed during fish surveys by divers "approximately every third day, singly and in pairs". Turtles also frequently were seen during the afternoon "eating seaweed (in particular *Ulva fasciata*) on the shallow reef flat. Residents commented that groups of ten to fifteen turtles often were present during high seas. Whales were not noted from inside Honaunau Bay, but on one occasion "a small school of pilot whales was observed … swimming north 500 m off Honaunau Bay. Fishermen claim they are common in winter with the offshore current southerly and strong, leaving in spring as the current slows and turns northwest".

Kimmerer and Durbin (1975) performed fish surveys in Honaunau Bay for a study evaluating the bay's suitability for protection as a marine conservation district. They surveyed 36 100 m (110 yard) transects in the bay (counting fish observed within 2.5 m/8' on each side) and grouped results by three major habitat zones: inshore (6 transects), mid-reef (26 transects), and outer reef (4 transects) (Figure 18). Results were reported as abundance (#/1000 m^2), biomass (kg/1000 m^2), species diversity (Shannon-Weaver index), and species/transect and were compared to similar results obtained from eight other sites, including Kealakekua Bay (Table 8). A total of 108 species were observed on transects, with 73 on inshore transects, 92 on mid-reef transects, and 56 on outer reef transects, with an additional 16 noted off transects and thus not included in quantitative surveys (Appendix E). Similar results were found at Kealakekua Bay, with 104 species total and 57, 93, and 70 species on inshore, mid-reef, and outer reef transects respectively. The number of species in Honaunau Bay was higher than observed previously by

Doty (1969) (108 versus 98), but significantly more unreplicated area was surveyed by the later study (36,000 vs 5,500 m^2). Abundance also appears to be higher in the later study (1,280 vs 616/1000 m^2), while biomass appears lower (25.3 vs 40.8 kg/1000 m^2). The ten most abundant species on inshore, mid-reef, and outer reef habitats are listed in Table 9.

Ludwig et al. (1980) censused reef fish on transects in three different habitat "zones" around PUHO from 1975 – 1978. Censuses were performed during the summer in an inshore "boulder zone" in Alahaka Bay, and in "coral-rich" and "drop-off" zones in Honaunau Bay (Figure 19).

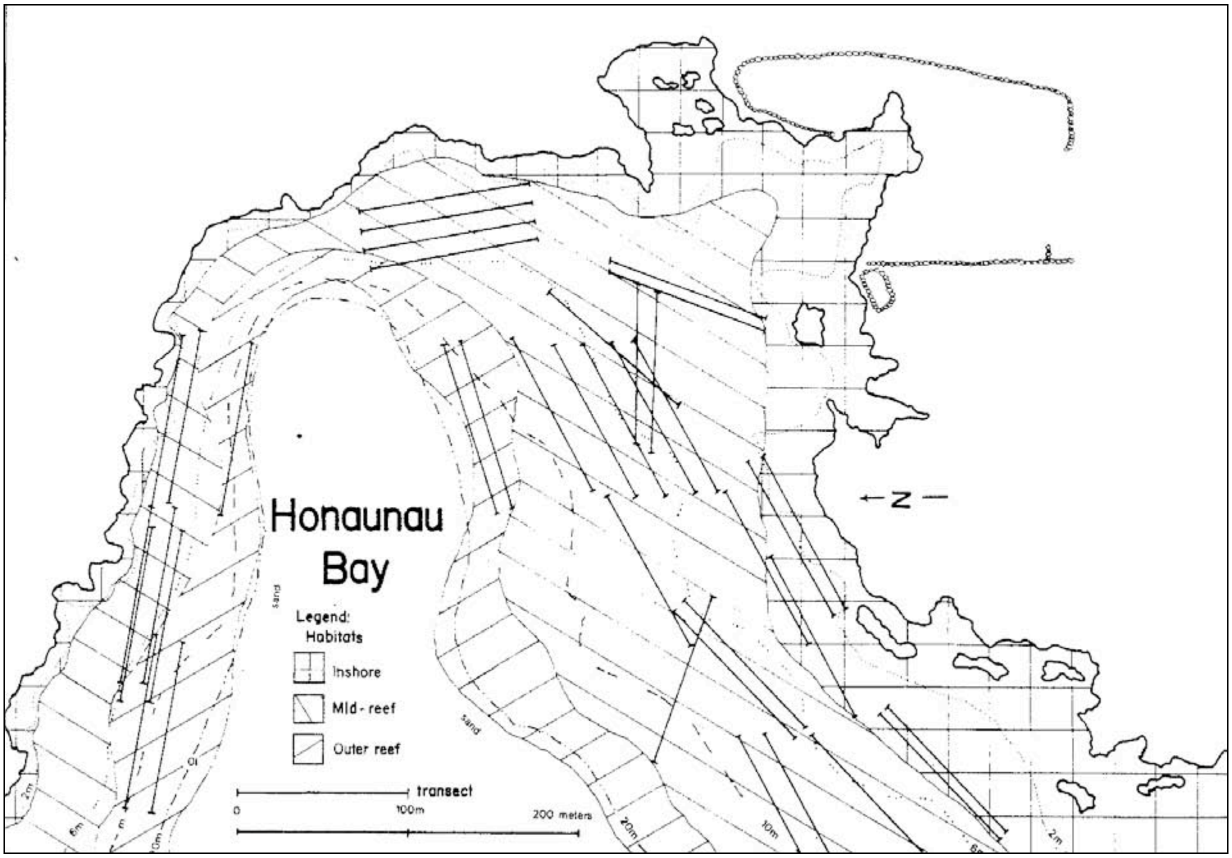

Figure 18. Transect locations in Honaunau Bay used for ~1975 surveys. From Kimmerer and Durbin (1975).

Table 8. Results from fish surveys along transects in Honaunau Bay conducted in ~1974 - 1975. Results from surveys in Kealakekua Bay also are shown for comparison. IN = inshore, MR = mid-reef, OR = outer reef. Data from Kimmerer and Durbin (1975).

	Honaunau			Kealakekua		
Parameter	IN	MR	OR	IN	MR	OR
Number of transects	6	26	4	2	26	10
Depth range (m)	1.0 – 7.0	3.0 – 16.0	12.0 – 20.0	3.0 – 5.0	3.0 – 13.0	12.0 – 25.0
Abundance (#/1000 m^2)	1098	1312	1379	987	1163	1125
Biomass (kg/1000 m^2)	25.6	25.2	25.9	24.9	25.1	30.8
Diversity index	2.53	2.36	2.22	2.56	2.34	2.40
Species (#/transect)	37	38	35	40	34	35

Three to five surveys were conducted on each transect in each year. Despite the smaller area of unreplicated habitat surveyed compared to Doty (1969) and Kimmerer and Durbin (1975) (1,500 m^2 versus 5,500 and 18,000 m^2 respectively), significantly more species were identified, with 126 observed along transects and 37 more noted during reconnaisance dives in the area (Appendix F). Species abundance and diversity from transect surveys are summarized in Table 10 with the ten dominant fish species on each transect listed in Table 11. Species commonly found on transects generally were similar to common species observed in earlier surveys (Appendices D and E, Table 9), but average abundances on the three transects varied from 1,300 to 1,700/1000 m^2, higher than previous studies in 1975 (1,280/1000 m^2; Kimmerer and Durbin 1975) and in 1968 – 1969 (616/1000 m^2; Doty 1969), suggesting that "Honaunau Bay appear[ed] to be recovering from previously documented human exploitation". Consistent with the greater number of species observed, diversity indices at the three transects were slightly higher (~2.7 – 2.85) than indices calculated by Kimmerer and Durbin (1975) for their inshore, mid-reef, and outer reef zones (~2.2 – 2.5). The study also documented some temporal variability in community structure and abundance: "changes in diversity and number of species showed generally parallel trends with a gradual annual increase in each habitat and a slight decrease in 1978. The total number of fish observed on each transect followed similar trends". The study identified three new species, one species not previously known from Hawai‘i, and observed "several very rare species" in Honaunau Bay.

Table 9. Relative abundance (% of total number) of the ten most common fish species found on inshore, mid-reef, and outer-reef transects in Honaunau Bay in ~1975. Common or Hawaiian names are used where possible. From Kimmerer and Durbin (1975).

Inshore Zone		Mid-reef		Outer Reef	
Species	%	Species	%	Species	%
Lavender tang	19.3	Kole	25.2	*Chromis agilis*	30.7
Kole	16.1	*Chromis agilis*	19.9	Kole	19.3
Yellow tang	11.7	Yellow tang	18.0	Yellow tang	18.1
Hinalea lauwi1i	9.9	Pebbled butterfly	6.6	*Acanthurus thompsoni*	5.6
Jenkins' damsel	6.6	Hinalea lauwili	3.3	Pebbled butterfly	4.1
‘Omaka	5.0	Blue damsel	2.3	Black damsel	3.2
Pebbled butterfly	3.5	Potter's angel	2.3	Hinalea lauwili	2.6
Chromis vanderbilti	*3.2*	*Chromis hanui*	2.2	Kala	2.4
Achilles tang	2.6	Lavender tang	1.8	*Scarus sordidus*	1.7
Plectroglyphidodon imparipennis	2.6	Black damsel	1.7	Potter's angel	1.5

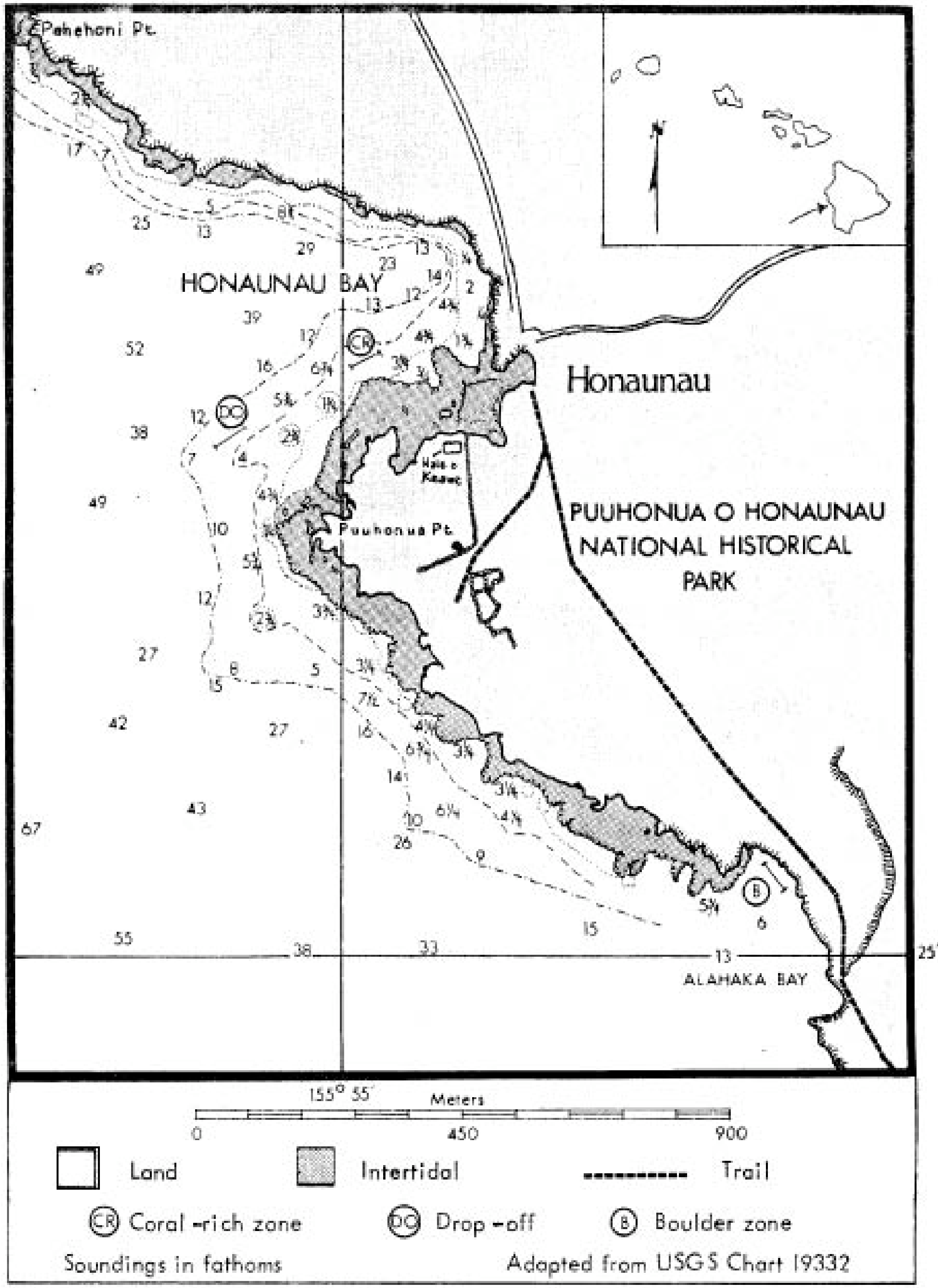

Figure 19. Transects (CR, DO, B) used for fish censuses off of PUHO from 1974 – 1978. From Ludwig et al. (1980).

Table 10. Number of fish species and fish abundance observed along transects off PUHO in the summers of 1975 – 1978. Yearly values are averages of 3 – 5 surveys (n) per year. HI = Shannon-Weiner (sic) diversity index, HWmax = Maximum diversity index, J = Equitability, s^2 = Variance. Modified from Ludwig et al. 1980. See Figure 19 for transect locations.

	n	Species (#/transect)	Abundance (#/transect)	HI	HWmax	J	s^2
Boulder							
1975	4	47	612.2	2.2946	3.8502	0.5960	0.0033
1976	5	59	664.7	2.4375	4.0775	0.5978	0.0029
1977	3	56	1024.4	2.9294	4.0254	0.7277	0.0015
1978	3	53	812.1	5.8294	3.9703	0.7127	0.0021
All Years	15	88	754.12	2.6958	4.4773	0.6021	0.0029
Average		54					
Drop-off							
1975	4	49	500.4	2.5433	3.8918	0.6535	0.0035
1976	5	68	853.8	2.5742	4.2195	0.6101	0.0025
1977	3	65	1164.5	2.9864	4.1744	0.7154	0.0014
1978	3	59	1048.9	2.9317	4.0775	0.7190	0.0015
A11 Years	15	93	860.7	2.8328	4.5326	0.6250	0.0024
Average		60.5					
Coral-rich							
1975	4	53	391.9	2.6840	3.9763	0.6760	0.0041
1976	5	65	580.7	2.7208	4.1744	0.6518	0.0031
1977	3	66	968.4	2.8245	4.1897	0.6742	0,0017
1978	3	57	868.3	2.7287	4.0431	0.6749	0.0017
All Years	15	95	665.2	2.8503	4.5539	0.6259	0.0027
Average		60.4					

Table 11. The ten dominant fish species on transects surveyed around PUHO from 1975 – 1978. Yearly values are averages of 3 – 5 surveys per site per year. R = rank (1 = most abundant). AI = percent of total represented by listed species. Modified from Ludwig et al. 1980.

	1975		**1976**		**1977**		**1978**		**Overall**	
	R	**AI**	**R**	**AI**	**R**	**AI**	**R**	**AI**	**R**	**AI**
Boulder zone										
Ctenochaetus strigosus	1	30.9	1	28.8	1	21.7	1	19.9	1	24.8
Acanthurus nigrofuscus	2	23.0	2	15.7	2	11.6	2	16.5	2	16.0
Zebrasoma flavescens	3	10.1	3	11.7	3	10.6	3	12.2	3	10.9
Thalassoma duperrey	5	6.1	4	9.1	4	9.4	5	6.2	4	7.6
Chaetodon mu1ticinctus	7	2.5	6	6.0	5	9.1	4	6.9	5	6.0
Paracirrhites arcatus	4	6.7	5	6.7	6	6.0	6	5.1	6	6.0
Eupomacentrus fasciolatus	6	4.2	7	3.7	7	5.7	7	4.5	7	4.4
Plectroglyphidodon johnstonianus	10	1.4	8	3.3	8	4.6	10	2.0	8	2.3
Stethojulis balteata			9	1.6	9	3.0	8	2.3	9	1.7
Halichoeres ornatissimus									10	1.6
Acanthurus leucopareius	8	2.0								
A. achilles	9	1.5								
Canthigaster jactator			10	1.3			9	2.2		
Acanthurus nigroris					10	2.9				
Total		88.4		87.9		84.6		77.8		81.3
Drop-off zone										
Ctenochaetus strigosus	1	25.0	2	21.6	1	17.5	2	15.7	1	18.9
Chromis vanderbilti	2	18.9	1	26.9	3	9.9	1	15.9	2	17.7
Zebrasoma flavescens	4	10.0	4	6.2	2	12.8	3	12.2	3	9.7
Acanthurus nigrofuscus	3	11.8	3	7.6	5	7.5	4	8.2	4	8.0
Thalassoma duperrey	6	6.1	7	4.2	4	8.1	5	5.9	5	5.3
Chromis agilis	5	7.0	5	5.2	8	3.7	6	5.2	6	4.9
Chaetodon mu1ticinctus	7	2.5	6	4.5	6	6.6	7	5.0	7	4.7
Chromis hanui	8	2.7	9	2.1	7	5.0	10	2.8	8	3.0
Halichoeres ornatissimus	10	2.3	10	2.0	9	2.6	8	3.0	9	2.4
Centropyge potteri	9	2.3	8	2.6	10	2.0			10	2.2
Hemitaurichthys thompsoni							9	2.8		
Total		88.6		82.9		75.7		76.7		76.8
Coral-rich zone										
Ctenochaetus strigosus	1	18.9	3	14.8	2	15.9	1	16.9	1	15.6
Zebrasoma flavescens	3	14.7	4	11.1	1	17.5	2	15.2	2	13.9
Chromis agilis	2	18.6	2	15.8	5	7.0	4	11.0	3	11.9
C. vanderbilti	10	1.7	1	16.2	3	9.6	3	12.2	4	10.4
Chaetodon mu1ticinctus	4	10.0	5	8.3	4	9.1	5	10.5	5	8.9
Thalassoma duperrey	5	5.4	6	6.1	7	5.6	7	5.1	6	5.4
Centropyge potteri	7	3.8	9	2.6	6	6.7	9	2.1	7	3.7
Acanthurus nigrofuscus					8	5.2	6	5.5	8	3.2
Chromis hanui	6	4.4	7	3.0	9	2.6	10	1.7	9	2.5
Plectroglyphidodon johnstonianus	9	2.6	8	2.9	10	2.4	8	2.5	10	2.5
Chaetodon ornatissimus	8	2.6								
Abudefduf abdominalis			10	1.9						
Total		82.7		82.7		81.6		82.7		78.0

Madden (1980) conducted a reconnaisance survey at a site near the head of Honaunau Bay that was being considered for a new small-boat launching ramp (Figure 20). Eighty- one fish species were noted in the immediate vicinity of the site at depths to 11 m (35'), but only qualitative observations were made of species diversity and abundance (Table 12). Diversity and abundance both were characterized as high, with large aggregations of surgeonfishes and wrasses in the 'surge zone' (the area from the shoreline to ~10 m/30' from shore, with depths to approximately 4.6 m/15'), and damselfishes, butterflyfishes, and surgeonfishes dominating the deeper 'coral zone' (4.6 m/15' to about 18 m/60' depth).

Dominant species noted included "the baitfish, *Spratelloides delicatulus*, the wrasse, *Thallasoma duppereyi*, and the surgeonfishes, *Acanthurus nigrofuscus*, *Zebrasoma flavescens*, and *Ctenochaetus strigosus*. *S. delicatulu*s occurs in the upper water column of the nearshore zone in large separate schools of adult, juvenile and post-larvae. The surgeonfishes, *A. nigrofuscus*, *Z. flavescens* and *C. strigosus* occur in large, mixed aggregations in the surge zone at the water's edge and the extensive coral growths covering the bottom at a depth of approximately 15 feet [4.6 m]. The wrasse, *T. duperreyi* was observed throughout the study area" (Madden 1980).

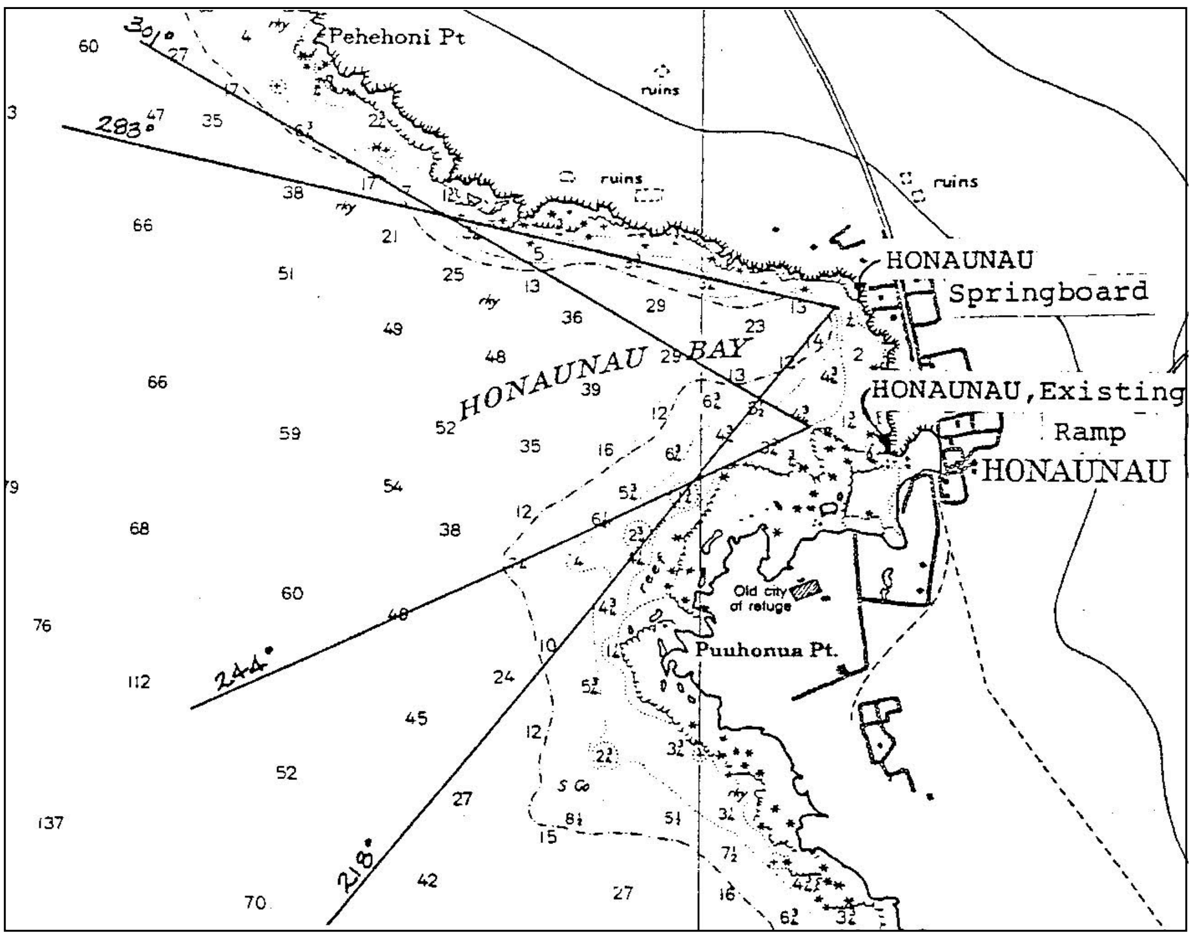

Figure 20. Location of nearshore region ("Springboard" area) of Honaunau Bay surveyed by Madden (1980). Angles show the approximate exposure of sites to swell energy (Madden 1980).

Table 12. Fish species observed near the head of Honaunau Bay by Madden (1980). Abundance codes are: 1 = dominant species; abundant, 2 = common species, not dominant; or dominant but not abundant, 3 = occasional (several individuals sighted in the transect area), and 4 = uncommon or rare (one, or at most a few, individuals sighted in an area).

Species	Abundance	Species	Abundance
Spratelloides delicatulus	1	*T. ballieui*	3
Chanos chanos	4	*T. fuscum*	2
Saurida gracilis	4	*Gomphosus varius*	2
Lycodontis meleagris	3	*Coris gaimardi*	3
Belone platyura	3	*Stethojulis balteata*	2
Fistularia commersoni	4	*Anampses cuvieri*	3
Flammeo sammara	3	*Calotomus sandwicensis*	3
Adioryx lacteoguttatus	2	*Scarus sordidus*	2
Myripristis sp.	2	*S. dubius*	3
Cephalopholis argus	4	*S. rubroviolaceus*	3
Priacanthus cruentatus	3	*S. perspicillatus*	3
Mulloidichthys flavolineatus	2	*Zanclus cornutus*	2
M. vanicolensis	3	*Acanthurus triostegus sandvicensis*	2
Parupeneus pleurostigma	3	*A. guttatus*	3
P. chryserydros	3	*A. achilles*	2
P. porphyreus	3	*A. leucopareius*	3
P. multifasciatus	2	*A. glaucopareius*	4
P. bifasciatus	3	*A. nigrofuscus*	1
Monotaxis grandoculis	4	*A. nigroris*	3
Forcipiger longirostris	3	*A. olivaceus*	3
F. flavissimus	2	*Ctenochaetus strigosus*	1
Centropyge potteri	3	*Zebrasoma flavescens*	1
Chaetodon fremblii	3	*Z. veliferum*	3
C. unimaculatus	3	*N. lituratus*	3
C. ornatissimus	2	*Exallias brevis*	2
C. quadrimaculatus	2	*Cirripectes variolosus*	3
C. multicinctus	2	*C. obscurus*	3
Paracirrhites arcatus	2	*Plagiotremus ewaensis*	3
P. forsteri	3	*Rhinecanthus rectangulus*	3
Cirrhitus pinnulatus	2	*Melichthys niger*	2
Cirrhitops fasciatus	2	*M. vidua*	3
Abudefduf abdominalis	2	*Sufflamen bursa*	3
Abudefduf sordidus	3	*Pervagor spilosoma*	3
Plectroglyphidodon imparipennis	3	*Cantherhines sandwichiensis*	4
P. johnstonianus	3	*Ostracion meleagris*	3
Stegastes fasciolatus	2	*Lactoria fornasini*	4
Labroides phthirophagus	3	*Arothron hispidus*	3
Chromis vanderbilti	2	*Canthigaster jacator*	2
C. hanui	3	*C. amboinensis*	3
C. leucurus	3	*Diodon hystrix.*	4
Thalassoma duperreyi	1		

Data are not yet available, but a 2005 survey in waters off of PUHO (Beets and Friedlander in prep.) will provide a quantitative assessment of marine vertebrates (primarily reef fish) with stratification by habitat type and depth using the NPS Inventory and Monitoring criterion of 90% species identification. These data will provide an excellent opportunity for comparison to earlier studies, and for comparison to ongoing monitoring of reef fish in other areas along the Kona coast by the West Hawaiʻi Aquarium Project (WHAP – http://www.coralreefnetwork.com/kona/).

In addition to fish, there are a number of other pelagic animals found in park waters that are of special interest. Threatened green sea turtles (*Chelonia mydas*) frequently are seen in Honaunau Bay (Doty 1969; D. Hoover pers. obs. 2004), and the endangered hawksbill turtle (*Eretmochelys imbricata*) is known infrequently from waters off the Kona coast (Beavers and Marrack in prep. 2005). Green sea turtles regularly feed in coastal waters around PUHO, and occasionally haul out on rocks and ledges around the perimeter of the bay, making them vulnerable to changes in habitat and water quality in the around the park. Sharks and manta rays occasionally are sighted in the waters around the park (Doty 1969), and spinner dolphins (*Stenella longirostris*) are thought to use Honaunau Bay as a primary resting area (Östman-Lind et al. 2004). Park waters also may be visited by endangered Hawaiian monk seals, and whales, including endangered humpback whales (*Megaptera novaeanglia*) can be found in offshore waters.

B.3.g.ii. Subtidal benthic resources

Subtidal areas around PUHO have a varied benthic geomorphology, often overlain with biogenically-structured habitats that combine to form a topographically complex range of substrates (Figures 4, 11, 12). These provide the foundation for diverse benthic communities, ecological processes, and resources. For example, corals are found throughout coastal waters, but the most extensive colonies are found along nearshore submarine cliffs (also known as the “Kona drop”) and in deeper waters offshore of the cliffs (Figures 11, 12). Shallow subtidal sands in Keoneʻele Cove appear to provide only minimal habitat for benthic organisms (Kay 1986), but infauna and meiofauna have not been characterized. There are no significant areas of muddy sediments around the park, but there are extensive areas of unconsolidated sand substrate at the base of the forereef slope in Honaunau Bay and offshore of Alahaka and Kiʻilae Bays (Figures 11, 12). Benthic resources around PUHO have been the subject of a number of surveys, often in association with the surveys of fish and other biota discussed above. However, most of the work has focused on distribution and abundance of corals and urchins, with only a few observations on benthic algae and crustaceans. Recent work has focused on using remote sensing data (aerial photographs and satellite images) to characterize the distribution of habitat types, particularly coral communities.

Kay (1986) included some description of benthic resources in Honaunau Bay from survey work conducted in 1957. The survey was intended to provide only “a generalized picture of the marine biota of the Honaunau Bay region” and was conducted primarily from shore, but in a discussion of the “shallow waters of the bay”, she observed that “at low tide the depth of shallow regions within 100 feet [30 m] of shore is less than 3 ft [1 m]. The rocks are strewn with echinoderms; particularly noticeable are the bright-red, flat-spined *Heterocentrotus mammillatus*, which may be 6 in. [15 cm] in diameter, and the black, long-spined *Centrechinus paucispinus*. The debris-carrying *Tripneustes* also occurs here. The holothurians, *Holothuria atra* and *Actinopyga mauritania* are also numerous. In the deeper waters (5-7 ft [~2 m]), large heads of coral are present: the white *Pocillopora meandrina* var. *nobilis*, and large yellow and purple heads of *Porites* spp.” Several species of mollusks, two ophiuroids, and two additional species of sea urchin also were listed under the "subtidal" heading in the species list included with the report (Appendix B).

The abundance and distribution of sea urchins were surveyed in Honaunau Bay in 1968 (Ebert 1971) along three transects "just north of the canoe landing at Honaunau village". Transects started "just shoreward of the dropoff" and ran perpendicular to shore. Substrate primarily was living coral, and "consisted of very large coral mounds, separated by coral-filled valleys", resulting in significant vertical relief. Depths varied from 10 to 35 feet (3 to 10 m). Observations were made using a plotless point-quarter method and separated into two groups based on spatial distributions, one with a mean density of 2.14/m^2, and a second of 1.08/m^2. *Heterocentrotus mammillatus* was by far the most abundant species in both groups, making up 98% of total numbers in the first group and 92% in the second. The remaining observations all were of *Echinothrix* spp. (*E. calamaris* and *E. diadema*, with data from both species pooled due to uncertainty in species identification). Observations also were made using quadrats along a transect at a site "1 mile south of Honaunau", from 20 to 60 feet (6 – 18 m) depth on lava substrate. Urchin densities at this site were not reported but the population was reproted to consist of *H. mammillatus* (45% of total numbers), *Tripneustes gratilla* (30%), *Echinometra* sp. (20%), and *Eucidaris metularia* (5%), and the urchin community was observed to be less abundant but more diverse than at Honaunau Bay. *Echinothrix* sp. was not observed at this site.

Doty (1969) performed extensive assessments of coral and echinoderm distributions in subtidal habitats in Honaunau Bay. Some observations also were made on algae, mollusks, and crustaceans, but less work was performed on these groups because of their relatively "inconspicuous role" in the ecosystem, which he ascribed to their preference for "high inorganic fertilizer … and detritus [especially bivalve mollusks]… Emphasis was increased accordingly on the showpieces of Honaunau Bay, the corals, … gastropod mollusks and echinoderms". The overall distribution of corals in Honaunau Bay was portrayed graphically as a band extending from just offshore to the sand bed at the bottom of the Bay (Figure 11).

Coral and urchin surveys were performed along four transects in Honaunau Bay and one in Alahaka Bay (Figure 21). Only seven coral species were observed along transects: *Porites compressa*, *P. pukoensis*, *Pavona varians*, *Pocillopora meandrina*, *Montipora* spp., *Leptastrea purpurea*, and *Cyphastrea ocellina*. Observations of *P. pukoensis* probably actually were *P. lobata*, as later surveys did not find *P. pukoensis* (a rare species in Hawai'i) but did note *P. lobata* in abundances similar to those observed by Doty (1969) for *P. pukoensis*. Species also observed but not counted on transects included *Fungia scutaria* (near the shallow end of Transect 1) and *Sarcothelia edmondsoni* and *Polythoa* sp. ("both observed at a depth of less than one fathom [6'/2 m] in contaminated Keone-eli cove and elsewhere"). They also noted five species that were "found in varying abundances at nearby areas along the Kona coast" but were not found on their survey: *Pocillopora damicornis*, *Psammocora stellata*, *Leptoseris hawaiiensis*, *Pavona explanata*, and *P. minuta*. Diversity overall was characterized as low, with diversity indices (cf., Shannon and Weaver 1949) of 0.846 for Honaunau Bay and 0.876 for Alahaka Bay. Total coral cover was significantly higher on transects in Honaunau Bay (68%) than on Transect 5 in Alahaka Bay (34%) (Table 13).

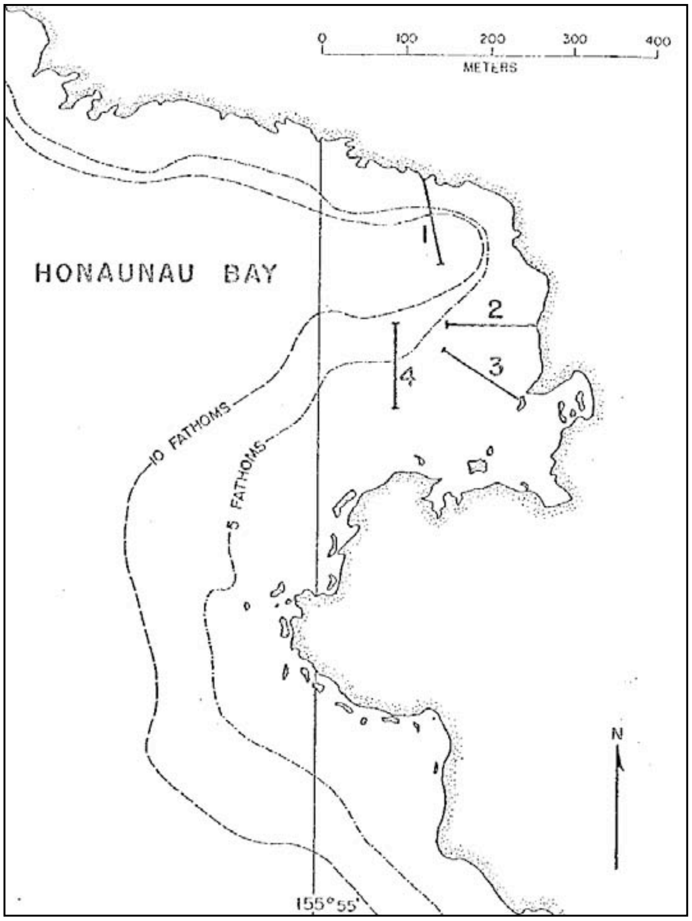

Figure 21. Underwater transects used for 1969 coral and urchin surveys. Transect 5 was located in Alahaka Bay, just south of the area in the map, starting "several meters in from the northwest extremity of [the] bay", and running along a heading of 153° magnetic. From Doty (1969).

Distributions of coral species along each transect showed that there was significant onshore-offshore and depth zonation (Figure 22). Two species dominated areal cover: *Porites pukoensis* (probably *P. lobata*) covered 35% of the substrate in Honaunau Bay and 19% in Alahaka Bay, while *P. compressa* was only slightly less widespread, covering 28% and 13%, respectively (Table 13). These two species combined were responsible for greater than 90% of total coral cover. Most of the variability in total cover on the four transects in Honaunau Bay was due to variations in *P. compressa*, suggesting that *P. compressa* was "sensitive to local variations in ecological conditions" compared to other species, particularly *P. pukoensis* (probably *P. lobata*). The relative absence of *P. compressa* in shallow regions of Transect 3, off of Keone'ele Cove, compared to a comparable portion of Transect 2, was interpreted as evidence of the effect of pollution (from cesspools inland of the cove) on *P. compressa* survival. Depth variations in relative abundance showed that *P. pukoensis* (probably *P. lobata*) was relatively more abundant in shallow waters (~10 – 25 feet/3 – 8 m) than in deeper waters, while *P. compressa* was more abundant in deeper waters (~25 – 45 feet/8 – 14 m; Figure 23). Total coral cover also varied significantly with depth on all transects, with maximum cover observed at depths between about 15 and 30 feet (5 – 9 m) (Figure 24).

Table 13. Coral cover on transects in Honaunau and Alahaka bays. From Doty (1969).

	Honaunau Bay (4 transect average)		Alahaka Bay (1 transect)	
Species	% cover	% total coral cover	% cover	% total coral cover
Porites pukoensis *	34.64	51.15	18.54	54.72
Porites compressa	27.54	40.66	12.90	38.07
Pavona varians	3.60	5.31	--	--
Leptastrea purpurea	0.68	1.00	--	--
Pocillopora meandrina	0.50	0.73	1. 61	4.75
Montipora spp.	0.50	0.73	0.80	2.36
Cyphastrea ocellina	< 0.50	<0.50	--	--
Total	67.5+	99.6+	33.8	99.9

* probably *P. lobata*

Urchin surveys identified seven common subtidal species: *Heterocentrotus mammillatus*, *Echinometra mathaei*, *E. oblonga*, *Echinothrix diadema*, *E. calamaris*, *Tripneustes gratilla*, and *Colobocentrotus atratus*, with *C. atratus* found only in the surf zone. Three other species also were observed but only rarely: *Echinostrephus aciculatus*, *Eucidaris metularia*, and *Diadema paucispinum*. *E. mathaei* and *E. oblonga* were most abundant at depths less than 15 feet (5 m), while *H. mammillatus* was the most abundant species from 20 to 45 feet (6 – 14 m) depth (Figure 25). Depth distributions of these three species were relatively similar across transects, with Transects 2 and 3 having somewhat greater *E mathaei* abundances in shallow regions (5 – 7 feet/1.5 – 2.1 m) than the other transects (Figure 26a), and Transect 3 exhibiting a peak in *H. mammillatus* abundance at 18 –21 feet (5.5 – 6.4 m) depth (Figure 26b).

Subtidal algae were observed only rarely by Doty (1969), as “the great majority of benthic species [were] restricted to the shoreline”. He provided a general description of the occurrence and distribution of some algae in “offshore habitats”:

> “The dominant alga in the Honaunau environs in terms of area coverage is a melobesioid encrusting sheltered surfaces of finger coral (*Porites compressa*). The second dominant is the red alga *Tolypiocladia glomerata*. It also grows in finger coral interstices and is exceedingly abundant on all the steeper slopes of the bay from three to at least 15 fathoms depth. However, this species also is found in trace quantities along the entire shoreline, in both exposed and protected areas.
>
> *Halimeda discoidea* and *Turbinaria ornata* were found in interstices of castle coral (*Porites pukoensis*), the latter in more exposed areas such as along the shoreline north and south of Honaunau Bay.
>
> Algal turfs and encrustments occur commonly on boulders and on dead coral, and in more exposed regions may contain rich floral aggregations of green, red, brown and blue-green algae. For instance, a one-half cm high brownish-colored mat on boulders near Keomo Point consisted primarily of *Laurencia* sp., with varying amounts of the genera *Herposiphonia*, *Erythrotrichia*, *Acrochaetium*, *Pseudobryopis* (sic), *Sphacelaria* and *Calothrix* represented.”

Doty’s (1969) map of benthic habitats in Honaunau Bay also appears to show benthic algae in nearshore areas off of Kapuwai and Keone‘ele Coves (Figure 11).

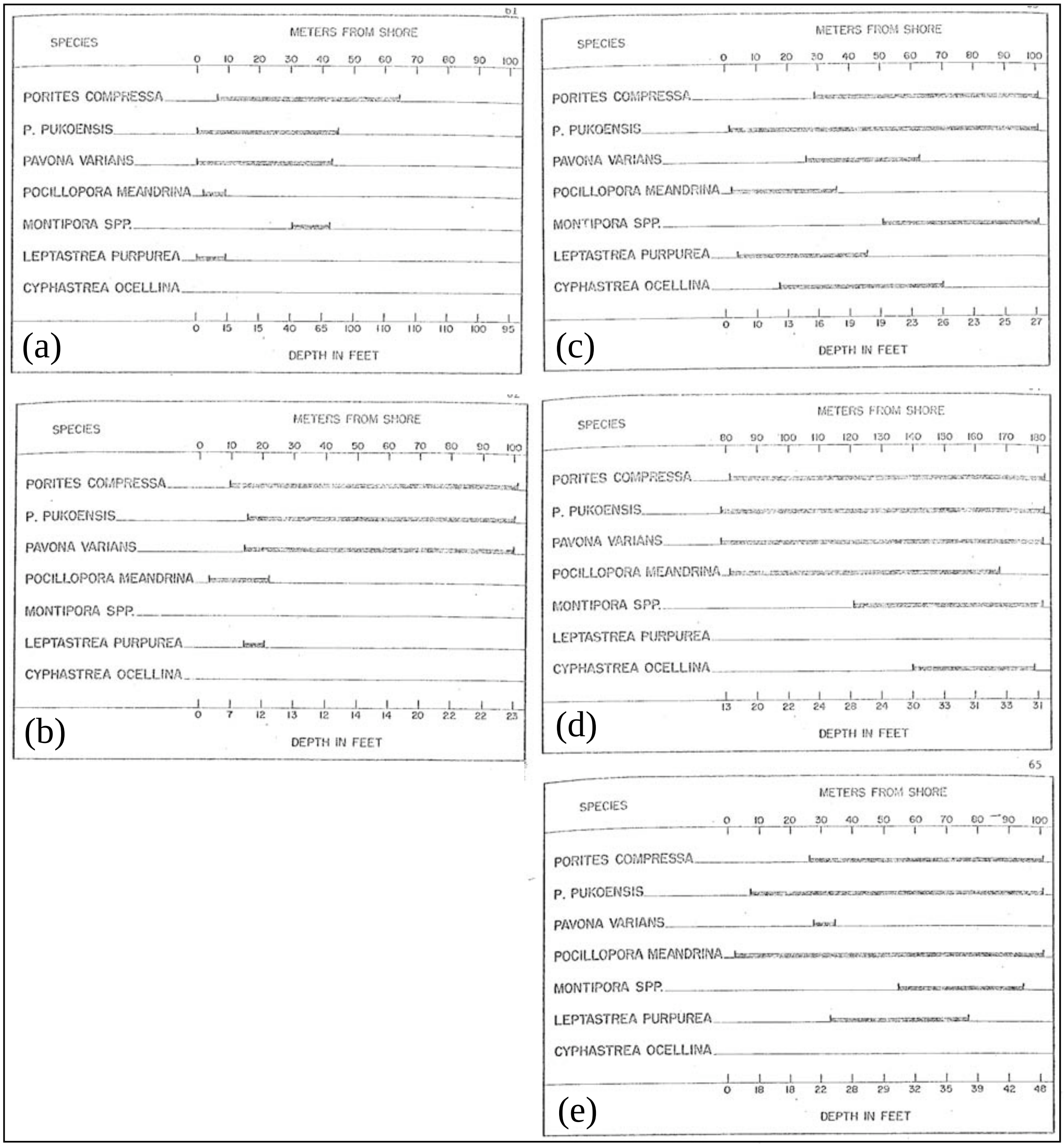

Figure 22. Coral distribution along transects in Honaunau Bay (a – d) and in Alahaka Bay (e) in 1968 – 1969. Note differences in depth scales on bottom axes. From Doty (1969).

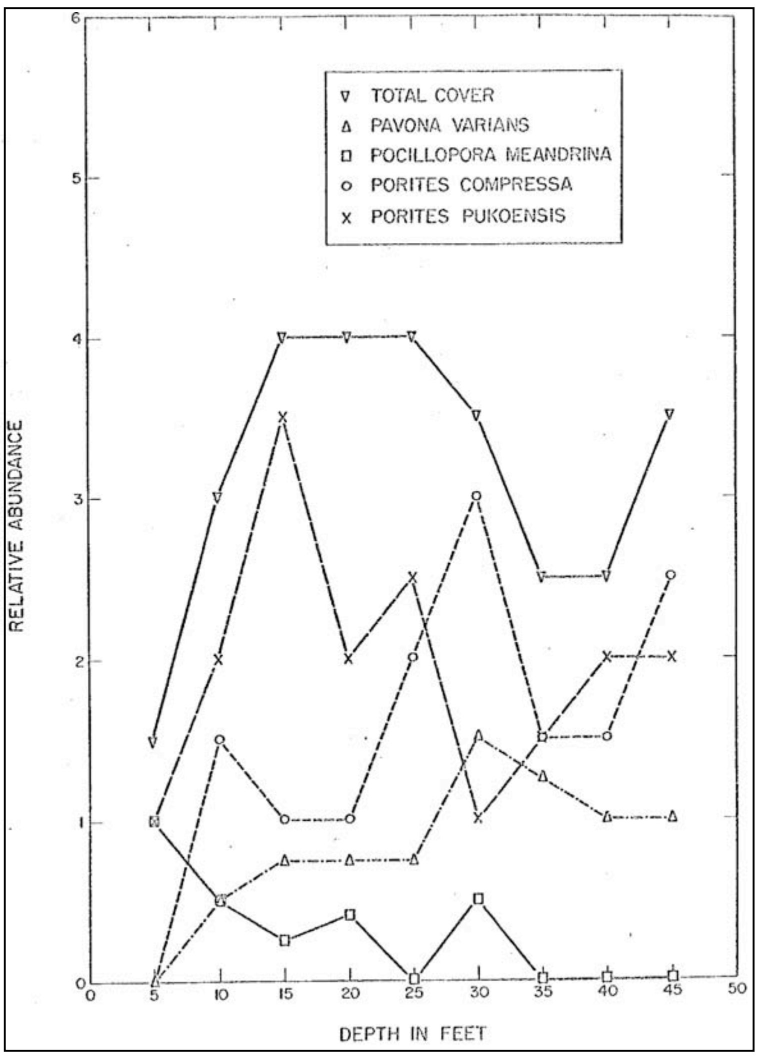

Figure 23. Variations in total coral cover and cover by major species with depth along transects in Honaunau Bay and Alahaka Bay. From Doty (1969).

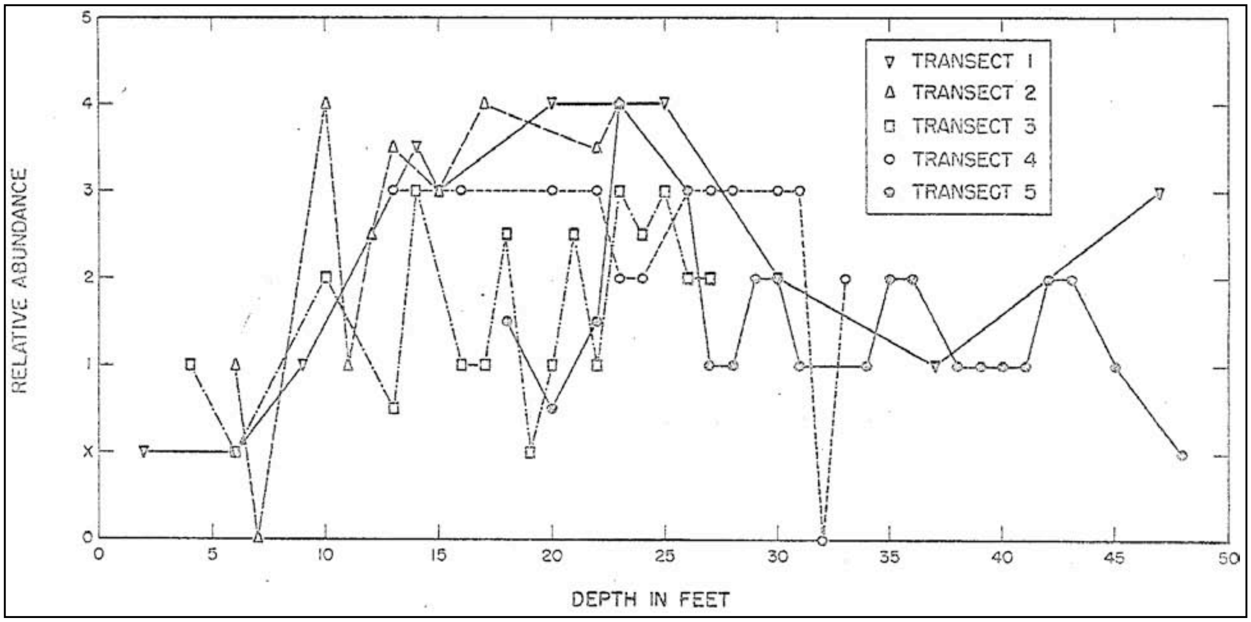

Figure 24. Variations in total coral cover with depth along transects in Honaunau Bay and Alahaka Bay. Relative abundance scale (y-axis) is based on the presence or absence of coral under the corners of and within the quadrat surveyed: "X" indicates coral was absent at corners but present within the quadrat, "4" indicates presence at all four corners. From Doty (1969).

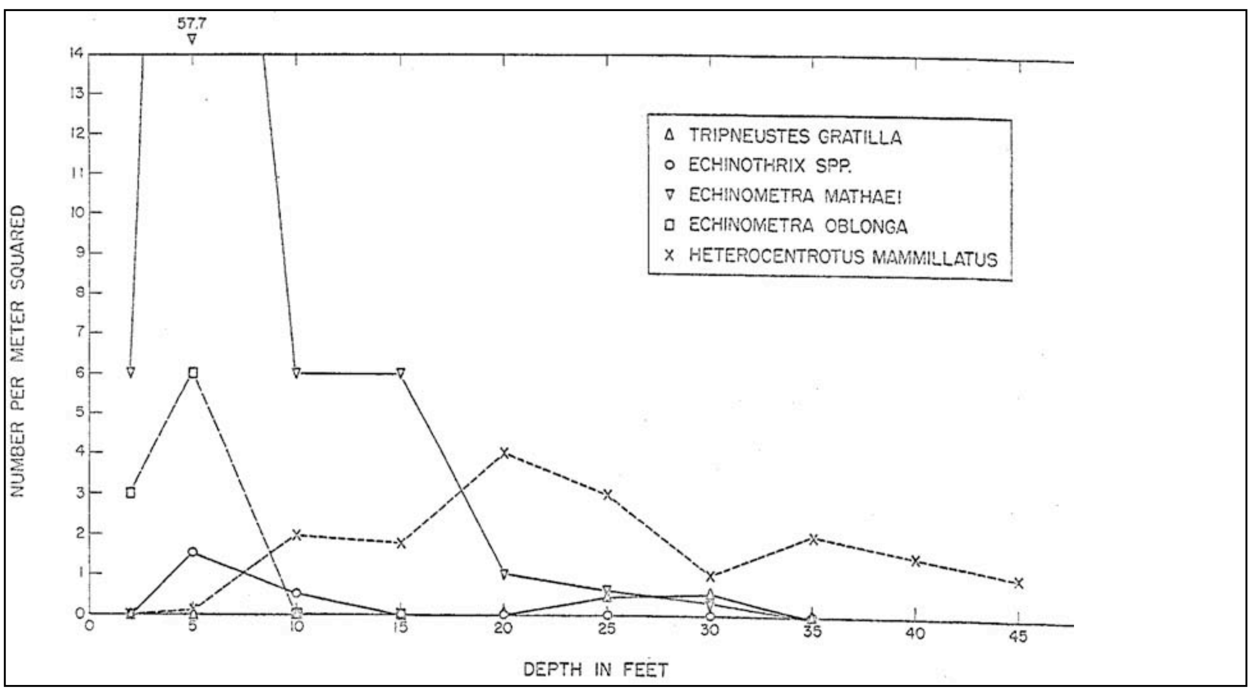

Figure 25. Variations in urchin density with depth for the five dominant subtidal species on transects in Honaunau Bay. Data for Transect 5 in Alahaka Bay are not included but "populations did not differ significantly from Honaunau Bay". From Doty (1969).

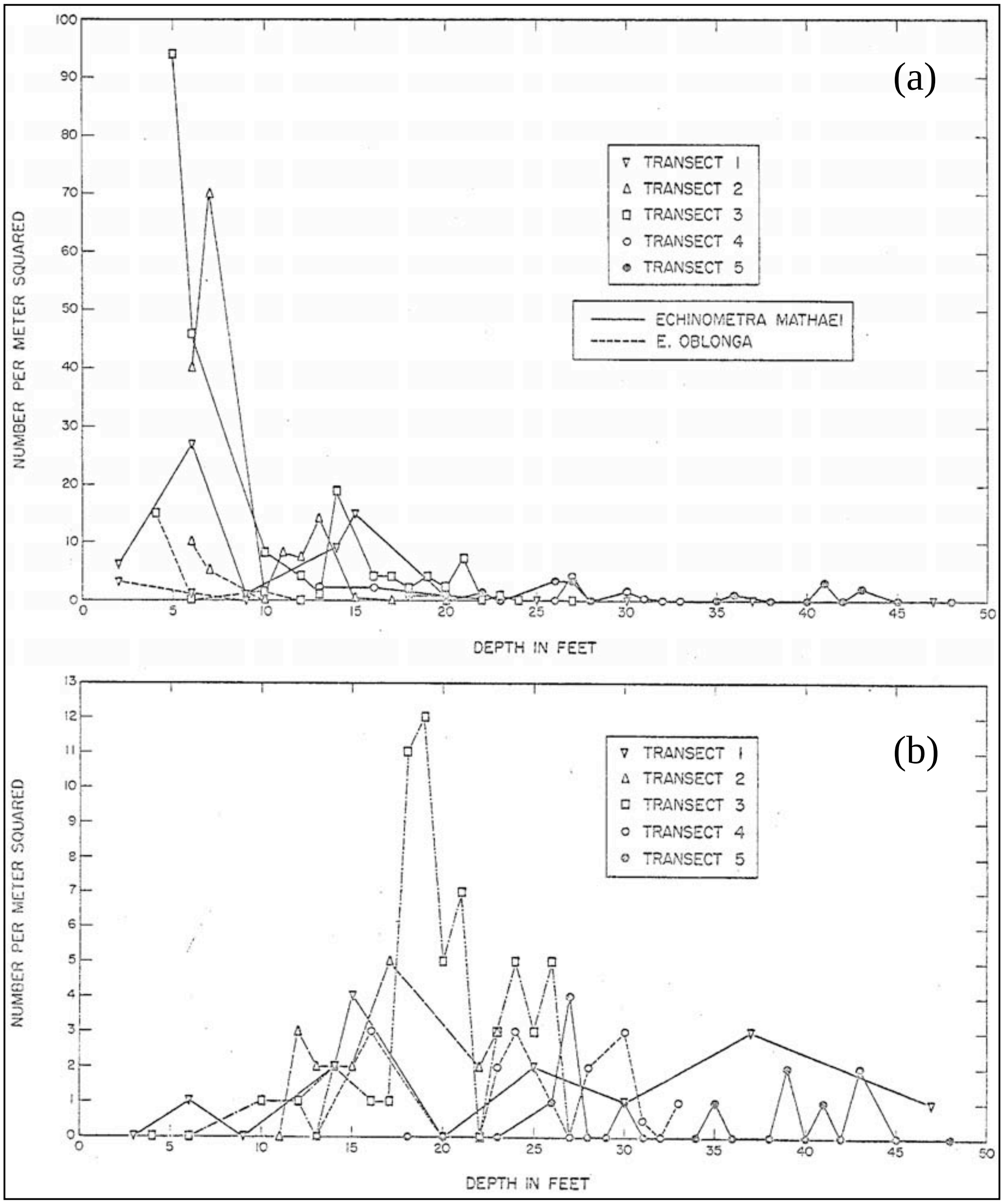

Figure 26. Variations in urchin density with depth on transects in Honaunau (Transects 1 – 4) and Alahaka (Transect 5) bays. (a) *Echinometra mathaei* and *E. oblonga*. (b) *Heterocentrotus mammillatus*. Note difference in y-axis scales. From Doty (1969).

Subtidal mollusks were not surveyed by Doty (1969), but the mollusk fauna that might be expected in the bay was discussed: “The subtidal fauna of the bay is apparently similar to that found in Kealakekua Bay, although there may be a somewhat less diverse fauna associated with a less diverse coral biota. The common larger and more spectacular mollusk such as the helmet shell, *Cassius cornuta*, the tiger cowry, *Cypraea tigris*, and the triton, *Charonia tritonis*, should all be found at depths of 10 feet [3 m] or more in the bay, and sand pockets should harbor a number of species of auger shells, *Terebra* spp., and bivalves such as tellinids.”

Crustaceans were not surveyed quantitatively, but notes were provided on the occurrence and distribution of subtidal shrimp, lobsters and crabs:

> "Shrimp
> The only larger crustacean seen in numbers was the "cleaning shrimp", *Stenopus hispidus*. Although it seems likely that many smaller decapods live among the deep interstices of the coral, it seems equally likely that such crustaceans would occur among the coral rubble bordering the deep sand. Several coral fragments were overturned without noting such crustacea.
>
> Lobsters
> The population of spiney lobsters (*Panulirus japonicus*) in the area was thought scant considering the amount of cover. A few were observed in deep crevasses along the rough shoreline north of Alahaka Bay, and in "pukas" or cracks near the bases of several exposed boulders northwest of Hale-o-Keawe.
>
> Spiney lobsters prefer rough waters and are hence in greater abundance along the windward side of Hawaii. Also, as might be expected, there is a human foraging factor affecting the population size.
>
> The occurrence of lobsters sharply increases approaching the uninhabited regions south of Honaunau beyond Hookena.
>
> Slipper lobsters (*Parabaccus antarcticus*) were not observed. They are often gathered in shallow waters of Oahu for human consumption."
>
> Crabs
> The Kona crab (*Ranina serrata*) is commercially the most valuable crab in Hawaii. Because of the bottom topography, however, they are not trapped in Honaunau Bay.
>
> Kona crabs were not observed by SCUBA divers during the present study as, besides their habitat, the crabs are dawn feeders. They remain burrowed in sand during the day. Kealakekua Bay has a flat sandy bottom at depth 300 feet [90 m]. Here Kona crabs are trapped. A similar sandy shelf exists at depth 200 feet [60 m] 500 m [550 yds] off Puuhonua Point and extends south 150 m [160 yds] off Alahaka Bay. Kona crabs are sporadically trapped at this depth off Alahaka Bay, and in times past it is reported the population has been severely decimated in this manner.
>
> The red pebblecrab (*Etisus splendidus*) was infrequently observed around Honaunau. Seven-eleven crabs (*Carpilius maculatus*) are caught at night with lights along the rough shoreline south of Puuhonua Point and in shallow waters off Miana Point."

Kimmerer and Durbin (1975) performed quantitative and semi-quantitative benthic surveys along 36 inshore (6), mid-reef (26), and outer reef (4) transects (Figure 18). Surveys included assessments of coral species and cover, macroinvertebrate species and abundance, and algal species and relative abundance (Table 14). Because "many of the common marine invertebrates are cryptic" and only larger visible organisms were noted, counts probably underestimated invertebrate abundances, particularly smaller species. A diversity index was computed only for echinoderms (starfish, sea urchins, and sea cucumbers), "because many [invertebrates] were identified only as far as family or genus, and because many of the mollusks and crustacea are cryptic". The dominant species of coral along all transects were *Porites lobata* and *P. compressa*, with all other species occurring at less than 5% bottom cover (Table 15). Macroinvertebrates consisted mostly of echinoderms, with sea urchins occurring at the highest densities (Table 16). *Tripneustes gratilla* and *Echinometra mathaei* were the most abundant urchins, with densities >100/m^2 on the inshore transects. "Common" urchins (10 – 100/m^2) included *Echinothrix* sp.

(inshore and mid-reef), *Eucidaris metularia* (mid-reef), *Chondrocidaris gigantea* (mid-reef), *T. gratilla and E. mathaei* (mid- and outer reef), *E. mathaei oblonga* (inner reef), and *Heterocentrotus mammillatus* (all three habitats). Few algae were observed on the transects, with only one "unspecified encrusting" species considered "dominant", and only on inshore transects (Table 17). The same unidentified species was considered "common" on mid-reef and outer reef transects. The only other species considered "common" was *Jania* sp. on mid-reef transects. All other species were considered uncommon or were noted off of transects.

Table 14. Results from benthic surveys performed along transects in Honaunau Bay in ~1974 - 1975. Results from Kealakekua Bay also are shown for comparison. IN = inshore, MR = mid-reef, OR = outer reef. Diversity is expressed "using the Shannon-Weaver method". After Kimmerer and Durbin (1975).

	Honaunau			Kealakekua		
Parameter	IN	MR	OR	IN	MR	OR
Number of transects	6	26	4	2	26	10
Depth range (m)	1.0 – 7.0	3.0 – 16.0	12.0 – 20.0	3.0 – 5.0	3.0 – 13.0	12.0 – 25.0
Coral cover (%)	25	57	52	60	72	60
Coral diversity	0.2	0.7	0.9	0.3	0.9	1.1
Coral species (#/transect)	2	4	5	4	3	3
Macroinvertebrates (#/100 m2)	305	141	66	297	376	123
Echinoderm diversity	1.2	1.5	1.4	1.1	1.1	0.8
Algae (species/transect)	1	3	3	0	2	3

Table 15. Coral species and relative abundance along transects in Honaunau Bay in ~1974 - 1975. Results from surveys in Kealakekua Bay also are shown for comparison. IN = inshore, MR = mid-reef, OR = outer reef. Relative abundance codes are: 1 = seen in habitat but not counted on transect, 2 = counted on transect but < 5% bottom cover, 3 = common – 5 to 25% bottom cover, 4 = dominant - >25% bottom cover. After Kimmerer and Durbin (1975).

	Honaunau			Kealakekua		
Species	IN	MR	OR	IN	MR	OR
Sarcothelia edmondsoni	1	1	1	-	2	-
Psammacora verrilli	-	2	1	-	2	3
P. stellata	-	-	-	-	1	2
Pocillopora damicornis	-	-	1	-	1	2
P. meandrina	2	2	2	2	2	2
Montipora verrucosa	2	2	-	2	2	2
Montipora verrilli	-	2	1	-	2	2
Pavona varians	2	2	2	2	3	3
P. explanulata	1	-	-	1	1	2
Leptoseris encrustans	-	-	1	-	2	-
Fungia scutaria	-	1	-	-	1	-
Porites lobata	4	4	3	4	4	4
P. compressa	3	3	4	3	4	4
P. brighami	-	2	-	-	-	-
L. purpurea	-	-	-	-	1	1
Cyphastrea ocellina	-	1	1	-	1	1
Tubastrea aurea	-	2	-	-	-	-
Palythoa sp.	-	2	-	-	2	2
Cycloseris vaughan	-	-	-	-	1	-

Table 16. Macroinvertebrate species and relative abundance along transects in Honaunau Bay in ~1974 - 1975. Results from surveys in Kealakekua Bay also are shown for comparison. IN = inshore, MR = mid-reef, OR = outer reef. Relative abundance codes are: 1 = seen in habitat but not counted on transect, 2 = uncommon – less than 10/100 m^2, 3 = common – 10 to 100/m^2, 4 = dominant - >100/m^2. After Kimmerer and Durbin (1975).

	Honaunau			Kealakekua		
Species	IN	MR	OR	IN	MR	OR
Porifera						
Demospongia sp.	-	1	-	1	-	-
Platyhelminthes						
Polycladida sp.	-	-	-	1	-	-
Annelida						
Terrebellidae sps.	1	-	-	-	-	-
Spirobranchus sp.	2	2	2	2	2	2
Arthropoda						
Panuliris sp.	-	1	-	-	-	-
Anomura sp.	-	2	2	2	2	-
Mollusca						
Vermetidae sp.	-	-	-	2	2	2
Nudibranchia sps.	-	-	-	-	2	-
Dolabella variegata	-	1	-	-	-	-
Echinodermata						
Culicita novaeguinea	-	-	-	-	1	-
Leiaster callipeplus	-	-	-	-	1	-
Linckia multifora	-	-	-	2	2	2
Acanthaster plancki	-	2	2	-	2	2
Echinothrix sp.	3	3	2	3	3	3
Diadema pucispinum	2	2	-	-	2	2
Eucidaris metularia	2	3	2	2	2	2
Chondrocidaris gigantea	-	3	-	-	1	2
Tripneustes gratilla	4	3	3	3	3	3
Echinometra mathaei	4	3	3	4	3	3
E. mathaei oblonga	3	2	-	2	-	-
Heterocentrotus mammillatus	3	3	3	3	4	4
Echinostrephus aciculatus	2	2	-	-	2	-
Lytechinus sp.	-	1	-	-	1	-
Holothuria atra	2	2	-	-	-	-
H. fuscorubra	-	2	-	-	-	-
Actinopyga obesa	2	2	-	-	-	2

Table 17. Algal species and relative abundance along transects in Honaunau Bay in ~1974 - 1975. Results from surveys in Kealakekua Bay also are shown for comparison. IN = inshore, MR = mid-reef, OR = outer reef. Relative abundance codes are: 1 = seen in habitat but not counted on transect, 2 = uncommon, 3 = common, 4 = dominant. After Kimmerer and Durbin (1975).

	Honaunau			Kealakekua		
Species	IN	MR	OR	IN	MR	OR
Chlorophyta						
Caulerpa sp.	-	2	-	1	1	-
Dictyosphaeria cavernosa	-	1	1	-	1	1
Halimeda opuntia	-	2	2	-	1	2
Microdictyon sp.	-	1	-	-	2	-
Valonia ventricosa	-	1	1	-	1	1
Phaeophyta						
Dictyopteris australis	-	2	-	-	2	-
Sargassum sp.	-	2	-	-	-	-
Turbinaria ornata	-	1	1	-	-	-
Rhodophyta						
Amansia glomerata	-	-	1	-	-	-
Ceramium sp.	-	1	-	-	-	-
Desmia hornamani	-	2	-	-	-	-
Galaxaura sp.	-	1	1	-	1	2
Hemitrema sp.	-	1	1	-	1	-
Jania sp.	2	3	2	-	2	3
Laurencia sp.	-	-	1	-	-	-
unspecified encrusrting	4	3	3	-	2	3
Cyanophyta						
Lyngbya sp.	-	2	-	-	-	-

Ludwig et al. (1980) included some notes on coral distribution from their 1975 – 1978 fish surveys along three transects around PUHO (Figure 19). Boulders in their shallow (2 – 4 m/7 – 13’) “boulder zone” were “dotted with various algae and corals (mainly *Pocillopora meandrina*), while more extensive coral cover was noted in their 5 – 10 m (16 – 33’) depth “coral-rich” zone (“characterized by a dominant bottom cover (80 – 100%) of various sized heads of *Porites lobata* with some fingerlike *P. compressa*”) and their 15 m (50’) depth “drop-off” zone (“generally overgrown with *Porites compressa* and *P. lobata* interspersed with sand patches and basaltic pavement and boulders”). They also noted that significant coral growth had occurred in the areas where transects had been conducted five years earlier by Doty (1969), as transect cables from the earlier study “were nearly enveloped by coral growth”.

Madden (1980) included some observations on benthic biota from his reconnaisance survey of nearshore waters around the head of Honaunau Bay (Figure 20):

> “…two distinct biological areas or biotomes occur … the surge zone exists as a narrow band up to 33 feet (10 m) wide extending from the shoreline to a depth of approximately 15 feet (4.6 m). The basalt and limestone boulders here are covered primarily by coralline algae with scattered coral colonies. Sea urchins and large aggregations of surgeonfishes and wrasses dominate the nearshore fauna. The coral zone, extending downslope from a depth of 15 feet (4.6 m) to approximately 60 feet (18 m) is characterized by extensive coral growth over the basalt talus. Dominant fauna here

includes sea urchins, damselfishes, butterflyfishes, surgeonfishes, as well as, cryptic and coral-eating species.

…

Coral covers up to 100% over most of the sloping bottom of the bay from a depth of 15 to 60 feet (4.6 to 18 m). The large numbers of fishes and fish species in this area reflect the high vertical relief afforded by the complex coral substrate. Coral cover abruptly decreases to less than 5% in the lower surge zone, increasing to about 10% in the upper surge zone. The dominant corals in the deeper, coral zone are *Pocillopora eydouxi*, and *Porites compressa* which comprise nearly the entire coral cover. However, the solitary coral, *Fungia scutaria* occurs at the bases of *P. compressa* colonies in moderate numbers. In the surge zone, *Pocillopora meandrina* and *Porites lobata* encrust the basalt boulders. Occasional colonies of *Montipora flabellata* also occur here.

Conspicuous invertebrates are represented primarily by echinoderms. The crown-of-thorns starfish, *Acanthaster planci*, is common feeding in the deeper, coral zone where numerous feeding scars and white coral heads were observed. The sea urchins, *Tripneustes gratilla*, *Diadema paucispinum*, *Echinothrix diadema*, and *Echinometra mathaei* are dominant in the surge zone. In some areas densities of up to 40 individuals per square meter were observed. The slate-pencil urchin, *Heterocentrotus mammillatus* is most common in the coral zone but is also present in moderate numbers in the nearshore areas.

The algae, *Lyngbya majuscula*, occurs as patchy turf covering the rocks in the nearshore zone. The coralline algae, of which *Porolithon gardineri* is most abundant, covers up to 90% of the nearshore bottom."

Three recent (2000 – 2005) studies have classified benthic habitat and associated biotopes around PUHO using aerial and satellite images. NOAA's Biogeography Program (http://ccma.nos.noaa.gov/about/biogeography/) analyzed satellite images (AURORA hyperspectral and IKONOS multispectral) and aerial color photos obtained in 2000 to determine the distribution of coral communities and other habitats throughout the main Hawaiian islands (Figure 12a). In 2005, new (2005) IKONOS satellite imagery and a revised classification scheme were used to produce a revised map (Figure 12b). The USGS produced a benthic habitat map specifically for the park using aerial photos and LIDAR bathymetry (obtained in 2000) supplemented by extensive data from underwater video and still photographs (collected in 2004) as well as 2005 field checks of classification accuracy (Figure 12c). All of the maps show generally similar distributions of coral reef habitat off of PUHO. The relatively coarse resolution available from remote sensing data (typically 1 - 4 m/3 – 13' per pixel), the delineation of features as polygons with areas typically greater than 1 acre (~4000 m^2) (NOAA) or 100 m^2 (120 yd^2) (USGS), and the limited field verification used make these maps most useful for assessing the general distribution of biotopes compared to other areas. The USGS classification scheme did allow for classification of "small" features when warranted (e.g. a 2 m/7' diameter coral head in an otherwise uncolonized area), and the underwater video and still photographs obtained by the USGS could provide additional insight into habitat distribution and quality.

C. ASSESSMENT OF COASTAL WATER RESOURCES

C.1. Sources of pollutants

C.1.a. Point and non-point sources

No point source discharges are present in PUHO, but a number of non-point sources in and around the park have the potential to affect coastal water resources. Potential sources inside the park include a small sewage treatment plant, a small cesspool in the maintenance/administration area, portable visitor bathrooms in the park picnic area, vehicles utilizing the main parking area and the picnic area, and activities of park personnel and visitors, including application of herbicides. Kiʻilae stream, which crosses the park near the southern boundary, normally is dry in its lower reaches, but may transport pollutants to park coastal waters during rare high-runoff events. Sources outside the park may affect water resources in and adjacent to the park through transport into the park via surface water, which probably only occurs during the rare high-runoff events noted above, by direct deposition into coastal waters adjacent to the park, for instance from activities in and around the coastal residences and small-boat ramp just north of the park, or by impacting groundwater upslope of the park which subsequently flows downslope through the park and discharges to park coastal waters. Non-point and possible point sources that might affect groundwater quality include a variety of residential, agricultural, and other activities upslope of and adjacent to the park. Activities within the park also could affect park groundwater, or could affect other water resources (anchialine pools, fishpond pools, etc.) directly. Sedimentation from non-point sources probably is only a minor concern due to the lack of surface runoff in the area, although Kiʻilae stream may occasionally discharge significant amounts of sediment into coastal waters adjacent to the park, and sediment from road and trail fill may be impacting adjacent anchialine pools. Airborne pollutants, including dust, also can be deposited in PUHO, and light and noise pollution may impact biological resources.

C.1.a.i. Surface runoff

While most freshwater inputs to PUHO coastal waters occur via groundwater discharges, occasional high-runoff events produce flow in the lower reaches of Kiʻilae Stream and result in significant discharges of water, sediment, and associated pollutants to coastal waters. A small amount of local runoff also may reach coastal waters; in particular, runoff from the paved parking area at the park entrance discharges directly to coastal waters, as does runoff from the road fronting Honaunau Bay. Runoff from the PUHO parking area has been treated since March 2003 using a passive filtration system that targets oil, grease, and suspended solids (Brzozowski 2004), but no data are available to assess pre- or post-installation water quality in adjacent coastal waters.

C.1.a.ii. Groundwater contamination

Because of the high permeability of soils and rocks along the Kona coast, the majority of freshwater in the area occurs as groundwater (Oki et al. 1999). Rainfall in the PUHO area is greater inland than along the coast, so most natural groundwater recharge occurs inland of the park, and groundwater should flow in a generally seaward direction through the park and into coastal waters (Oki et al. 1999). Groundwater in PUHO thus will be affected by activities both in, and inland of, the park, and groundwater pollutants ultimately will pass through PUHO's anchialine pools, fishpond, and tidepools enroute to discharging into coastal waters. Groundwater is an important resource in PUHO, as historically it was a critical resource for native Hawaiians living in the region, and because it plays a major role in determining water quality in anchialine pools and in the Royal Fishpond, and to a lesser degree in coastal tidepools and coastal waters.

Groundwater pollutants can be separated into two general classes – nutrients (usually nitrogen and phosphorus) that have the potential to enhance primary production (i.e., the growth of phytoplankton, benthic micro- and macroalgae, and aquatic plants), and toxic pollutants that may interfere with biological activity. The latter includes a wide variety of chemicals related to human activities such as metals, pesticides, solvents, and petroleum products. It also can include pharmaceutical compounds and their byproducts. Because of the difficulty and expense of analyzing water samples for industrial, agricultural, and pharmaceutical contaminants, these analyses are performed only rarely, and the effects of many contaminants on biological systems are poorly known. Nutrients are measured more frequently, but their effects on natural systems also can be complex.

Contamination of groundwater upslope of and in the park may occur due to infiltration of wastewater from cesspools and septic leach fields, fertilizer, herbicide and pesticide use, stormwater runoff from developed areas, and improper disposal or spills of toxic substances. The impacts of these contaminants on PUHO ecosystems will depend on the type and extent of contamination and the vulnerability of receiving ecosystems. While dilution should disperse most groundwater contaminants to some degree as groundwater flows downslope, dilution may be less effective than expected if contaminated recharge does not mix extensively with underlying uncontaminated water during transport, and if lateral mixing is slow, resulting in relatively narrow contaminant plumes flowing downslope on top of otherwise 'typical' groundwater. Downgradient monitoring wells or sampling at springs or discharge points along the coast thus may not detect contamination unless they fortuitously are located in plumes and samples are collected near the surface of the water table.

C.1.a.ii. Herbicide use

Maintenance of park grounds historically has included extensive use of herbicides on plants growing around cultural sites, along the shoreline trail, and around the Royal Fishpond (M. Laber pers. comm. 2004). Some information on herbicide use and vegetation management practices in the park was obtained in 2006 from Victorino Bio, the Integrated Pest Management (IPM) coordinator for the park: herbicides have not been used in the last couple of years due to personnel safety issues, but herbicides used since 1985 include Rodeo® around aquatic features and Roundup® in other areas, switching to Roundup Pro® around 1987. Garlon 4® is used for "stumping" of opiuma, keawe, Christmas Berry, and lantana. Herbicides used prior to 1985 include Paraquat®, 2-4 D, and Tordon, and atrazine was used as a soil sterilant in 1968. Vegetation clearing in the early 1960's used diesel fuel to initiate burning of debris piles throughout the park. Detailed data on chemicals used in the park should be available since 1985 from entries recorded in the park's pesticide use log, but these data currently are stored at another location and were not available for this report. The effects of these chemicals on water resources in the park are not known (Else 2004), but may be significant if toxic compounds persist in dissolved forms or in association with sediments or biota in park waters.

C.1.a.iii. Garbage and animal waste

There are no perennial streams or significant areas of surface runoff in the park, and wind transport of solid waste probably is a minor source, so most of the garbage impacting coastal resources in the park likely will be due to local inputs. Inputs probably are focused around areas with high visitor use, such as the picnic area inside the park and coastal areas in Honaunau Bay immediately north of the park. Some garbage also may reach PUHO's intertidal areas and adjacent coastal waters from offshore sources and from sources in Honaunau Bay. Plastics can be a significant problem in marine environments, as turtles, seabirds and other marine vertebrates may ingest some items, and others represent entanglement hazards for marine birds and other wildlife. Animal waste probably will be most significant around high-use areas, particularly if dogs are not leashed. Impacts on PUHO's ecosystems due to animal wastes probably are minor, but aesthetic impacts can be significant, and wastes may carry pathogens that could adversely affect the quality of coastal waters for recreational use.

C.1.a.iv. Sedimentation

Soil is scarce in and around PUHO, and there are no perennial streams or other significant sources of surface runoff that normally would transport soil particles to PUHO's anchialine pools, ponds, or coastal waters. As a result, most of the sediments currently accumulating in PUHO's waters are derived from biological sources, either in the waters themselves or from adjacent terrestrial vegetation. Sediment accumulation from biological activity is a natural process and leads eventually to infilling of open-water areas, but excessive biological production due to eutrophication or to excessive litter production by alien plants can lead to premature senescence of anchialine pools and fishpond pools – for instance, Youth Conservation Corps volunteers removed sediment from the south pool of the Royal Fishpond on at least four occasions between 1976 and 1980 to preserve the cultural scene (National Park Service 1976; 1977; 1979; 1980). Some sediment issues may be associated with erosion of material from the beach at the head of Keoneʻele Cove, with eroded sediments depositing in the cove and offshore. This beach is maintained using imported crushed coral fill that contains fine sediments that can easily be winnowed from the sand matrix by wave action and transported offshore (M. Laber pers. comm. 2004). Fill used on park roads and trails also appears to be impacting anchialine pools in the Palace grounds area (M. Laber pers. comm. 2006). Unusually large waves may result in significant redistribution of loose material and the deposition of new material - tidal waves probably are responsible for the occasional deposition of significant amounts of sediment and larger material into PUHO's fishpond, anchialine pools and tidepools, and rare large storms also may result in significant sediment impacts. For instance, "lots of fist sized stone" was deposited in the south pool of the Royal Fishpond by waves associated with an unusually large storm in January 1980 (National Park Service 1980), and an anchialine pool noted as a well on early archaeological maps apparently was filled with sediment and rubble during hurricane Iniki in 1992 (M. Laber pers. comm. 2006). Some sediment also arrives as windblown dust, but this source is likely to be quantitatively minor and impacts small, unless the dust contains toxic organisms (e.g. fungi), elements, or compounds. The most significant potential sediment source in and around the park is Ki'ilae Stream, which probably discharges large quantities of sediments to coastal waters during rare high-runoff events. Significant sedimentation impacts might also result from development of coastal zone areas immediately north or south of the park, such as expansion of the small-boat launching ramp in Honaunau Bay, but no developments are known to be planned for the near future, and construction-related sediment issues should be small if activities are conducted according to established guidelines for prevention of sediment mobilization and transport. However, poor project planning or implementation, or unusual events such as heavy rainfall or winter storm conditions could result in significant sediment inputs. A recent example of this is sediment runoff from the Hokulia development project, approximately 3 km (2 miles) north of Kealakekua Bay, which affected reefs adjacent to the project and in Kealakekua Bay in 2000 (Thompson 2006).

C.1.a.iii. Air, noise and light pollution

Air pollution may impact park water resources via the deposition of particulate contaminants in park waters or the dissolution of contaminant gases in park waters. While development in the area must affect air quality, quality overall is relatively good and prevailing winds normally are onshore, so the park probably receives only very modest inputs of anthropogenic airborne contaminants. The most important local anthropogenic sources probably are vehicles entering and leaving the park, and boats utilizing the small-boat ramp just north of the park. A significant source also may be emissions from the nearby Kilauea volcano (DeVerse and DiDonato 2005). Volcanic emissions include a number of constituents that could affect PUHO's coastal resources, including compounds that increase the acidity of waters and toxic constituents such as mercury (Brock and Kam 1997). However, VOGNET monitoring has shown that a relatively clean layer of air normally is present near sea level in the PUHO area, with no evidence of volcanic particulates, and that volcanic emissions affect air quality primarily at higher elevations (Ryan 2003). Thus, impacts due to deposition of volcanic contaminants probably also are minor.

Noise pollution might affect the suitability of park waters and wetlands for use by dolphins, whales, birds, and other organisms sensitive to noise. The most significant noise sources probably are small boats traveling to and from the small-boat ramp in Honaunau Bay, but no data are available on the magnitude or possible impacts of noise pollution in the area.

Light pollution has been noted as a potential issue for some animals. Light pollution can affect birds, turtles, and other organisms that navigate using the night sky, or that require darkness for certain activities. Artificial lights also can alter ecosystem function in coastal waters by attracting plankton, resulting in behaviorial impacts on plankton predators such as giant manta rays. Light pollution has not been studied in the park, but seems likely to be a relatively minor issue in most areas, unless lighting around the park parking area and visitor center impacts nearby coastal waters.

C.1.a.iv. Honaunau small-boat launching ramp

The small-boat launching ramp immediately north of the park represents a potentially significant source of non-point source pollutants (McCoy and Johnson 1995). Because few locations are available for launching along the Kona coast, the ramp is heavily used by local boaters. Neighbor Island Consultants (1972) stated that roughly 1800 launchings occurred from the area in 1970, while Okahara (1982) noted that approximately 50-75 boat owners were regular users of the ramp in 1982, and that 20 or more launchings might take place on any given day.

Nutrients, metals, petroleum products, marine debris, offal from fish cleaning, and other pollutants all may be discharged in association with boating operations, either in nearshore areas during launching and retrieval, or as boats transit coastal waters enroute to and from the ramp. There are no posted signs or other informational resources at the ramp promoting best practices for boat users. Table 18 summarizes the environmental impacts of some pollutants commonly associated with boating.

Table 18. Environmental impacts of boating pollutants. From McCoy and Johnson (1995).

Pollutant	Sources and Characteristics	Environmental Activity	Environmental or Human Health Effects
Detergents	* Most cleaning agents, detergents and soaps * Oil spill dispersants * Breaks down oils and greases on boats	* Accumulates in sediments * Broken down by microorganisms	* Toxic to marine plants and animals * Impairs breathing in fish * Reduces amounts of oxygen in affected waters * Produces unsightly foam on the water surface
Marine Debris	* Commercial and recreational boating * Plastics, food wastes, packaging, lines, nets, fish cleaning wastes * Plastics degrade very slowly * Some wastes become nutrients	* Persistent in the environment	* Can choke/strangle sea animals * Can transport harmful non-native species * Snagged by props and engines * Ruins recreational beaches
Metals	* Paint particles from hydro-washing, metal shavings from engine wear, and consumer products containing metals * Dissolves according to water conditions	* Accumulate in sediments, marine plants, and animals * Persistent in the environment * Some metals broken down by microorganisms	* Toxic to marine plants and animals * Changes the food web in the marine environment by eliminating certain species
Copper (Cu)	* Used as a toxic agent in antifouling paints * Dissolves according to water conditions	* Accumulates in sediments, marine plants, and animals * Persistent in the environment	* Very toxic to fish when combined with zinc * Long term toxicity to marine plants and animals
Acidic & Alkaline Substances	* Battery acid, lye and other strong acids or bases in vessel cleaning products * Dissolves easily in water	* Increases natural acidity or alkalinity of water by decreasing or increasing pH respectively	* Toxic to marine plants and animals * Increases the toxicity of other toxic substances, metals, other pollutants and chemicals * can irritate or damage skin
Tributlytin (TBT)	* Still used as a toxic agent in antifouling paint on aluminum hulls, outboard motors and lower drive units	* Accumulates in sediments, marine plants, and animals * Persistent in the environment	* Toxic even in small amounts to marine plants and animals, especially bottom feeders
Zinc (Zn)	* Anticorrosive zinc and paint pigments * Dissolves slowly in water, clings to particles and sediments in marine environments	* Accumulates in sediments, marine plants, and animals * Persistent in the environment	* Toxic to marine plants and animals, even in small amounts
Oil/Fuel	* Normal boat operation, fueling, engine maintenance, spills, runoff, and bilge discharge * Dissolves slowly in water, clings to particles and sediments in marine	* Fuels evaporate in air * Broken down by sediment microorganisms * Accumulates in sediments, marine plants, and animals * High accumulation in estuaries and intertidal areas	* Some components toxic to marine plants and animals even at low concentrations * Some components cause cancer, mutations * Discoloring and bad taste in flesh of fish
Dusts and sediments	* Vessel scraping and sanding, erosion during construction and urban runoff * Heavy metals, nutrients, hydrocarbons, etc., adhere to dusts and sediments	* Accumulate in sediments near the discharge of water * Sediment-bound contaminants released to water if disturbed	* May reduce amounts of oxygen in affected waters * General lowering of water quality * Burial of habitat, food and/or organisms * Increased turbidity can clog gills of fish
Nutrients	* Runoff, sewage, erosion, garbage & detergents containing (P)hosphorus or (N)itrogen	* Used by marine plants and organisms for food (P,N) * Accumulates in sediment (P)	* Increase in algae growth which decreases light and oxygen in the water (eutrophication) * (N) can be toxic in higher concentrations

C.2. Assessment of biological resources with respect to water quality

Water quality affects biological resources in multiple ways. Dissolved nutrients can stimulate plant growth, while toxic substances can inhibit growth of plants and other organisms. Physical and chemical parameters such as temperature, pH, turbidity, and dissolved oxygen levels also can inhibit or promote the growth of different classes of organisms. In the following sections, water quality in PUHO's coastal resources is assessed first with respect to existing State of Hawaiʻi water quality standards, then with respect to observed or potential effects of water quality on associated ecosystems (flora, fauna, and habitat), and finally with respect to human health issues. Because groundwater impacts on coastal resources depend on the quantity of groundwater as well as the quality, groundwater flow through the park also is considered as a water 'quality' issue.

C.2.a. Water quality standards

Water quality standards in Hawaiʻi are promulgated through Chapter 54 of the Hawaiʻi revised statutes (Department of Health 2004). All of Hawaiʻi's waters are subject to a "general policy of water quality anti-degradation," including the provision that "where high quality waters constitute an outstanding national resource, such as waters of national and state parks …, that water quality shall be maintained and protected." Narrative criteria also prohibit the introduction of "substances attributable to domestic, industrial, or other controllable sources of pollutants", including pathogens, chemical contaminants, and sediment. Allowable concentrations for some toxic contaminants are specified, and narrative and numeric criteria are provided for individual classes of water resources within 'inland' and 'marine' categories, and for various levels of protection.

'Inland' waters in PUHO include anchialine pools, the Royal Fishpond, and wetlands. PUHO's inland waters are designated Class 1a and are subject to narrative criteria that specify their protection for "scientific and educational purposes, protection of native breeding stock, baseline references from which human-caused changes can be measured, compatible recreation, aesthetic enjoyment, and other nondegrading uses which are compatible with the protection of the ecosystems associated with waters of this class." (Department of Health 2004). Inland waters used for recreation also are subject to specific criteria for allowable levels of *Enterococcus* and sewage contamination (Department of Health 2004).

'Marine' waters in and adjacent to PUHO include intertidal areas and coastal waters and associated benthic habitats. Separate criteria are provided for coastal waters, sandy and rocky intertidal areas, marine pools and coves, reef flats and reef communities, and soft bottom communities. Marine waters in and adjacent to PUHO are designated Class AA by the State of Hawaiʻi (Department of Health 2004). Class AA marine waters are protected such that they "remain in their natural pristine state as nearly as possible with an absolute minimum of pollution or alteration of water quality from any human-caused source or actions". In addition to narrative criteria applicable to all Hawaiian waters, coastal waters off PUHO are subject to area-specific criteria established for the Kona coast of the island of Hawaiʻi. These include numeric criteria for nutrients (nitrogen and phosphorus), chlorophyll-*a*, turbidity, pH, dissolved oxygen, temperature, and salinity. Criteria for nutrients include adjustments for salinity to reflect the effects of groundwater inputs to coastal waters in this area. Marine waters used for recreation are subject to specific criteria for allowable levels of *Enterococcus* and sewage contamination. Criteria also are provided for benthic habitats, including sand beaches, rocky intertidal areas, marine pools and coves, reef flats and reef communities, and soft bottom communities (Department of Health 2004). Standards relevant to coastal water resources in and adjacent to PUHO are excerpted in Appendix G and discussed in the following sections as they relate to specific resources.

Although the water quality criteria outlined above clearly are intended to maintain PUHO's water resources in or near to their pristine state, data suitable for assessment of water quality relative to numeric standards are very limited. Existing data compilations in the PUHO "Horizon" report (National Park Service 2000) and in a recent USGS data compilation (Wolff unpubl. 2005) contain some data, but they are from a number of different studies and the parameters measured and methods used frequently differ between studies, making comparison difficult. Sampling frequencies also generally are too low for computation of the statistics required for comparison to State standards, and data generally are insufficient to address the salinity-dependent criteria unique to the Kona coast. However, combining these data with additional data from published reports and ongoing studies does provide some insights into water quality in PUHO, and into the degree to which park waters comply with narrative criteria.

C.2.a.i.Groundwater

Groundwater flow

Groundwater flow has not been studied in the park, but flow probably is complex due to the highly heterogeneous permeability of the lavas making up the Kona coast. The overall permeability of the lavas is high (Oki et al. 1999), but flow occurs preferentially along the more permeable beds separating successive vertically layered flows, and through the many cracks and other passageways that riddle the substrate. Lava tubes, which are common features of Hawaiian pahoehoe flows, also form extremely effective conduits for groundwater flow (Halliday 2003). Lava tubes can range in diameter from centimeters to tens of meters, and extend in some case for many kilometers. Barriers that restrict or divert groundwater flow also may occur in the form of dikes and other subsurface features. Thus, while the overall direction of groundwater transport through PUHO should be seaward, the details of groundwater transport and the fate of associated contaminants are less predictable.

The magnitude of groundwater flow through the park may be affected significantly by upslope additions and withdrawals. No studies have been performed on the impacts of upslope withdrawals on groundwater flow through PUHO, but a study for Kaloko-Honokohau National Historical park (KAHO), also on the Kona coast, showed that upslope well development could have reduced groundwater flow through the park by nearly 50% between 1978 and 1997, and water quality data from brackish wells inland and north of the park and from Keone‘ele Cove suggest that salinities have increased in the last 20 – 30 years (Figures 27 and 28a). Reductions in groundwater flow reduce the total discharge to coastal waters, increasing the salinity of brackish groundwater near the coast, and reduce the ability of groundwater to dilute contaminant inputs by reducing groundwater volume and flow velocity. Artificial recharge, for instance due

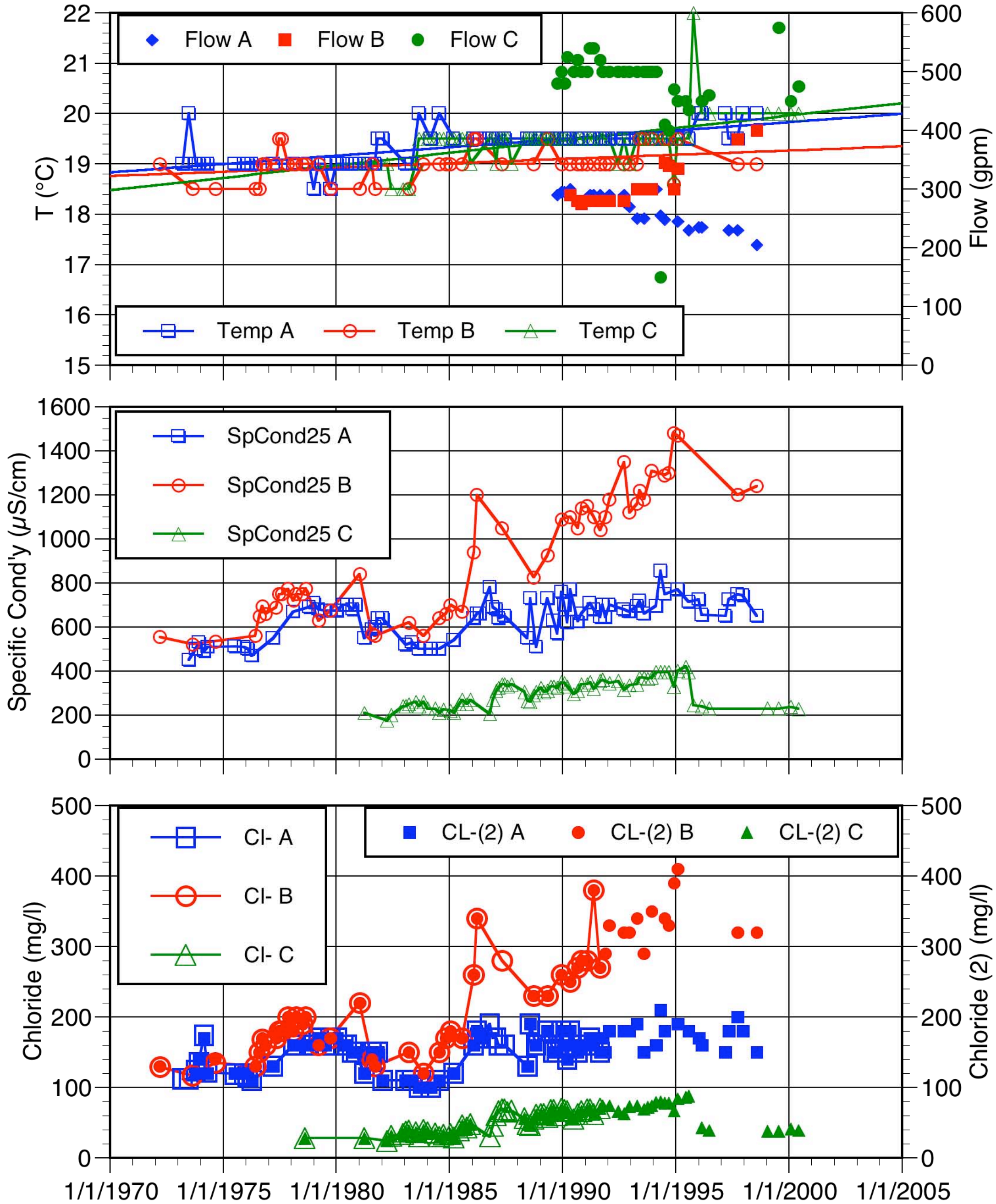

Figure 27. Water quality data from wells Keei A ("A"), Keei B ("B"), and Keei C ("C"). Second set of chloride data in bottom panel is from replicate analyses using a different method. While these wells are located over 3 km (2 miles) in from the coast, high specific conductivities and chlorinities (middle and bottom panels) show that groundwater in the area still is brackish due to mixing with underlying seawater. Increasing temperatures (linear fits in top panel), specific conductivities, and salinities show that the proportion of seawater increased over time. Pumping data ('Flow' in upper panel) only are available starting in 1989, but changes in pumping rate do not correlate with changes in salinity, indicating that the increasing salinity is due primarily to withdrawals and does not depend significantly on the rate of withdrawal. Data from Wolff (unpubl.).

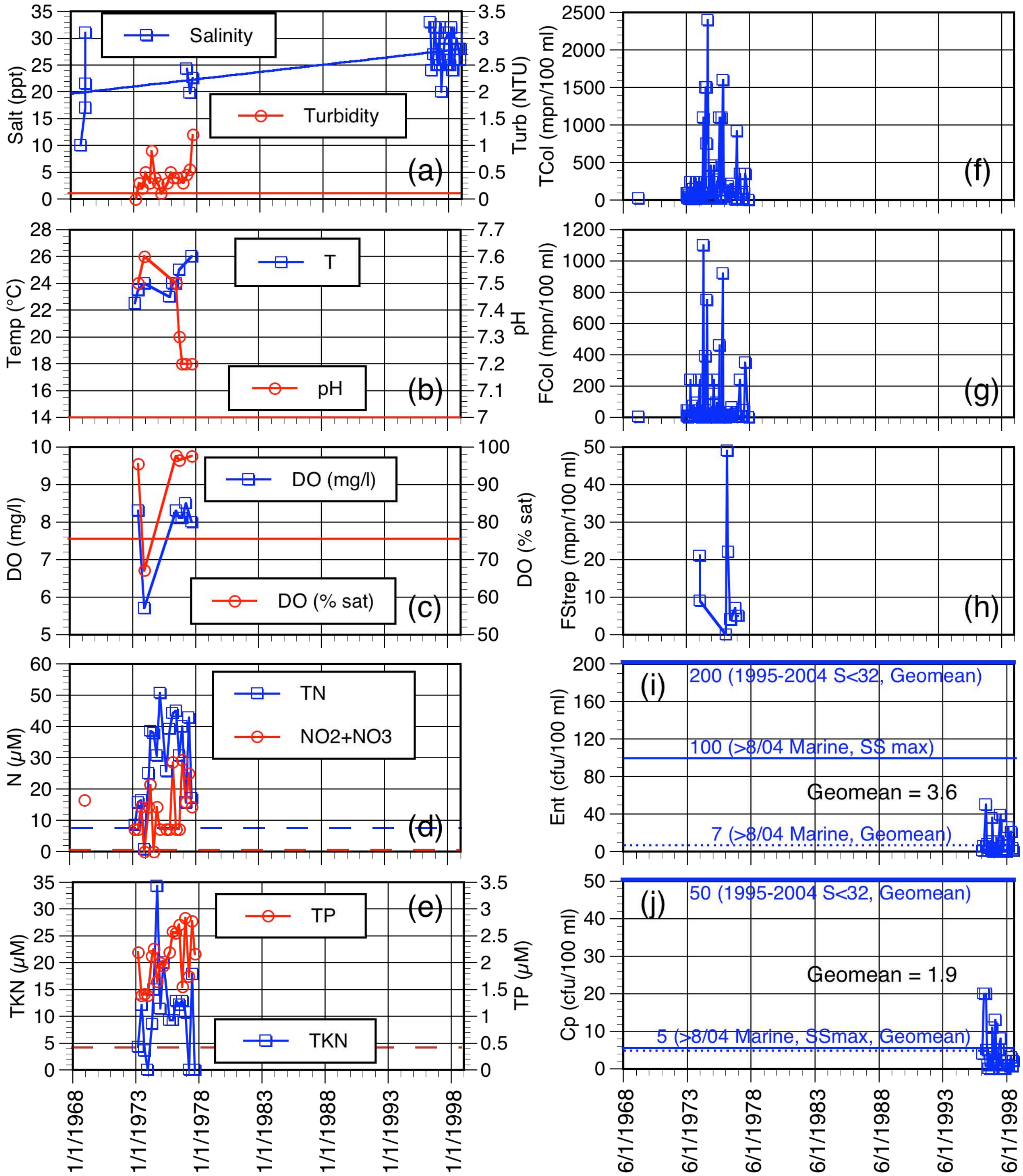

Figure 28. Water quality data from Hawai'i DOH site 0001201 in Keone'ele Cove in Honaunau Bay. Plots include data from Doty (1969) Site 13, from Wolff (unpubl.), and State water quality criteria where applicable. Linear regression in (a) is Salinity = 0.27(Year) – 512, R^2 = 0.34, p < .001.

to irrigation or disposal of waste water via leach fields or dry wells, increases groundwater flow if the recharge water is obtained outside the contributing watershed. If local groundwater is utilized for irrigation or other uses, local flow will be altered as water is removed in one area and added in another. Local flow also may be altered by construction activities that increase or decrease the permeability of soils and rocks that control infiltration and groundwater flow. No data are available to directly assess long-term changes in groundwater flow in the PUHO area, but changes in the areal extent of the Royal Fishpond (Figure 9) suggest that significant changes may occur on timescales of months to years. These changes could be related to changes in local climate that affect natural recharge, to human activities in the watershed, or both.

Groundwater quality

There are no groundwater monitoring locations in PUHO, and no data from wells directly upslope of the park. The closest upslope well with water quality data is Keei C, approximately 3 km (2 miles) upslope and over 1 km (0.6 mile) north of PUHO at about 900' (220 m) elevation (Figure 4). Two additional wells (Keei A and B) are located to the north of Keei C and at slightly lower elevations (Figure 4). These wells all are well north of the area likely to be contributing to groundwater impacting PUHO, but hydrologic conditions and upslope land use generally appear similar to those upslope of PUHO (e.g., Figures 2 - 4), although the inland extension of the fault system that forms the cliffs in Kealakekua Bay may alter groundwater flow in this area (Figure 4). Measured water quality parameters consist mostly of parameters like temperature and specific conductivity that show that the sampled groundwater is slightly brackish (~0.1 to 2% seawater) but do not provide significant insight into the potential for contamination due to upslope activities (Figure 27). There are a very few measurements of nitrate, phosphate and total phosphorus from samples collected in 1972 - 1978 (Table 19). While these data are very sparse, concentrations are similar to recent values found in (presumably uncontaminated) high-level groundwater upslope of KAHO (~70 µM NO_3^-, ~3.5 µM PO_4^{3-}; Hoover and Gold 2005), suggesting that groundwater quality at these wells was not affected significantly by upslope nutrient inputs in 1972 - 1978.

Table 19. Groundwater nutrient data from Keei wells B and C. Data from Wolff (unpubl.).

	Keei B		**Keei C**	
Parameter	Date	Conc (µM)	Date	Conc (µM)
NO_3^-			3/16/72	92.8
NO_2^-+NO_3^-	8/10/78	78.6	8/27/74	47.1
PO_4^{3-}			8/27/74	4.84
Total P	8/10/78	3.87		
Silica	8/10/78	815	3/16/72	865
Silica			8/27/74	832

One other dataset offers some insight into the quality of groundwater in the park. Doty (1969) analyzed water quality at 19 brackish-water sites along the shoreline of Honaunau Bay, on Pu‘uhonua Point, and in Alahaka Bay (Figure 29). Most of the samples were analyzed only for salinity, but samples from 7 sites included analyses of coliform and fecal coliform bacteria, nitrate, nitrite, phosphate, and ammonia (Table 20). Plotting the dissolved nutrient data against salinity shows that nitrate and phosphate follow a generally linear relationship consistent with dilution of high-nutrient groundwater by low-nutrient seawater (Figure 30b). Nitrite and ammonia occurred at much lower concentrations than nitrate and did not show any relationship with salinity, suggesting that concentrations in groundwater either were similar to those in seawater, or that the processes controlling concentrations were rapid compared to the time elapsed since the groundwater was discharged into coastal waters (Figure 30c). The linear relationships for nitrate and phosphate suggests a groundwater endmember having concentrations of about 750 and 150 µg/l, respectively. Assuming that the concentration units are in µg N and µg P (instead of µg NO_3^- and µg PO_4^{3-}), these values are equivalent to 54 µM N and 4.8 µM P, rather similar to concentrations observed in Keei B and C groundwater (Table 19) and in the KAHO-area high-level groundwater discussed above. The one exception to the linear trend is the sample from the Royal Fishpond, which has nitrate and phosphate concentrations well below the

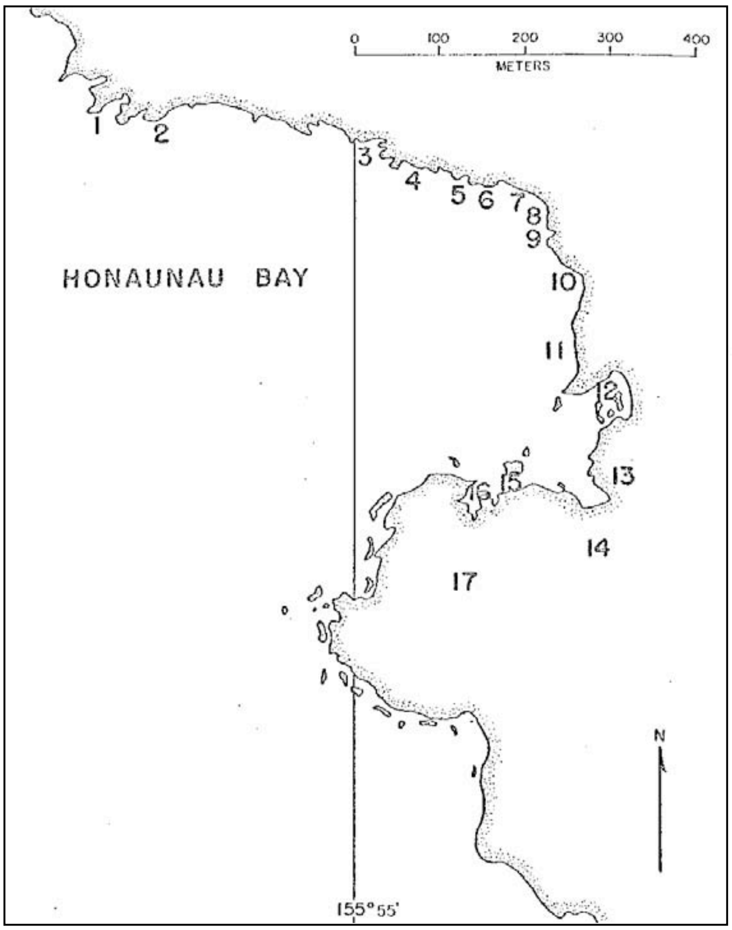

Figure 29. Brackish water discharge sites around PUHO in 1968-69. No discharges were noted from this area south to Loa Point except for two in the Alahaka Bay area: Site 18 in Alahaka Bay where several freshwater "chimneys" were observed rising from the floor of the bay, and Site 19, "a rocky cove south of where Pali Alahaka enters Alahaka Bay", where fresh water was detected 50 m from shore during an ebb tide. Sites are coastal and represent point sources of brackish water except for sites 11 and 15 which were areas where multiple discharges were noted along the coast, site 14 (the Royal Fishpond), and site 17, which was a shallow tidepool by Alealea Heiau. The greatest volume discharge was observed at site 12, followed by site 13. Surveys were conducted on 8 days from October 20, 1968 to March 11, 1969, with many sites sampled on multiple days (Table 20). Figure from Doty (1969).

Table 20. Water quality data from brackish water sites around PUHO (Figure 29). All data are from surface samples except as noted. Col = Coliform, FC = Fecal coliform. Data are from Doty (1969).

Site	Date	Tide	Status	Description	Salinity	Col	FC	NO3	NO2	PO4	NH4
					ppt	/100 ml	/100 ml	µg/l	µg/l	µg/l	µg/l
1	3/2/69	0.0	low	shoreline	29.0						
2	3/2/69	0.0	low	tidepool	7.0						
3	3/2/69	0.0	low	shoreline	32.0						
4	3/2/69	0.0	low	shoreline	24.0						
5	3/2/69	0.0	low	shoreline	28.0						
6	3/2/69	0.0	low	shoreline	25.0						
7	3/2/69	0.1	rising	shoreline	26.0						
8	3/2/69	0.1	rising	shoreline	31.0						
9	3/2/69	0.1	rising	shoreline	31.0						
				30 m offshore	32.0						
10	3/2/69	0.1	rising	shoreline	25.0						
				shore 3 m S	29.0						
	3/9/69	1.8	high	shoreline	34.0						
				20 m offshore	34.5						
	3/11/69	0.2	falling	shoreline	32.5	9	4	74.0	0.6	19.3	~0
11	3/2/69	0.1	rising	shore & offshore	*31.0						
	3/11/69	0.2	falling	shoreline	33.0	93	~0	18.9	0.5	8.9	~0
12	10/20/68	1.0	falling	shoreline	10.0						
				shore 30 m N	34.0						
				shore 10 m S	24.0						
	3/4/69	0.1	rising	shore	3.0						
				30 m offshore	23.0						
				30 m offshore, bottom (1 m)	27.0						
	3/9/69	1.8	high	shore	25.0						
				30 m offshore	29.0						
				30 m offshore, bottom (1 m)	32.0						
	3/11/69	0.2	falling	shore	5.5	93	9	727	0.6	141	~0
				30 m offshore	20.0	93	15	193	1.5	47.8	~0
13	10/20/68	1.0	falling	shore	10.0						
				shore 15 m N	30.0						
	3/4/69	0.1	rising	shore	17.0						
				20 m offshore	28.0						
	3/9/69	1.8	high	shore	31.0						
				20 m offshore	32.0						
	3/11/69	0.2	falling	shore	21.5	23	4	228	2.9	45.5	~0
				20 m offshore	24.5	1100	460	147	1.5	38.7	2.0
				20 m offshore, bottom (1 m)	26.5	240	23	130	1.4	47.1	6.0

Table 20 (cont.). Water quality data from brackish water sites around PUHO (Figure 29). All data are from surface samples except as noted. Col = Coliform, FC = Fecal coliform. Data are from Doty (1969).

Site	Date	Tide	Status	Description	Salinity	Col	FC	NO3	NO2	PO4	NH4
					ppt	/100 ml	/100 ml	µg/l	µg/l	µg/l	µg/l
14	3/9/69	1.8	high	makai end	9.0						
				mauka end	7.0						
	3/11/69	0.2	falling	surface, 1/4 m depth	8.0	93	43	232	3.2	65.4	11.7
15	3/1/69	0.2	falling	shoreline	24.0						
	3/9/69	1.8	high	shoreline	34.0						
	3/11/69	0.2	falling	shoreline	31.0	9	9	36.4	0.7	16.5	5.1
				replicated analyses:		9	9				
16	3/4/69	0.1	rising	surface, lowest reading	32.0						
				inlet mouth	34.0						
17	3/2/69	0.0	low	tidepool	**15.0						
	3/11/69	0.2	falling	tidepool, near heiau	31.0	9	9	97.1	0.8	20.9	11.9
				tidepool, draining into surf	34.5	~0	~0	~0	4.8	12.7	~0
				shoreline, 20 m W	34.5	15	3	2.6	0.1	4.3	~0
18	10/29/68	2.0	high	bay surface mean	34.0						
				1 m depth mean	35.0						
	3/8/69	0.0	low	bay surface mean	***34.0						
19	10/28/68	1.7	falling	shore	30.0						
				50 m offshore	33.0						
				100 m offshore	34.0						

* average; low = 29.0, high = 33.5
** average; low = 12.0, seaward end = 20.0
*** low = 33.0, high = 34.5

dilution line, consistent with the expected uptake of dissolved nutrients in the pond. These data thus suggest that groundwater reaching park coastal waters was not contaminated significantly by wastewater or fertilizer nitrogen or phosphorus in 1969, despite the potential for nutrient inputs from agricultural activity in the watershed and from a cesspool just inland of the sampling sites.

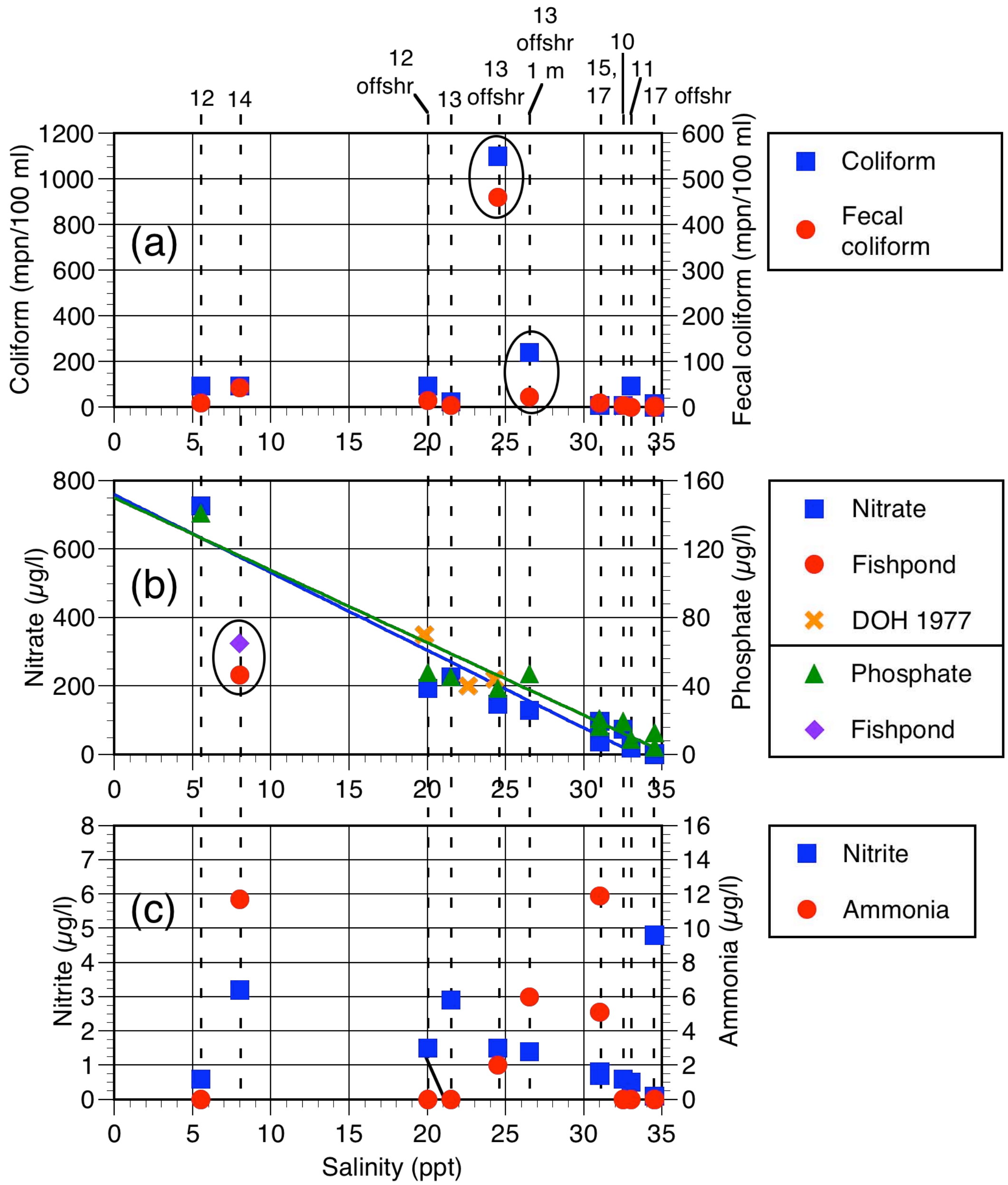

Figure 30. Water quality data from brackish sites around PUHO plotted against salinity. Site numbers from Figure 29 are shown at top, noteworthy data discussed in text are circled. Fishpond nitrate and phosphate data and nitrate data obtained by DOH in 1977 from Keone‘ele cove (~site 13) are plotted separately in (b) for comparison to other data. Nitrogen and phosphorus concentrations are in units of µg/l; see text for discussion of equivalent micromolar concentrations. Linear regressions in (b) (without fishpond data) are: Nitrate = -22.7S+758 (R^2 = 0.92), Phosphate = -4.23S +150 (R^2 = 0.93). Data primarily are from Doty (1969), nitrate data from 1977 DOH monitoring (Wolff unpubl.) are plotted separately in (b).

C.2.a.ii. Anchialine pools

Because anchialine systems exist in areas of brackish groundwater, and are influenced by tidal fluctuations, water quality varies considerably, particularly with respect to salinity and nutrients (Brock and Kam 1997). There are no numeric criteria for anchialine pools, but they are subject to narrative criteria that specify their protection for "scientific and educational purposes, protection of native breeding stock, baseline references from which human-caused changes can be measured, compatible recreation, aesthetic enjoyment, and other nondegrading uses which are compatible with the protection of the ecosystems associated with waters of this class" (Department of Health 2004). Although some work has been done on locating pools in the park and on collecting basic salinity and temperature data, the data are preliminary and probably are not suitable for analysis (M. Laber pers. comm. 2006). Published compilations of anchialine pools along the Kona coast have not included any pools in PUHO, although one pool has been noted at a site just south of PUHO in the village of Ki'ilae, within the proposed addition to the park. Maciolek and Brock (1974) sampled that pool on 8/20/1972 and recorded a salinity of 3 ppt. This pool frequently is referred to in historical documents, as it was used as a well by the inhabitants of the village (Greene 1993).

C.2.a.iii. Fishponds

The Royal Fishpond is classified as an anchialine pool under State criteria and thus would be subject to the inland water quality criteria listed above for anchialine pools. However, the large size of the Royal Fishpond compared to most anchialine pools results in a much longer residence time for groundwater in the pond, and thus for much larger potential impacts from groundwater contaminants.

The earliest water quality information for the Royal Fishpond are from Doty (1969), who described the northern pool as a "brackish pond, polluted and with an average depth of one foot [30 cm]", and noted that "a second regal fishpond in similar condition lies behind it". Water quality was obtained on two dates: 3/9/1969 (salinity = 9.0 ppt at the mauka end and 7.0 ppt at the makai end) and 3/11/1969 (salinity, coliform, fecal coliform, nitrate, nitrite, phosphate, and ammonia) (Table 20 Site 14), although he also observed that pool salinity "show[ed] no diurnal variation". All measurements appear to have been made in the north pool. Bacterial levels were similar to values in other brackish waters in the area (Figure 30a), despite the presence of a cesspool nearby. Nitrate and phosphate were elevated compared to offshore waters, but were depleted significantly compared to other brackish waters in the area due to biological uptake in the pond (Figure 30b). Nitrite and ammonia both were elevated slightly in the pond compared to most other brackish sites, probably due to biological sources in the pond, but concentrations of both were much lower than nitrate (Figure 30c).

Water quality in both pools of the Royal Fishpond was measured eight times over a period of 2 months in the summer of 1992 by students in the Oceanic Institute's Summer Aquaculture Workshop (Oceanic Institute et al. 1992). Water samples from two sites in each pool (Figure 31) were analyzed for temperature, pH, salinity, dissolved oxygen, and nutrients (Figure 32). All analyses were performed by workshop students, and some of the methods used were relatively imprecise, such as the use of a refractometer for salinity determination, and the use of Hach

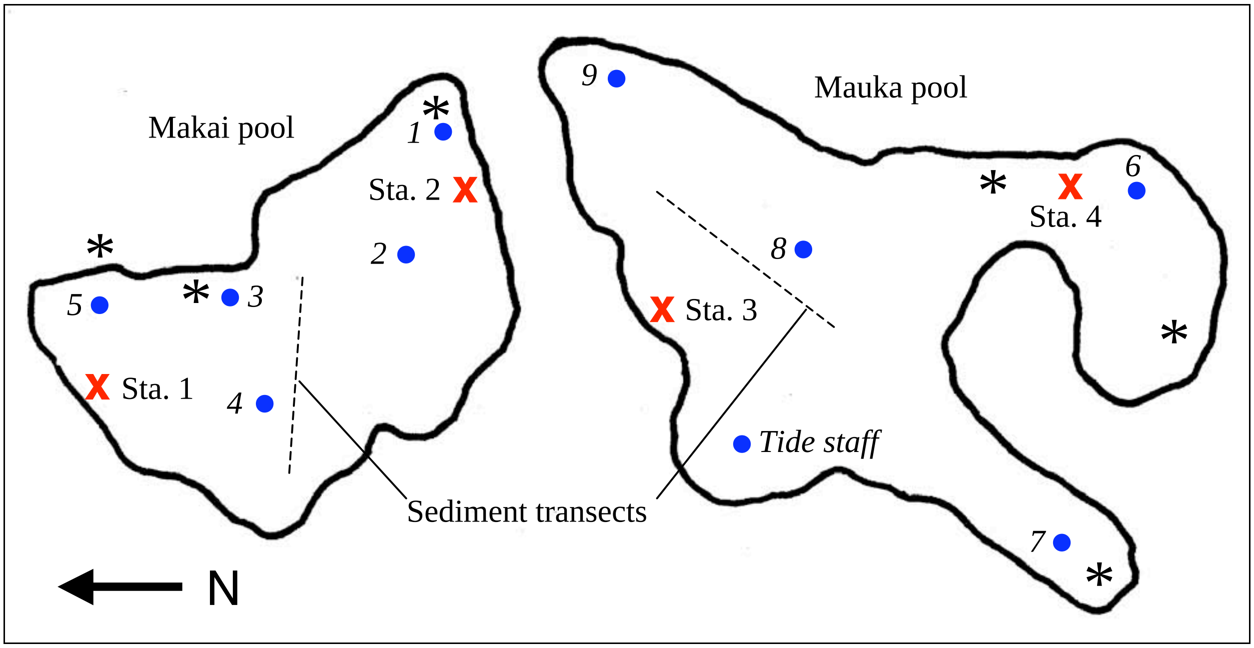

Figure 31. Sampling sites in Royal Fishpond pools used by Oceanic Institute et al. (1992) (X's labeled Sta. 1 – Sta. 4, sediment transects) and Chai (1999) (Blue dots labeled *1 – 9*, "*Tide staff*"). Asterisks denote locations of springs noted by Chai (1999). Figure redrawn from Oceanic Institute et al. (1992) and Chai (1999).

spectrophotometric methods for nutrient analyses. Significant fluctuations were seen in temperature, pH, and dissolved oxygen. Much of the variability in temperature may have been due to diurnal variability, as the range of values reported (26 – 34.5°C) is very similar to the difference between values recorded for morning samples and for afternoon samples. Some variation also may have been due to groundwater flow and tidal effects on the proportions of groundwater and seawater in the pools, as groundwater typically is cooler than seawater. Salinities mostly varied between about 9 and 15 ppt, and generally were higher than values observed by Doty (1969) (7 – 9 ppt). Values varied relatively consistently across sites, suggesting that most of the variation was due to changes in the overall proportions of groundwater and seawater in the pools, probably due to tidal fluctuations, although some unusually low values may reflect sampling near groundwater springs in the pools. Variations in pH and dissolved oxygen probably reflect primarily the effects of biological activity in the ponds (photosynthetic production of dissolved oxygen and consumption of dissolved inorganic carbon (raising pH) during the day, and respiratory consumption of dissolved oxygen and associated CO_2 production (lowering pH). Dissolved oxygen concentrations below 4 mg/l were observed on 3 of the 8 sampling dates, corresponding to oxygen saturations as low as 40%. These values suggest potentially significant oxygen stress in the pools, as much lower concentrations probably occurred at night (all measurements were made during the day) and in water closer to pool sediments, where much of the respiration takes place (samples were collected 10 – 15 cm/4 – 6" below the surface of the water). Anoxic conditions in pool sediments were noted based on the release of hydrogen sulfide when pond sediments were disturbed (Oceanic Institute et al. 1992).

Nutrients were measured in the pools on only three dates and at only one site in each pool (Figure 32). Nitrate concentrations ranged from about 16 to 46 μM, similar to or somewhat higher than would be expected from the single sample obtained in 1969 by Doty (1969). However, the values are within the range of values expected for groundwater mixing conservatively with seawater, so the increase may simply reflect less uptake by biota in the pond. Ammonia values are difficult to interpret, as several sets of values are available that appear to reflect different analytical procedures or calculations (Figure 32). Values reported by Oceanic

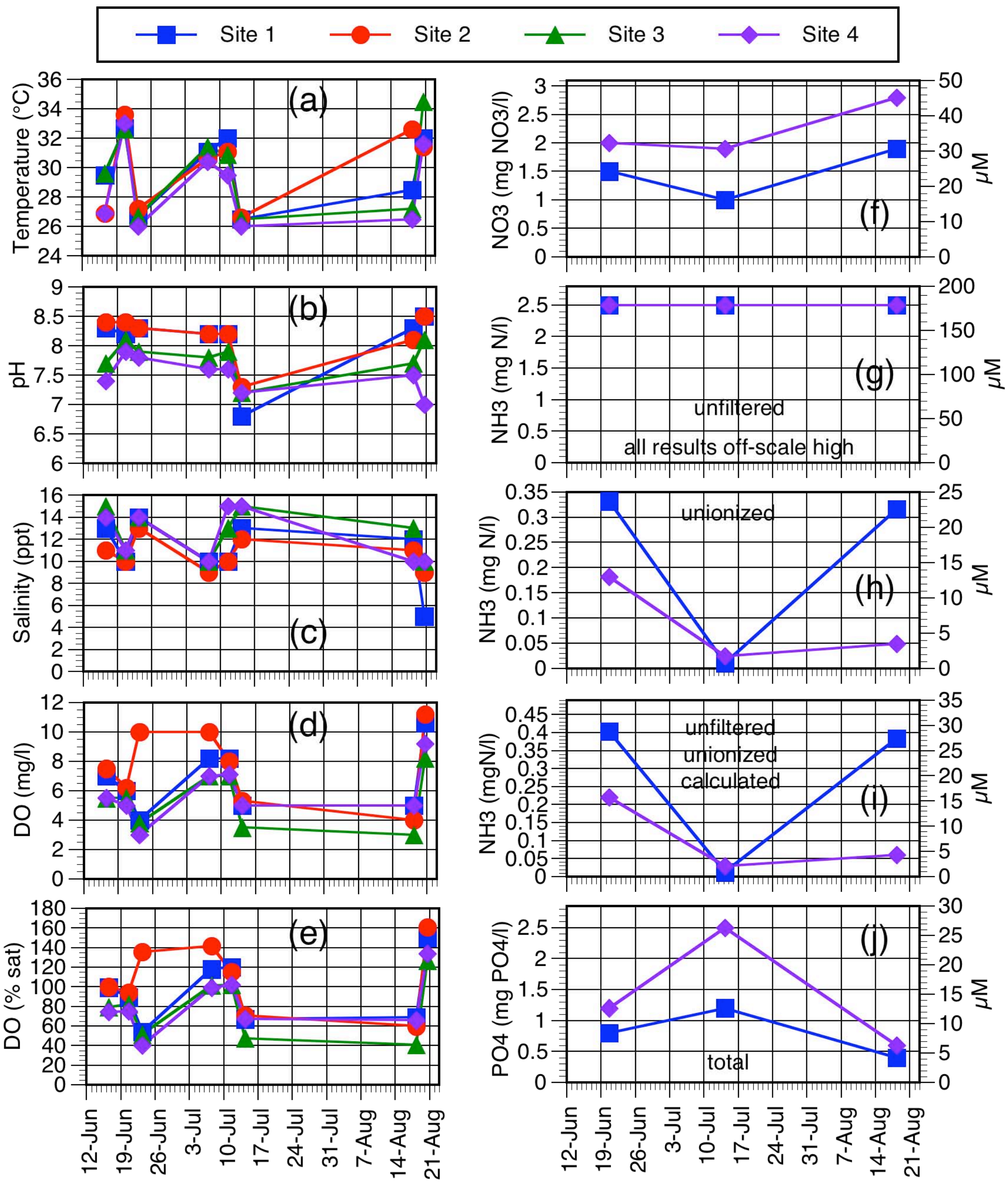

Figure 32. Water quality at four sites in Royal Fishpond in summer 1992. Data from Oceanic Institute et al. (1992) and Wolff (unpubl.) except oxygen saturation values which are estimated from oxygen, temperature, and salinity data.

Institute et al. (1992) are for unfiltered samples and all results were off-scale high (Figure 32g), indicating that concentrations exceeded 180 µM at both sites on all three sampling dates. These results would be exceptionally high for dissolved ammonia, and Oceanic Institute et al. (1992) note that they might reflect analytical errors. Other values reported in the USGS water quality database (Wolff unpubl.) are considerably lower, ranging from about 0.7 to 29 µM (Figure 32h and i), but even these values mostly still are well above the single 1969 value of 0.8 µM determined by Doty (1969). Unfortunately, ammonia analyses frequently are complicated by contamination issues, so it is not possible to say whether the high ammonia concentrations observed in 1992 reflect significant changes in water quality or analytical artifacts. Phosphate concentrations varied from about 4 to >26 µM, much higher than the 1969 value of about 2 µM observed by Doty (1969), and mostly well above concentrations expected in the absence of biological uptake (~4 µM). Thus, groundwater phosphate concentrations either had increased dramatically by 1992, or the high concentrations observed were due to other sources, for instance phosphate remobilized from sediment porewaters if sediments were disturbed prior to sampling.

Water quality was measured at 9 sites in the two fishpond pools in the summer of 1999 by Chai (1999) (Figure 31). Measurements were made on 11 days between 8/10/99 and 9/24/99, and included measurements of salinity using a refractometer, and of temperature, pH, and dissolved oxygen using handheld meters. All measurements were made midway between the surface and the bottom. Only a draft report containing no raw data is available, but summary statistics (Table 21) show values quite similar to those obtained by Oceanic Institute et al. (1992). Tidal fluctuations in the makai pond also were measured for comparison to ocean tides. Observations on 8/25, 8/28, and 9/2/99 showed that changes in water level in the mauka pond lagged tidal changes by 2:44 to 3:38. While these results seem relatively reasonable, no raw data are provided and it is unclear how the ocean tide was determined, so these results also should be interpreted cautiously.

Table 21. Summary water quality data from PUHO fishpond pools. Measurements were made on 11 dates between 8/10 and 9/24/1999. Data from Chai (1999).

Parameter	Mean	Std. dev.	Minimum	Maximum
Mauka (south) pool				
Temperature (°C)	28.437	1.901	26	31.6
pH	7.495	0.557	6.75	9.28
Salinity (ppt)	12.285	1.856	9	13
DO (mg/l)	6.146	2.304	3.03	9.65
Makai (north) pool				
Temp	28.621	2.132	26.4	35.3
pH	7.505	0.57	6.57	8.5
salinity	12.429	1.865	9	16
DO	6.178	2.358	1.84	13.3

C.2.a.iv. Wetlands

There are no specific numeric criteria for water quality in wetlands, and no water quality data for wetlands in PUHO.

C.2.a.v. Rocky and sandy intertidal

Intertidal rocky shoreline

Rocky intertidal areas along PUHO's coastline are designated Class I by the State of Hawaiʻi and are subject to specific criteria relating to deposition of flood-borne sediment. These criteria are related to water quality through the potential presence of fine, organic-rich sediment in overlying waters and the subsequent deposition of that sediment on intertidal areas. No data are available for quantitative evaluation of these criteria in PUHO's rocky intertidal areas, but given the general lack of sediment sources and transport mechanisms in and adjacent to the park, it seems unlikely that the criteria have been violated to any significant extent in the recent history of the park. Criteria may be violated during rare high-runoff events when Kiʻilae Stream discharges to coastal waters in the southern portion of the park, but no data are available to assess the frequency or severity of sediment inputs by this process.

Intertidal sand beaches

Sand beaches in PUHO are designated Class II by the State of Hawaiʻi and are subject to specific criteria relating to deposition of flood-borne sediment similar to those noted above for rocky intertidal areas. Although no data are available for evaluation of these criteria on PUHO's beaches, it seems unlikely that sufficient flood-derived sediments have been present in PUHO's coastal waters to result in significant violations. Some fine sediment may be winnowed from crushed coral fill used to replenish park beaches, impacting adjacent coastal waters, but no data are available to determine whether this represents a significant water quality issue.

C.2.a.vi. Coastal waters

Planktonic and pelagic resources

The overall quality of PUHO's coastal waters probably is most affected by the numerous brackish groundwater inputs along the shoreline, with less significant effects associated with inputs of contaminants from boats and individuals using park waters, from runoff from the visitor parking lot and the road fronting Honaunau Bay, and from occasional discharges from Kiʻilae Stream. Unfortunately, few data are available to support quantitative assessment of impacts associated with specific sources, and the effects of individual sources may vary significantly with the type of contaminant and how it is introduced into coastal waters. However, the persistent, strong natural discharge of brackish ground water along the shoreline (Doty 1969; Kay 1986; Gold pers. obs. 2005), and offshore at shallow subtidal reef depths (Doty 1969), suggests that this will be a major factor. In contrast, contamination from boats and people in the water is episodic and localized, and should be diluted rapidly, so contamination from these sources seems unlikely to affect park waters significantly. Runoff from the visitor parking area and the road fronting Honaunau Bay also occur only intermittently, and inputs should be diluted fairly rapidly. Inputs of nutrients and sediment due to rare high flow events in Kiʻilae Stream probably are significant, but also should be diluted and dispersed rapidly in coastal waters.

- Groundwater discharge

Groundwater discharge is the main pathway by which freshwater reaches the ocean in west Hawai‘i (Oki et al. 1999). Groundwater discharges in the PUHO area are important culturally and historically as brackish water from springs was used as drinking water and for other purposes (Greene 1993). Groundwater discharges have not yet been quantified in the PUHO area, but a modeling study for KAHO, north of PUHO, showed that groundwater flow through KAHO may have been reduced by as much as 50% between 1978 and 1997 due to upslope withdrawals, so groundwater development also seems likely to be impacting groundwater flow through PUHO. PUHO is known to be an area of significant groundwater discharge: Fischer et al. (1966) identified two major areas of freshwater discharges along PUHO's coast using infrared photographs (Figure 33), and Doty (1969) identified 18 coastal sites around the park with significant brackish water inputs (Figure 29). The greatest inputs were found at site 12 in Kapuwai cove (Figure 29), where water was observed pouring from rock fissures at low tide at a rate of 20 liters/minute (5 gallons per minute), and dogs were seen drinking from the streams. Strong discharge also was observed from the beach area in Keone‘ele Cove (site 13). More recently, a cooperative study between NPS and USGS has begun to address water quality and circulation in PUHO coastal waters; preliminary results show a complex pattern of freshwater and subterranean ground water discharges across the reef off PUHO (Gibbs et al. 2004). This complexity will make monitoring difficult, as the combination of focused/channeled groundwater inputs and temporally and spatially heterogeneous mixing in coastal waters will exacerbate temporal and spatial variability in water quality in nearshore areas.

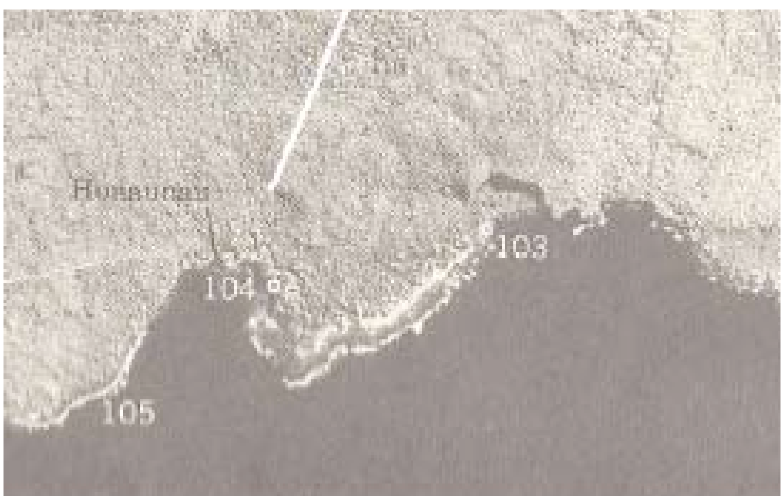

Figure 33. Freshwater springs noted in the PUHO area in 1966. Site 103 is in Alahaka Bay, Site 104 is in the vicinity of Keone‘ele Cove. From Fischer et al. (1966).

Both the quantity and quality of groundwater reaching PUHO coastal waters are affected by natural and human activities that affect recharge within and upslope of the park (i.e. withdrawals and additions, see *Groundwater* above), but water quality also can be affected by processes occurring in subaerial groundwater exposures in the park, i.e. in the Royal Fishpond, and in anchialine pools in the park. Groundwater passing through these features is warmed and chemically altered by exposure to the atmosphere and by biogeochemical processes in the pools.

As a result, the quality of groundwater reaching coastal waters may vary from that entering the park. In addition to variability due to spatial heterogeneity in upslope processes (contaminant inputs and reactions in subaerial pools), groundwater quantity and quality probably vary on seasonal, annual and longer time scales due to changes in natural recharge and human impacts, and on shorter time scales, such as those associated with storm events and tidal cycles. Groundwater heads in PUHO likely are small, with maximum water levels inside the park probably less than 1 –2 feet (0.3 – 0.6 m) above mean sea level (c.f., Oki et al. 1999), so large rainfall events might result in significant changes in groundwater heads and associated discharge. Oki et al. (1999) also noted that groundwater flows near the Kona coast probably vary significantly with tidal level, with flows actually reversing and flowing inland during high tides.

- Water quality

Water quality data for PUHO coastal waters are very limited. Doty (1969) performed some analyses of coastal water samples collected around the park (Table 20), but very few samples were analyzed for more than salinity, and sampling was targeted specifically to brackish waters, so no data are available from areas not affected by groundwater inputs. Bacterial data showed that there was contamination by cesspool effluent at one site (13) off of Keoneʻele Cove, both in surface samples and at 1 m (3’) depth, but none of the nearshore samples were contaminated (Figure 30a). Nutrient data were quite variable, but as noted above, plotting against salinity shows that nitrate and phosphate concentrations in most samples are consistent with simple dilution of high nutrient (but probably uncontaminated) groundwater by low-nutrient seawater (Figure 30b). Nitrite and ammonia did not show any relationship with salinity and occurred at much lower concentrations than nitrate (Figure 30c).

The Hawaiʻi Department of Health (DOH) monitored water quality at a site in Keoneʻele Cove from 1973 – 1977 and from 1996 – 1998. The DOH site should be comparable to Doty’s (1969) site 13 (Figure 29), but the only parameters measured in both studies are salinity, nitrate, total coliform, and fecal coliform, and only one data point is available for the latter three parameters, making comparisons difficult (Figure 28). Salinity data appear to show an increasing trend from 1969 to ~1997, consistent with the expectation that groundwater discharge probably has decreased with increasing withdrawals in upslope areas. Very few of the nutrient data have associated salinity values, so it is difficult to determine whether the observed concentrations reflect significantly different groundwater quality than that observed by Doty (1969), but three 1977 samples with salinity data plot very close to the dilution line obtained from Doty’s (1969) data (Figure 30b), suggesting that groundwater quality at that site did not change significantly between 1969 and 1977. The similarity is noteworthy, because until 1971 sewage from the park restrooms was disposed of using cesspools located just 34 and 53 m (37 and 58 yds) inland (Doty 1969). The data thus suggest that the degraded water quality observed in 1969 at site 13 may have been due more to simple groundwater effects than to the park cesspool impacts suggested by Doty (1969), although Okahara (1982) found high bacterial levels in Kapuwai cove in 1982 that they attributed to contamination from nearby domestic cesspools. It is difficult to assess historical changes in bacterial water quality at the Keoneʻele Cove site because Doty’s (1969) one measurement of total and fecal coliform produced very low values for both, and recent monitoring has used different indicators (*Enterococcus* and *Clostridium perfringens*). However, recent data appear to indicate relatively good conditions, with *Enterococcus* consistently below DOH criteria, and *C. perfringens* normally below the criterion as well.

C.2.a.vii. Subtidal benthic resources

- Reef flats and reef communities

PUHO's reef communities are designated Class I by the State of Hawai'i and are subject to specific criteria relating to deposition of flood-borne sediment, within-sediment redox potential, and grain size. Narrative criteria also stipulate that "no action shall be undertaken which would substantially risk damage, impairment, or alteration of … biological characteristics". As noted above for PUHO's rocky and sandy intertidal areas, sediment deposition is unlikely to be a significant issue in PUHO's coastal waters.

- Soft bottom communities

Soft bottom communities in PUHO's coastal waters would be designated Class II by the State of Hawai'i and would be subject to specific criteria for within-sediment redox potential. Only relatively small patches of primarily coarse sand sediment deposits have been identified in park coastal waters. The generally good quality of coastal waters and the very low inputs of sediment and organic material to coastal waters suggest that these and any other areas that might qualify as soft-bottom communities mostly would be in good condition. One exception may be the very limited area of subtidal sands adjacent to the beach in Keone'ele Cove, which may be impacted by foreign material winnowed from crushed coral fill used to replenish the beach.

C.2.b. Ecosystem effects

C.2.b.i. Groundwater/Anchialine Pools

Although groundwater contains biological resources, no data are available on the relationships between groundwater ecosystems and groundwater quality. However, anchialine pools are surface expressions of groundwater, so anchialine ecosystems may provide insights into water quality effects on both anchialine and groundwater ecosystems.

Anchialine ecosystems and associated species still are poorly understood (Brock 1985). Anchialine and other mixohaline fauna generally seem to be tolerant of a fairly wide range in water quality, at least with respect to salinity and nutrients (Brock and Kam 1997). Tolerance to other contaminants is less well known. Oil and grease pollution in an anchialine pool near Honokohau Harbor, north of PUHO, resulted in the disappearance of endemic shrimp from the pool, but these pollutants likely would not be transported effectively through groundwater due to sorption of contaminants to solid surfaces.

The historical water quality data discussed above suggest that groundwater quantity, and thus anchialine pool water quality, may have changed significantly due to human activities upslope of the park. The very few data available do not show evidence of major nutrient contamination, although ammonia and phosphate concentrations appear to be elevated in Oceanic Institute et al.’s (1992) fishpond samples. Brock and Kam (1997) and Nance (2000) argue that even relatively large changes in salinity and nutrient concentrations are unlikely to affect anchialine ecosystems because these parameters vary widely in natural systems, and because nutrients normally are present at relatively high concentrations and are not limiting to photosynthesis. Some anchialine systems may be more susceptible than others: mixing diagrams in Brock and Kam (1997) show significant nutrient depletion in many pools, with a few having very low nutrient concentrations, so nutrient additions to low-nutrient pools might stimulate plant production and impact pool ecosystems. However, most of PUHO’s anchialine pools appear to be small (D. Hoover pers. obs. 2004; M. Laber pers. comm. 2006) and water residence times should be very short, so they seem unlikely to deplete nutrients to limiting levels.

While salinity and nutrient changes seem unlikely to be having major impacts on PUHO’s anchialine ecosystems, other dissolved and particulate inputs may have significant impacts. There appear to be no major sources of urban or industrial contamination upslope of the park, but residential, agricultural, and light industrial development along Mamalahoa Highway could result in the introduction of a variety of chemical contaminants to groundwater. No testing has been performed to determine whether contaminants are present and in what quantities, so there is no way to assess potential impacts on biological resources in groundwater and anchialine pools, but the relatively sparse development upslope suggests that inputs probably are small and relatively dispersed. Activities within the park also may result in contaminant inputs, such as the historical use of diesel for burning debris piles and of herbicides to control vegetation in the park. Particulate inputs to pools likely are associated primarily with accumulation of organic matter produced within the pools or by adjacent terrestrial (often alien) vegetation, although at least one pool by the access road to the picnic area appears to be accumulating material from adjacent road fill, another pool is impacted by a nearby stockpile of plant waste from park maintenance activities, and a pool noted as a well on early archaeological maps was filled with sediment and rubble by hurricane Iniki in 1992 (D. Hoover pers. obs. 2004, M. Laber pers. comm. 2006). Accelerated sedimentation in pools reduces water exchange and can lead to premature pool senescence (Brock and Kam 1997).

Perhaps the most widespread and serious impacts on anchialine ecosystems are associated with the accidental or deliberate introduction of alien fish (Brock 1985). Brock and Kam (1997) noted that many of Kona’s anchialine ecosystems are in a state of biological change and that their unique attributes are being lost, primarily due to the introduction of exotic fishes (particularly poecilliids and tilapia) that prey on the shrimp and other crustaceans that naturally occur in the ponds. Healthy anchialine systems along the Kona coast commonly contain clear waters and a characteristic “cyano-bacterial, carbonate producing mat or crust comprised of an actively growing matrix of [algae], bacteria, diatoms, and protozoans, as well as [macroalgae] and the aquatic phanerogam, *Ruppia maritima*.” (Brock 1985), but predation on crustacean grazers and detritivores often leads to overgrowth of the characteristic mat/crust by macroalgae and the accumulation of detritus (Brock 1985). In addition, because ponds often exist in clusters that are connected at high tide or by subterranean passageways, exotic fish introduced into one pool frequently spread to nearby pools (Brock 1985). In KAHO, the spread of alien fish in anchialine pools from 1972 to 1997 was associated with a parallel decline in the percentage of ponds containing the characteristic anchialine shrimp *Halocaridina rubra* (Brock and Kam 1997). Alien fish are present in the Royal Fishpond, but *H. rubra* have been observed in at least one park pool (DeVerse and DiDonato 2005), and most of the anchialine pools in the park appear to be small, shallow, and relatively distant from the fishpond pools (D. Hoover pers. obs. 2004), so they may be relatively resistant to invasion by alien fish. Terrestrial aliens, such as ants and spiders, also may impact pool fauna (Foote 2005).

C.2.b.ii. The Royal Fishpond

Both pools of the Royal Fishpond contain a high proportion of groundwater (~55 – 75% during Oceanic Institute et al.'s 1992 sampling), and the residence time of groundwater in the pools will be much longer than in smaller anchialine pools, so groundwater quality clearly will play a major role in determining pond water quality and ecosystem function. As noted above, the limited data available suggest that nutrients in groundwater reaching coastal waters were not elevated significantly in 1969 or in 1977, suggesting that the apparently eutrophic conditions noted in the pools by Doty (1969) may have been due to natural processes, or to a combination of natural processes and localized nutrient subsidies from the adjacent cesspools. The pond currently contains a large population of alien fish (particularly tilapia and mosquito fish) (D. Hoover pers. obs. 2004), which have been present at least since 1992 (Oceanic Institute et al. 1992), and may have been introduced much earlier in an attempt to control excessive algal growth (M. Laber pers. comm. 2006). The presence of alien fish may be contributing to the current eutrophication of the pools, but the shallow depths in both pools (generally less than 0.5 m/1.5'), natural algal production in the pools, and the presence of vegetation around the pools likely would lead to relatively eutrophic conditions even without alien fish. Thus, although there may be water-quality related impacts on the pond ecosystem, the lack of data on groundwater and pond water quality coupled with the obvious effects of alien fish make it difficult to assess the importance of water-quality factors. One significant concern in eutrophic systems is dissolved oxygen depletion. Oxygen depletion was observed in surface water samples (~10 – 15 cm/4 – 6" depth) during Oceanic Institute et al.'s 1992 sampling, with daytime values as low as 3 mg/l corresponded to saturations of only ~40%. Values deeper in the water column and night-time values likely were much lower, and fish kills were observed on two of their study days. While they were unable to determine the cause of the kills, oxygen depletion may well have played a role. Pond sediments also may sequester toxic contaminants carried by groundwater or introduced via activities in or around the pools, resulting in the potential for biogeochemical conversion to new forms, and possible impacts on benthic and aquatic organisms and on organisms, such as birds, that feed on them. PUHO currently does not provide significant habitat for bird species of concern such as the endangered Hawaiian coot and stilt, so contaminants would be unlikely to affect these species.

C.2.b.iii. Wetlands

No water quality data are available for wetland areas, and there are no data on aquatic ecosystems in wetland areas except for plants (e.g., Doty 1969; Smith et al. 1986; Pratt and Abbott 1996; Pratt 1998). The spatial variability in groundwater discharges in coastal areas suggests that water quality impacts on wetland ecosystems will be localized around groundwater inputs. Sediments in wetland areas may accumulate toxic contaminants as noted above for fishpond sediments, resulting in potential impacts on wetland flora and fauna as noted above for pond organisms.

C.2.b.iv. Rocky and sandy intertidal

No chemical water quality data are available for rocky and sandy intertidal areas. Observations of intertidal ecosystems in 1957 by Kay (1986) suggest that there were no obvious indications of ecosystem degradation related to water quality at that time, and none of the more recent studies have noted significant changes in intertidal communities around PUHO. The most likely source of contaminants in intertidal areas would be groundwater discharging to tidepools or through rocky or sandy substrates. Increased nutrients in groundwater could enhance algal growth in intertidal areas; for instance *Ulva* sp. often is locally abundant around coastal groundwater seeps. Sessile flora and fauna also might accumulate pollutants if these were present in groundwater, resulting in pollutant transfer to higher trophic levels, such as waterbirds and turtles. However, no testing has been conducted in these areas, and in general, rocky and sandy intertidal areas should be relatively insensitive to contaminant inputs due to the short residence time of groundwater and seawater in these areas. Moderate increases in nutrient concentrations also may not have noticeable impacts because of the relatively high concentrations already present in natural groundwater.

C.2.b.v. Coastal waters

Planktonic and pelagic

The response of planktonic and pelagic organisms to aquatic pollutants depends heavily on pollutant concentration and duration of exposure. Because the biggest potential source of contaminants to coastal waters probably is groundwater, ecosystem impacts should depend primarily on the balance between groundwater supply and mixing in receiving waters. Groundwater is less dense than seawater, and in the absence of mixing by wind and waves, groundwater inputs will produce laterally extensive but relatively thin layers of brackish water floating on the sea surface. If calm conditions allow these layers to persist, gradual mixing between the surface layer and underlying seawater can result in a mixture of intermediate salinity that is suitable for the growth of marine phytoplankton, which then can grow rapidly in response to nutrients in the groundwater. The presence of toxic contaminants under these conditions could result in significant effects on phytoplankton populations due to increased concentrations and exposure times, with additional bottom-up effects on higher trophic levels. While these conditions occasionally may be found in enclosed bays or harbors (and in fishponds and anchialine pools), they are extremely rare in open coastal settings in Hawaiʻi. As a result, although groundwater additions clearly alter coastal water quality in the immediate area of discharges, there probably is relatively little impact on planktonic and pelagic biota under most conditions (Dollar and Atkinson 1992; Dollar and Andrews 1997). In PUHO, groundwater discharges in the areas of Kapuwai cove and Keoneʻele Cove produce a noticeable surface layer of brackish water that extends out into Honaunau Bay (Doty 1969), but no significant impacts on the planktonic or pelagic communities have been identified to date. Flushing of these areas due to tidal cycling and wave action probably keeps exposure times and contaminant impacts low, but possible inputs of contaminants from the visitor parking lot and from the road fronting Honaunau Bay may be a concern.

Subtidal benthic

As noted previously, the most significant pathway for contaminants reaching PUHO coastal waters probably is through groundwater discharge. Most of the groundwater discharge in the park probably occurs near the coastline, and because groundwater is more buoyant than seawater, groundwater floats to the surface and normally has little effect on subtidal benthos. Some groundwater does discharge subtidally through rocky and sandy substrates, so flora and fauna in these areas may be affected by groundwater quality, but no quantitative surveys have been performed to locate subtidal discharges or to assess possible impacts on benthic resources. Previous surveys of benthic resources generally concluded that benthic resources appeared healthy and typical of other West Hawaiʻi coastal areas (e.g., Doty 1969; Kimmerer and Durbin Jr. 1975; Kay 1986). One exception is the observation by Doty (1969) of degraded conditions in Keoneʻele Cove. However, data collected at that time suggest that cesspool effluent was not affecting water quality in the cove significantly (Figure 30), so the observed degradation may have been due to other causes, including the natural effects of groundwater discharging in the area.

C.2.c. Human health effects

Human health effects associated with water quality could result either from disease associated with water-borne pathogens, or from assimilation of toxic substances via consumption of contaminated aquatic organisms.

C.2.c.i. Groundwater

Groundwater in the park is not used for human consumption or for other purposes that might result in human contact, so groundwater does not pose a direct threat to human health. Groundwater does make up a significant portion of the water in the park's anchialine pools and in the fishpond pools. Potential human health effects in these areas are discussed briefly below.

C.2.c.ii. Anchialine pools

Anchialine pools historically have been used for a variety of purposes that may have human health implications. Bathing in pools may expose humans to bacteria in contaminated groundwater, and may increase the risk of disease transmission between users via bacteria left in the pool (Brock and Kam 1997). Some of the larger anchialine pools in Hawaiʻi were used as recently as 1972 for aquaculture, and harvesting of cultivated or natural pool resources [e.g. shellfish (hihiwai)] carries a risk of ingestion of toxins accumulated by the organisms. There have been no analyses of water quality in PUHO's anchialine pools or of organism tissues that would allow assessment of this risk, but the small size of PUHO's pools and the lack of major contamination sources upslope of the park suggest that the risk is low.

C.2.c.iii. The Royal Fishpond

The Royal Fishpond pools are relatively unattractive for contact recreation, and the historical emphasis in PUHO probably discourages visitors from wading in the pools. Fishing or harvesting from the pools also seems unlikely to be a common occurrence. As a result, exposure to fishpond water and to organisms in the pools likely is rare and the potential for human health problems due to water-borne pathogens or ingestion of contaminated resources probably is minimal.

C.2.c.iv. Wetlands

There are no data on the frequency with which visitors or park personnel utilize wetlands or vegetation in ways that might promote pathogen transfer, but this type of activity seems likely to be rare and human health risks very small. While some wetland organisms probably have the potential to accumulate toxic contaminants, upslope contaminant inputs seem likely to be small, and it seems unlikely that there is significant consumption of wetland organisms. Thus, the risk of human health issues related to wetland water quality seems very small.

C.2.c.v. Rocky and sandy intertidal

Bacterial contamination might occur in tidepools, but the residence time of water in pools usually is relatively low, so the risk of human health effects seems small. Health effects related to consumption of contaminated organisms also are possible, but probably are negligible. The most likely pathway for consumption of contaminated organisms probably is through shellfish, particularly native limpets, or opihi. However, there is no significant evidence of contamination by toxics in the park in general, and opihi generally occur at low densities in accessible areas of the Kona coast due to heavy harvesting pressure. As a result they probably do not represent a significant food resource in the park.

C.2.c.vi. Coastal waters

Planktonic and pelagic

Bacterial contamination of coastal waters may occur in association with discharges of contaminated groundwater, or due to discharges of waste from boats. There is significant visitor use of the beach area immediately north of PUHO, and boats regularly transit Honaunau Bay enroute to and from the small boat launching ramp in the bay. Okahara (1982) measured high levels of bacterial contamination in Kapuwai Cove that they suggested were due to contamination from cesspools in the area. Circulation in the bay appears to promote flushing (Doty 1969), so impacts in most areas probably are small, but there may be a slight risk of human health issues, particularly in the Kapuwai Cove area.

Fishing does occur in coastal waters off PUHO, and carries some risk of consumption of contaminated organisms. However, rapid mixing in coastal waters minimizes the residence time and adverse effects of contaminants in the water column, so fish and other pelagic organisms seem unlikely to be contaminated significantly. One possible pathway for transfer of contaminants to humans through fish caught in coastal waters adjacent to PUHO would be if the fish accumulated contaminants released from boats and vehicles using the small-boat launching ramp in Honaunau Bay. The risk associated with this pathway is not known, but some contaminants common in boat harbors (e.g., heavy metals) can bioaccumulate and might result in a human health risk.

Subtidal benthic

Some of the subtidal benthic resources in waters off of PUHO probably are harvested for consumption (e.g., octopus, lobster, sea urchins and snails are heavily fished in many areas in Hawai‘i). There are no data on contaminants in subtidal benthic resources adjacent to PUHO, but the generally good water quality in the area suggests that human health risk is low. As for pelagic resources, the most credible threat probably would be if boating-related contaminants are accumulating in benthic organisms in Honaunau Bay, but the magnitude of this threat is not known at this time.

C.3. List of impairments

None of the coastal water resources adjacent to PUHO are listed on the State of Hawai‘i's most recent 303(d) list of impaired waters (Koch et al. 2004).

C.4. List of water bodies with undocumented conditions/status

At present none of PUHO's water bodies are monitored sufficiently to establish compliance with water quality standards or to accurately assess the condition of associated ecosystems relative to water quality. There are no groundwater data, and for all practical purposes, no data from anchialine pools. Some data are available from the Royal Fishpond pools, but most of the data are old, incomplete, and of questionable quality. Some data also are available from brackish water sites along the coast, but most of the sites have not been sampled since 1969, and more recent (1998) data are limited to a single site in Keone‘ele Cove where only salinity and bacterial indicators were measured. While the relatively sparse development upslope of the park suggests that groundwater contamination may not be a major concern, groundwater quality is a major factor controlling water quality in PUHO's anchialine pools and fishpond pools, and at brackish water discharge sites along the coast, so groundwater quality data are essential for managing these resources. Groundwater flow also is an uncharacterized but important factor that affects the salinity and residence time of groundwater in the park and thus of water quality in the park's anchialine and fishpond pools. PUHO's anchialine pools are not well-characterized, and almost no data exist on water quality or ecosystem status in pools. While PUHO's anchialine pools are smaller and perhaps less spectacular than pools in other areas of the Kona coast, they may be important biogeographically, and anchialine pools are threatened by development in many areas of the state. The two fishpond pools are centrally located in the park and appear to be eutrophic, but no recent data are available to characterize water quality or ecosystem function in the pools. While current conditions may reflect natural processes, data on water quality and associated biological systems would facilitate management of this resource. Coastal waters adjacent to the park mostly are well-mixed by natural processes, making them relatively insensitive to most land-derived pollutants, and appear to be in good condition. Extensive monitoring thus does not appear to be warranted, although sampling at the coastal sites used by Doty (1969) could provide useful data on groundwater quality, and possibly on quantity. The one coastal area that may warrant more detailed study is Keone‘ele Cove, and possibly adjacent Kapuwai cove, where historical surveys have identified degraded benthic habitat and bacterial pollution thought to be associated with land-derived pollutants. While available data suggest that conditions in Keone‘ele Cove may actually have been due to other factors, the available data are sparse and very old, and at least a cursory study of environmental conditions and water quality in these areas seems warranted.

D. ISSUES AND THREATS TO COASTAL RESOURCES

D.1. Coastal development

D.1.a. Population & land use

Population growth and coastal development are major issues in West Hawai‘i and pose potentially significant threats to PUHO’s coastal resources. From 1990 to 2000, population in the State grew by 9%, while the population of North and South Kona grew by about 24% (http://www.hawaii-county.com/planning/konaroads.htm). More recent data show that from July 1, 2003 to July 1, 2004, Hawai‘i county had the highest growth rate in the State (Table 22). Growth-driven changes in land use are expanding urban areas at the expense of conservation and agricultural lands in many areas in West Hawai‘i, although areas adjacent to and upslope of PUHO thus far have been spared major developments. Development in the South Kona district (where PUHO is located) still is dominated by agriculture, with approximately 2000 acres of coffee and 4000 acres of macadamia nuts providing the largest employment base, supplemented by small-scale diversified agriculture, floral and nursery production, and some ranching (http://www.hiedb.org/strategy.html). Development upslope of the park currently includes a commercial coffee farm, livestock ranching, houses, highways, and parking lots (Daniel and Minton 2004). Recent and historical land use proposals that would have impacted PUHO’s resources include expansion of the boat launching ramp facility in Honaunau Bay or the construction of a new facility in the northwest corner of the bay (Madden 1980; Okahara 1982), and a residential project adjacent to the park’s southern boundary that would have developed land in what is now the proposed Ki‘ilae addition to the park. While major development has not yet occurred in the immediate area, development plans are continuing for lands adjacent to the Ki‘ilae parcel, and development trends in West Hawai‘i suggest that it is only a matter of time before significant new development occurs. Upslope developments can contaminate groundwater that subsequently flows downslope to the park, and coastal developments may impact nearby PUHO resources via increases in sediment, nutrient, and other chemical pollutants, introduction of alien species, alteration of habitat around the park and thus of the potential for dispersal and colonization of species in the park, and through increased visitor use and associated impacts. For instance, in November 2000, heavy rains resulted in runoff and sediment losses from construction sites in the Hokulia Development Project, ~3 km (2 miles) north of Kealakekua Bay, that produced visible sediment deposits on corals in Kealakekua Bay. The development currently is on hold pending the resolution of lawsuits brought by community groups, but a recent newspaper article (Thompson 2006) suggests that construction probably will resume in the near future, and that the issues resolved by the lawsuits may facilitate additional development in the area. Habitat impacts also may be associated with the construction of marinas, breakwaters, and seawalls, and with grading and paving of nearshore areas that result in the loss of existing anchialine habitats and of the potential for new anchialine habitats under conditions of future sea level rise and island subsidence.

Table 22. Population change by county in the State of Hawaiʻi (Gima 2005).

	July 1, 2004	July 1, 2003	% Change
Hawaiʻi County	162,971	158,735	2.7
Honolulu County	899,593	893,358	0.7
Kalawao County (Kalaupapa)	126	130	-3.1
Kauai County	61,929	60,736	2.0
Maui County	138,221	135,796	1.8
State of Hawaiʻi (total)	1,262,840	1,248,755	1.1

In addition to impacts associated with new development, population growth will increase the impacts of existing developments. For instance, increasing population is likely to result in increased demand on the small-boat launching ramp in Honaunau Bay, with attendant increases in visitor and boat traffic. Increased usage likely would increase impacts in a number of areas, including nutrient and chemical pollutant loading to park waters, marine debris, boat groundings and turtle strikes, underwater noise, introduction of alien algae and invertebrates, and recreational impacts associated with increased fishing, SCUBA, and snorkel diving.

Increased resident and visitor populations also will result in increased park visitation, with attendant impacts on park coastal water resources. Visitation is associated with impacts like increased garbage and animal waste and direct inputs of contaminants to park waters. Visitors also may take items from tidepools and fishpond pools. For instance, because corals in the intertidal zone are conspicuous and can be taken easily without swimming, they often are removed as ornamental curios by visitors (Parrish et al. 1990). Native edible limpets are heavily harvested from intertidal areas along the Kona coast, and cowries and other large shelled and unshelled (octopus) mollusks also may be collected for food or decorative purposes. The presence of visitors around nearshore habitats may stress turtles, fish, and invertebrates in shallow pools, ponds, and on beaches, and visitor activity around bird habitats in the park stresses waterbirds, making the already marginal habitat even less suitable for bird use (cf., Morin 1998). Recreational fishing in coastal waters adjacent to the park may be impacting fish populations, and impacts likely will increase in the future, but neither the park nor the State of Hawaiʻi collects recreational catch or effort data suitable for assessing the effects of recreational fishing on these resources.

D.1.b. Surface and groundwater withdrawals and inputs

No surface water resources are utilized in the PUHO area, but developments adjacent to and upslope of the park affect groundwater flow and quality via groundwater pumping and wastewater disposal, and via increases in impervious surfaces that enhance surface water runoff and infiltration. Oki et al. (1999) modeled groundwater flow in KAHO, and showed that withdrawals had a negligible effect on flow through the park in 1978, but that by 1997 there was sufficient pumping capacity to reduce groundwater flow through the park by 47%. Pumping in the PUHO area probably is lower, but may still have a significant impact on groundwater flow through the park, and pumping probably will increase with population growth and development in the area. Development impacts on recharge probably already are significant, as increases in impervious surfaces and storm runoff collection systems enhance and concentrate contaminated runoff into infiltration areas, and wastewater disposal primarily is through cesspools and septic systems that produce localized inputs of contaminated water at multiple sites in the watershed. Changes in groundwater withdrawals and recharge thus could have significant impacts on PUHO's coastal water resources, particularly its anchialine and fishpond pools.

D.1.c. Park maintenance

Maintaining archaeological and cultural resources in PUHO historically has required extensive removal and disposal of vegetation and application of herbicides (see Herbicide use). During at least one period in the early 1960's, disposal was via burning at multiple sites throughout the park, with diesel fuel used as a fire starter (V. Bio pers. comm. 2006). Currently, a significant amount of plant waste is stockpiled at a location that is impacting an adjacent anchialine pool (D. Hoover pers. obs. 2004). Potential impacts of chemical contaminants associated with these activities on coastal water resources are difficult to assess due to the variety of chemicals used, the lack of data on actual contaminant inputs and reactivity in PUHO's unique environment, and the lack of data on the sensitivity of biological resources to specific contaminants, but the potential for contaminant transport in groundwater to anchialine pools, fishpond pools, wetlands, and intertidal suggests that these activities may represent a threat to these resources.

D.2. Nuisance species

Invasive species are a major concern in Hawai'i due to the unusual vulnerability of Hawaiian ecosystems to alien introductions, particularly in terrestrial ecosystems. Hawaiian marine ecosystems have been thought to be somewhat more resistant to alien introductions than terrestrial systems due to their lower degree of endemism (Eldredge and Carlton 2002), but most areas have not been surveyed extensively for invasives and the vulnerability of specific ecosystems probably varies. Because PUHO's coastal water resources include both offshore marine waters and brackish inland waters, both terrestrial and marine invasive species potentially can impact coastal water resources. Organisms other than plants or animals that can seriously affect biological resources include microbes and fungi. Viruses are linked to the occurrence of fibropapilloma tumors on green sea turtles (Herbst and Klein 1995), and the occurrence and extent of tumors may be related to water quality in certain areas of the main Hawaiian Islands (Larry Basch pers. comm. 2005). Coral diseases also recently have been documented in Hawai'i, including on Kona reefs, and are believed to be caused by pathogenic microbes or fungi (Larry Basch. pers. comm. 2005).

D.2.a. Terrestrial plants and animals

Alien plants are a significant problem in PUHO, as they are in most developed coastal areas in Hawai'i (Pratt 1998). Of particular concern are alien species in PUHO's wetlands and around the Royal Fishpond pools that may displace native species (e.g., the historical colonization by the alien pickleweed *Batis maritima*) and species such as *Leucaena leucocephal*a (Koa haole, Ekoa), *Pithecellobium dulce* (Manila tamarind, opiuma), and *Schinus terebinthifolius* (Christmas Berry) that currently are accelerating eutrophication and pool senescence via production of leaf litter and encroachment on open water areas.

Mongooses, rats, mice, goats, domestic and feral cats and dogs, and wild pigs all have either been seen in the park or are known to be established in the area (Morin 1998; DeVerse and DiDonato 2004; DeVerse and DiDonato 2005). Herbivores can impact native plants in PUHO's wetland, anchialine pool, fishpond, and coastal strand communities. Predators prey on herbivores, represent a significant hazard to birds, and may harass native animals, such as turtles and monk seals. Invasive insects and spiders also may impact biological resources; alien ants prey on anchialine crustaceans at low tide, and alien spiders prey on native insects (Foote 2005).

D.2.b. Algae

Alien and invasive algae are considered a major threat to coral reef ecosystems in Hawai‘i (Davidson et al. 2005). Invasive algae have had significant impacts on reef ecosystems on Oahu, but appear to be less established on the other islands. In a 2000 survey of several sites along the Kona coast north of PUHO, only one site was found to have an invasive species (*Acanthophora spicifera*) (http://www.hawaii.edu/ssri/hcri/rbi/hawaii/honokohau_bay.htm; Smith et al. 2002). The same species was found to be abundant inside Kaloko pond in KAHO in 2000 (Marine Research Consultants 2000), and is the subject of ongoing management/eradication efforts by KAHO park staff. A recent survey of macroalgae in intertidal and subtidal areas around PUHO found *A. spicifera* at two intertidal sites, but the algal community generally appeared healthy and the presence of *A. spicifera* is not thought to represent a significant threat at this time (C. Squair pers. comm. 2006). Macroalgae historically have been noted to be only a small component of the biota in coastal waters around the park, and the risk of introductions probably is small compared to areas such as KAHO that are located next to major harbors.

D.2.c. Fish and aquatic invertebrates

Introduced fish and invertebrates can have significant impacts on brackish and marine ecosystems in and adjacent to PUHO. Invasive fish already appear to be having significant impacts on endemic species and habitat in PUHO's fishpond pools – the presence of alien fish in anchialine habitats commonly leads to a reduction in grazing and detrital processing by endemic shrimp, resulting in increased algal growth, debris accumulation, and accelerated senescence of the ponds. Introduced shrimp and prawns also may compete with or prey on native shrimp, altering the ecological balance in anchialine environments.

Alien fish and invertebrates also could have significant impacts on coastal ecosystems in and adjacent to PUHO. No data are available on alien invertebrates, but several introduced fish are present in PUHO's coastal waters, including the peacock grouper or roi (*Cephalopholis argus*), black tail snapper (to‘au - *Lutjanus fulvus*), and blue-striped snapper (ta‘ape - *Lutjanus kasmira*). Parrish et al. (1990) suggested that roi and to‘au might have relatively insignificant effects on the natural community structure in KAHO's coastal waters, but that ta‘ape might produce significant impacts due to their "piscivorous habits and extreme abundance achieved over a short time in many areas". These and other fishes will be part of long-term community monitoring efforts by NPS Pacific Islands Coral Reef Program staff in future studies (Larry Basch pers. comm. 2005).

D.3. Physical impacts

Significant physical impacts to PUHO's coastal resources by visitors are unlikely as most resources are robust and park guidelines discourage visitor activities that might damage fishpond walls or other vulnerable resources. Inside the park, the most obvious physical impact issue probably is with overflow of stockpiled plant waste into one of the park's anchialine pools (D. Hoover pers. obs. 2004). In coastal waters adjacent to the park, some impacts to benthic resources might occur in association with diving, fishing, and boating. Fishing and diving also may have some minor impacts on benthic substrates, but a study at a popular nearby SCUBA diving site in Kealakekua Bay showed no significant physical effects due to diving activity (Tissot and Hallacher 2000), and no significant impacts were observed in an area frequented by aquarium fishermen in KAHO (Tissot and Hallacher 2003). Boating may have significant local impacts where boat groundings occur, and some contact with the substrate in Honaunau Bay probably does occur, particularly in shallow nearshore areas around the small-boat ramp, but benthic substrate in these areas mostly is sparsely colonized basalt, so contact in these areas probably has minimal impacts on the benthic substrate and associated flora and fauna. The most significant physical impacts to coastal water resources in and around the park probably occur in association with rare but highly destructive tidal waves.

D.4. Global change

D.4.a. Sea level rise

Apple and MacDonald (1966) documented the effects of recent sea level rise on PUHO's coastal resources, noting that many cultural resources and man-made coastal features, such as bait cups, net-tanning tubs, and playing boards, were submerged and unusable for their original purpose. More recent data show that sea levels are continuing to rise: from 1946 to 2002, sea level at Hilo (Figure 1) rose an average of 0.34 cm/y (0.13"/y), likely due both to global sea level rise and local subsidence of the island (Hapke et al. 2005). Global sea level almost certainly will continue to rise due to global climate change, and the island of Hawai‘i will continue to sink as the mass of the growing volcanic edifice depresses the underlying oceanic crust. As a result, PUHO's beaches and other intertidal resources will slowly be inundated, with the intertidal zone moving further inshore. One result will be that nearshore mixohaline resources, such as tidepools, will become more saline, some intertidal resources will become permanently subtidal, and new anchialine pools in the park will be formed where local topographic depressions drop below sea level. However, these changes will take place relatively slowly and probably will not affect the overall condition of the resources significantly. Cultural resources in or just above intertidal areas, such as the Sun Stone and culturally significant pools, will be more affected, as they will become progressively less accessible. Increasing sea level will increase the depth and areal extent of the Royal Fishpond pools, particularly the southern pool and its extension into the Pu‘uhonua grounds, and rising sea level likely will continue to erode the beach at the head of Keone‘ele Cove, potentially altering the effectiveness of the sand barrier between the north pool and Honaunau Bay.

D.4.b. Climate change

Global climate change may impact PUHO's coastal water resources through the effects of increasing air and sea temperatures, and through the effects of changes in the frequency and intensity of storms. The impacts of these changes on coastal water quality and associated flora and fauna are difficult to predict, but might be significant, for instance if changing climate alters upslope rainfall and groundwater recharge, affecting groundwater flow through the park. Changes in the frequency and intensity of storms also could affect the direction and intensity of wave energy reaching PUHO's shoreline, affecting the distribution of sand along the coast, potentially adding to or eroding the beach at the head of Keone‘ele Cove, and likely altering the distribution, abundance, and diversity of organisms in nearshore areas subject to storm disturbance. Increased temperatures also correlate with increased coral bleaching and the susceptibility of corals to disease.

D.4.c. Increasing atmospheric carbon dioxide

In addition to its greenhouse-gas role in altering global temperatures and climate, atmospheric carbon dioxide (CO_2) plays important roles in both aquatic photosynthesis and in carbonate biogeochemistry. Increasing atmospheric CO_2 results in higher levels of dissolved CO_2 in coastal waters, increasing the availability of CO_2 for photosynthesis and changing the concentrations of the carbonate ions that buffer ocean pH, or acid-base balance, ultimately increasing seawater acidity. Increases in dissolved CO_2 probably will not enhance aquatic photosynthesis significantly in the park, because other nutrients (usually nitrogen or phosphorus) usually are more limiting and CO_2 always should be present at concentrations well in excess of plant needs. However, the addition of atmospheric CO_2 to ocean waters is increasing seawater acidity, which may lead to increased dissolution of carbonate minerals (i.e., the biominerals secreted by many marine organisms, including corals and calcifying marine algae), and may also inhibit organisms' ability to secrete biominerals in the first place. Increasing CO_2 thus may affect PUHO's aquatic communities in the Royal Fishpond pools and nearshore intertidal areas, which are areas of very active photosynthesis and carbonate synthesis, and in subtidal areas where the growth of corals and a number of other marine organisms depends on calcification, and where reef accretion depends on coral growth and the ability of calcifying marine algae to cement reef rubble into solid substrate. Increasing CO_2 also may affect the health of hermatypic zooxanthellate corals indirectly by altering the competitive balance between calcification and primary production by symbiotic zooxanthellae (Langdon and Atkinson 2005).

D.5. Fisheries

Fishing and collecting of marine organisms is allowed in intertidal areas and coastal waters around PUHO (Daniel and Minton 2004), so harvesting may represent a threat to resources in these areas. Traditional harvesting for opihi (*Cellana* spp.), pipipi (*Nerita* spp.), a‘ama (the crab *Grapsus grapsus*), and wana (*Centrechinus paucispinus* - collected seasonally for their edible gonads), occurs along the shoreline and in tidepools (Else 2004), and subtidal harvesting of octopus, lobster and food fish probably impacts local populations (Doty 1969). Kay et al. (2005)

noted that opihi harvesting may have interfered significantly with their attempts to monitor growth at a site near the southern boundary of the park (only 30 of 300 tagged individuals were recovered in their first study, and only 4 of 165 were recovered in a second study), although tag retention problems also may have been a factor. Their analysis of reproductive state and size data showed that the existing State size limit (31 mm; applicable to harvesting of all *Cellana* spp.) is much too low for *C. talcosa*, which matures at a much larger size (40 – 45 mm) and thus will be impacted disproportionately by harvesting. Fishing in the PUHO area probably occurs mostly around Honaunau Bay, both from shore and by boat, but there are no data available on catch or effort. In 1999, PUHO's coastal waters were designated as an aquarium Fish Replenishment Area (FRA), and aquarium fish collecting was prohibited. Monitoring prior to and following the ban showed significant increases in species targeted by aquarium fishers in several West Hawai'i FRAs, but monitoring is not conducted in PUHO's coastal waters, so the effects of the FRA on aquarium fish populations around PUHO are not known. Other fishing activities are allowed subject to size and season limits applicable to all State waters, but the majority of fishable/harvestable waters are outside of PUHO's jurisdiction so park staff have no authority to regulate activities in these areas, and monitoring and enforcement by the State of Hawai'i are very limited.

D.6. SCUBA/Snorkeling

Honaunau Bay is considered one of the best snorkeling sites along the Kona coast, so snorkelers frequently can be found just off of the northern boundary of the park. Park personnel encourage visitors to access the water from sites outside the park, so most access occurs from rocky outcrops just north of Kapuwai Cove. SCUBA diving probably is less common, but also occurs. Snorkelers and divers seem unlikely to have significant physical impacts on benthic resources, as most of the areas frequented by snorkelers are too deep to stand, and shallow water areas susceptible to trampling are only sparsely colonized by corals. A recent study of SCUBA impacts on deep benthic resources in Kealakekua Bay showed no significant impacts (Tissot and Hallacher 2000).

E. SUMMARY AND RECOMMENDATIONS FOR ADDRESSING EXISTING IMPAIRMENTS, POTENTIAL IMPACTS, AND INFORMATION GAPS

E.1. Summary

Table 23 summarizes existing impairments and the potential for impairment of PUHO's coastal water resources based on available data and our best professional judgement. Brief rationales for the classifications listed in Table 23 are provided below.

E.1.a. Surface water

Surface water is not included as a resource for assessment of impairments in Table 23 because there are no perennial streams or other surface water bodies in the main park parcel. The lower portion of Ki'ilae Stream crosses the southern end of the main park parcel, but the stream is intermittent in its lower reaches and no data are available for water quality or biological resources in this area.

Table 23. Existing and potential impairments in PUHO's coastal water resources.

Stressor	Ground-water	Anchialine Pools	Royal Fishpond	Wetlands	Intertidal	Coastal Waters
Water Quality						
Nutrients	OK	PP	PP	OK	OK	OK
Fecal bacteria	OK	OK	OK	OK	OK	PP
Dissolved oxygen	OK	PP	PP	OK	OK	OK
Metal contamination	OK	OK	OK	OK	OK	PP
Toxic compounds	PP	PP	PP	PP	OK	PP
Increased temperature	OK	OK	OK	OK	OK	PP
Water Quantity						
Changing GW flux	OK	PP	PP	PP	OK	OK
Population Effects						
Fish/shellfish harvest	na	OK	OK	OK	PP	PP
Invasive species	PP	PP	EP	EP	EP	PP
Physical impacts	na	PP	OK	OK	OK	OK
Behavioral impacts	na	OK	PP	OK	PP	OK
Habitat Disruption						
Sea level rise	OK	OK	PP	PP	PP	OK
Sound pollution	na	OK	OK	OK	OK	PP
Light pollution	na	OK	PP	OK	OK	PP

EP - existing problem, PP – potential problem, OK – not currently or expected to be a problem, shaded - limited data, na - not applicable.

E.1.b. Groundwater

There is no data on groundwater in the park. Very limited water quality data are available from three groundwater wells north of and upslope of the park, but water quality in these wells may not be representative of groundwater transiting the park. Some information on groundwater quality can be inferred from brackish coastal water samples obtained in 1969 and 1977, but no recent data are available. The lack of obvious contaminant sources in the watershed, and the apparently low level of nutrient contamination in samples obtained in 1969 and 1977 suggest that the risk of significant groundwater contamination is fairly low. However, groundwater may provide important habitat for hypogeal anchialine organisms, so potentially toxic contaminants may be a concern, as are invasive species that could displace endemic hypogeal species.

E.1.c. Anchialine pools

Anchialine pools are rare, and associated ecosystems are poorly understood. There are several pools in the park, but the number and locations of the pools are not well characterized, and no quantitative data are available to assess water quality or biological conditions. Anchialine pools are affected significantly by groundwater quality, but because the probability of groundwater contamination seems low, groundwater contaminants also seem unlikely to be a major issue for anchialine systems. However, the lack of data on park pools suggests that it is prudent to leave open the possibility that contamination by nutrients and toxic compounds, such as herbicides used in the park, could be an issue. Information obtained from park personnel and observations made during a site visit suggest that several pools may be impacted by natural and anthropogenic sediment inputs, including stockpiling of plant waste near one pool which is resulting in physical impacts and seems likely to also affect dissolved oxygen levels and water chemistry in the pool. Pool ecosystems also may be impacted by changes in groundwater flow due to upslope development. While anchialine ecosystems in general appear to be relatively tolerant of variations in salinity, temperature, and nutrients, tolerance probably varies from pool to pool, and they may be vulnerable to toxic contaminants. Anchialine pools provide habitat for some rare and candidate endangered species, such as the orange-black damselfly (*Megalagrion xanthophelas*), which may be vulnerable to changes in habitat and to predation by alien species, such as orb-weaver spiders (Foote 2005).

E.1.d. The Royal Fishpond

The Royal Fishpond was studied briefly in 1969, 1992 and in 1999. Water quality data are of questionable quality and the quantity of data and parameters measured are insufficient for a complete assessment, but the data do show significant nutrient uptake from groundwater inputs and large fluctuations in dissolved oxygen, both of which are consistent with the elevated productivity and respiration expected in large, shallow eutrophic pools. Both fishpond pools contain significant accumulations of sediment that may contain residues from herbicides and other chemicals used in the park. Biological observations show that the fishpond pools are impacted heavily by alien fish, particularly tilapia and mosquito fish.

E.1.e. Wetlands

PUHO’s wetlands primarily are associated with the Royal Fishpond pools, especially the southern pool and an associated extension that crosses into the pu‘uhonua grounds. Wetlands are rare in west Hawai‘i, so PUHO’s wetlands provide potentially important habitat for insects, plants, and transient birds. No water quality data are available, but there is no obvious indication of water quality impacts on PUHO’s wetland biota. Alien species that displace native species have been an issue in the past, and woody aliens that produce large quantities of leaf litter and encroach on open water areas (e.g., opiuma (*Pithecelobium dulce*), Koa haole (*Leucena leucocephala*) and Christmas Berry (*Schinus terebinthifolius*)) are a significant issue.

E.1.f. Intertidal

Biological resources in PUHO's intertidal have received only cursory study, but there is no indication that they are impacted significantly by water quality changes or by invasive species. A potentially invasive alien alga (*Acanthophora spicifera*) recently has been documented in the park, but does not appear to be a significant threat at this time. Recreational harvesting of intertidal organisms may be a significant issue, particularly of heavily exploited resources like endemic limpets (opihi). Intertidal zones provide significant habitat for green sea turtles (*Chelonia mydas*), and potential habitat for threatened hawksbill turtles (*Eretmochelys imbricata*) and endangered Hawaiian monk seals (*Monachus schauislandi*), creating potential conflicts with visitor activities in these areas.

E.1.g. Coastal waters

Coastal waters include both pelagic and benthic habitats, from subtidal sands to extensive coral communities, that support a diverse community of resident and transient fish, reptiles, mammals, invertebrates, and other organisms, including turtles, monk seals, spinner dolphins, sharks, manta rays, and threatened humpback whales (*Megaptera novaeangliae*) offshore of the park. Studies that have addressed pelagic and benthic biological resources generally have concluded that they are in good condition, although several alien fish are established in park waters, and stressors such as sound and light pollution and behavioral impacts due to visitor activities (e.g. wading, swimming, snorkeling, SCUBA diving, and boating) have not been addressed. Water quality in Keone‘ele Cove may be negatively affected by sediment and contaminants from crushed coral fill used along the beach at the head of the cove, but no data are available to quantify possible impacts. Although coastal waters and associated biota adjacent to the park probably are relatively tolerant of contaminant inputs due to the strong natural dilution characterizing Hawai‘i's coastal waters, contaminant inputs from the visitor parking lot, from adjacent residences, and from the boat launch in Honaunau Bay are possible concerns. Other stressors that warrant additional study and monitoring include the potential for increased coral bleaching and disease with increasing ocean temperatures, and the continuing potential for alien species introductions, including pathogens that may result in disease in corals and other organisms.

E.2. <u>Recommendations</u>

While PUHO's coastal water resources mostly appear to be in relatively good condition, there are known impairments in some areas and potential impairments in others (Table 23). However, even areas with known impairments lack sufficient data to document existing conditions adequately and to determine the degree to which park resources are impacted, and many areas where impairments are likely have no data at all. As a result, there are significant and fundamental information needs for the park related to most of the known and potential impairments in Table 23. These are listed below, followed by recommended courses of action for other known impacts and issues. Some of the information needs will be addressed by studies currently planned for the park and by "Vital Signs" monitoring planned under the NPS Inventory and Monitoring Program. Ongoing and planned studies are noted where appropriate, but details of Vital Signs monitoring are not yet available, so the relevance of those activities to issues identified below cannot be determined at this time. It should be noted that for all of the recommended water quality studies, the potential for vertical stratification and water quality gradients due to the presence of groundwater mixing with underlying seawater makes it extremely important that sampling be performed using protocols that control and document the depth at which samples are collected, preferably with parallel data on associated depth variations in salinity.

E.2.a. Information needs

E.2.a.i. Water quality

Groundwater supply and quality

1. Conduct a preliminary study of groundwater dynamics and quality in the park. Water quality parameters should include T, S, DO, and dissolved inorganic nutrients. Additional parameters can be analyzed (e.g., degradation products of diesel fuel and herbicides used in the park, and contaminants likely to be introduced upslope of the park) if appropriate. "Total" N and P probably can be omitted, as the analyses are expensive and the resulting data provide little insight into ecosystem processes. Use the resulting information and available data on groundwater development in the upslope watershed to estimate the potential impacts of groundwater development on flow through the park (cf., Oki 1999), and to assess the sensitivity of anchialine systems to variations in water quality (cf., Brock and Kam 1997). Monitoring of groundwater dynamics will require one or preferably a few monitoring wells in the park, but some data may be available from existing wells upslope of the park, and some aspects of groundwater quality also can be inferred from coastal water samples at sites of brackish water discharge (cf., Figure 30).

2. Monitor groundwater dynamics and groundwater quality in the park on roughly a weekly basis for at least a year to characterize variability associated with factors that may impact groundwater discharge (e.g., seasonal changes in upslope recharge, intermittent storms).

Water quality in anchialine pools

1. Perform an initial survey of water quality in anchialine pools in the park. While Brock and Kam (1997) argue that anchialine pool ecosystems in general are relatively insensitive to changes in water quality, there are no baseline data for park pools with which to assess current conditions or future changes. In addition, because anchialine pools are subaerial exposures of groundwater, water quality in anchialine pools probably can be used to infer groundwater quality at greater spatial resolution than would be possible with monitoring wells alone. Analyses probably could be limited to basic water quality parameters (T, S, dissolved inorganic nutrients, chlorophyll-*a*), although additional parameters (e.g., toxic contaminants noted above for groundwater) could be analyzed if needed.

Water quality in the Royal Fishpond

1. Conduct a rigorous study of water quality in both pools of the Royal Fishpond with the goal of characterizing the impacts of groundwater nutrients and biological processes in the pools on pool water quality and on the potential for restoration of one or both pools to less eutrophic conditions. The study should include an assessment of the role of pond sediments in pool water quality and the impacts and feasibility of removing some or most of the sediments in the pools (note that sediments apparently were removed three times in the 1970's, but no details were available for this report). Previous water quality studies have suffered from poor quality control and relatively haphazard sampling and analytical approaches - initial measurements should include the full suite of basic water quality parameters (T, S, DO, inorganic species of nitrogen and phosphorus, silica, chlorophyll-*a*), and sampling should be designed to address expected diurnal variations in production and respiration as well as tidal impacts on water levels and the relative contributions of groundwater and seawater to pool water. Water sampling can be focused primarily on surface waters, but where possible high resolution (cm-scale) depth profiles of temperature, salinity, and dissolved oxygen should be collected simultaneously with water samples to characterize stratification and bottom-water oxygen levels. Dissolved organic nitrogen and phosphorus probably can be omitted as these parameters are difficult and expensive to measure and probably would not provide significant insight into pond ecosystem function. Measurements to be used to characterize 'typical' conditions and long-term (>months) trends should be conducted at similar tidal conditions and time of day, as water quality probably varies significantly with both factors. At least one set of high-frequency measurements (e.g. hourly sampling for 12 – 24 hours, if possible combined with continuous monitoring of T, S, and DO using an automated recording instrument) should be made to characterize variations in water quality associated with tidal and diurnal effects.

2. Perform limited analyses of pool water and sediment samples for toxic contaminants to assess the potential for contaminant release from sediments or delivery via groundwater. Sampling of fish or other organism tissue also may be appropriate for some contaminants.

3. Establish long-term monitoring of water quality in the Royal Fishpond pools. Monthly sampling probably would be appropriate, but the sampling interval, locations, and parameters measured should be determined based on the results of items 1 and 2 above.

Water quality in coastal waters

1. Characterize the locations and intensity of groundwater inputs to coastal waters. Some data already may be available from an ongoing USGS study examining groundwater fluxes to coastal waters (cf., Grossman et al. 2006). Water quality sampling at the sites used by Doty (1969) would provide insight into potential changes in groundwater discharge over time as well as into groundwater quality (cf., Figure 30).

2. Characterize water quality in Honaunau Bay and at an offshore site off of the southern portion of the park, possibly off of Ki'ilae Stream. Baseline data on water quality in

coastal waters that are relatively unaffected by brackish water inputs are needed to provide an appropriate context for interpretation of the effects of brackish water inputs.

3. Establish long-term monitoring of nearshore water quality at the DOH site in Keoneʻele Cove, and at a site in Kapuwai cove. Previous studies have shown that these areas are impacted significantly by groundwater discharges, with potentially significant impacts on associated nearshore ecosystems and possible human health risks associated with bacterial and other pathogens from cesspools in the area. Thus, monitoring should include bacterial indicators in addition to basic water quality parameters. Monitoring should be coordinated with recently initiated DOH monitoring at sites 001244 and 001245 (‘2 step’ and ‘Boat Ramp’) (T. Teruya pers. comm. 2006).

E.2.a.ii. Biological resources

Anchialine pools

1. Map, describe, and document the biological status of anchialine pools in the park. Discussions with park personnel indicate that there are a number of pools in the park, but basic data on pool locations, size, and condition are not available, although a recent survey of biological resources (Tango et al. submitted 2005) should provide useful data when it becomes available.

2. Monitor the status of anchialine pools and associated biota, including rare and endangered species as appropriate. Anchialine pools in the park may be important biogeographically, as anchialine pools appear to be scarce in the PUHO area, and may provide habitat for rare and endangered species. Monitoring should be designed based on the results of item 1 above and the recent biological survey (Tango et al. submitted 2005) to provide data on the long-term status of anchialine ecosystems in the park and on any associated species of interest.

The Royal Fishpond

1. Characterize ecosystem structure and function in the Royal Fishpond to evaluate the impact of alien fish on ecosystem function. Include an assessment of the feasibility and benefits of removing alien fish from one or both pools. Alien fish (tilapia and mosquito fish) have been established in both fishpond pools since at least 1992 and probably much earlier, but the relatively small size of the fishpond pools, particularly the northern pool, suggests that removal of alien fish might be possible. However, removal alone might not be sufficient to restore the pools to pre-invasion conditions, as other factors also may be impacting the pools, such as excessive sediment accumulation. Thus, an ecosystem-level assessment of the pools is needed to determine whether the pools can be restored to pre-invasion conditions and how best to approach the restoration. One possibility suggested by the existing pool configuration is to restore the northern pool to conditions suitable for stocking food fish, which might require dredging a significant proportion of the existing sediments from the pool, but to perform a less extensive restoration on the southern pool,

removing alien fish but leaving most of the sediments in place and maintaining the southern pool complex as a pond/wetland system.

2. Establish long-term monitoring of ecosystem status in the Royal Fishpond pools. Monitoring is needed both to assess existing ecosystem function and to determine the long-term effects of any restoration efforts, including early warning of any new alien species introductions.

3. Assess the feasibility and benefits of eradicating alien plants from park wetlands. Wetlands are rare in West Hawaiʻi and PUHO's wetlands provide potentially important habitat for native species, including some rare and candidate endangered species. PUHO's wetlands also provide a unique opportunity to educate visitors on the importance of wetlands in West Hawaiʻi and their role in Hawaiian culture.

Intertidal areas

1. Perform a quantitative survey of biological resources in rocky intertidal zones in the park. Previous intertidal surveys have produced a substantial amount of anecdotal information but have not used quantitative methods, so appropriate baseline data are not available to assess the current status of these resources, or to assess future trends in resource condition. Some data on opihi biology are available from recent work performed by Kay et al. (2005), and algal species and abundance data should be forthcoming from a rapid assessment project that conducted initial fieldwork in November and December of 2005, with additional fieldwork scheduled for summer 2006 (C. Squair pers. comm. 2006).

Coastal waters

1. Perform quantitative surveys of fish populations in Honaunau Bay for comparison to recent and historical assessments and ongoing WHAP monitoring at other Kona sites, including alien species. Recent (~2005) data acquired by Beets and Friedlander (in prep) probably will be suitable for assessing the current status of fish, but may need to be evaluated for comparison to earlier studies, and for its suitability for assessment of future trends.

2. Perform quantitative benthic community surveys along permanent transects to assess benthic community structure and condition, including invasive species and coral bleaching and disease. Consider utilizing transects used by previous investigators if appropriate.

3. Establish a long-term monitoring program to assess benthic ecosystem status using permanent transects used in item 2 above. Monitoring should be designed to detect long-term changes in ecosystem health, including potential effects of development and recreation in the area (e.g., effects of boating and diving, introduction of alien species and coral disease). The number of transects and the monitoring interval should be established after consultation with coral reef ecologists familiar with Kona reef conditions and should be conducted to take advantage of ongoing monitoring by CRAMP at other Kona sites.

4. Consider performing an initial assessment of sea turtle numbers, size, and condition in waters adjacent to the park. The study should be coordinated with ongoing work in KAHO and with other monitoring in West Hawaiʻi by NMFS. If appropriate, this assessment could be coordinated with a planned herpetological inventory of West Hawaiʻi parks (F. Klasner, pers. comm. 2006).

E.2.a.iii. Recreational and development impacts

1. Summarize pesticide and other chemical use in the park and assess the potential for impacts on coastal water resources.

2. Obtain quantitative or at least semi-quantitative data on recreational fishing catch and effort in waters adjacent to the park, including intertidal areas.

3. Obtain quantitative or at least semi-quantitative data on recreational snorkeling and SCUBA activity in the park.

4. Characterize frequency and type of use of the small-boat launching ramp adjacent to the park and of boating activities in Honaunau Bay.

5. Perform a preliminary assessment of underwater noise pollution in coastal waters adjacent to the park and the potential for impacts to biological resources.

E.2.b. Recommendations for existing/potential impairments

1. If determined to be feasible and beneficial, remove tilapia and mosquito fish from Royal Fishpond pools.

2. If justified by study, remove sediments from one or both fishpond pools.

3. If determined to be feasible and beneficial, eradicate invasive wetland plants from the park.

4. Monitor invasive algae in intertidal and subtidal areas around the park.

5. Consider working with the State of Hawaiʻi to prohibit harvesting of endemic Hawaiian limpets (opihi) in intertidal areas around the park.

6. Increase public education regarding fishing regulations in and around the park.

7. Collaborate with researchers working in the park to maximize the relevance of ongoing and planned studies to park needs for basic, robust data on water quality and aquatic biological resources in the park.

8. Expand park interpretive materials to include information on park water resources and their vulnerability to development in and around the park.

9. Expand park interpretive materials to include information on culturally significant coastal water resources, such as brackish springs, the ‘Sun Stone’, Keawe-wai tidepool, Kekuai‘o tidepool, coastal bait cups, net-tanning tubs, and the submerged offshore formation reputed to be of Hawa‘e.

10. Coordinate with appropriate State agencies to provide informational materials to boaters using the small-boat launch to minimize pollutant releases and impacts to coastal water resources.

11. Collaborate with the State of Hawai‘i and others to enhance the level of resource protection and conservation of adjacent lands and coastal waters, including Honaunau Bay.

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APPENDIX B. INTERTIDAL AND NEARSHORE SUBTIDAL MARINE BIOTA

Marine biota observed in 1957 in PUHO intertidal and nearshore subtidal zones. See Figure 14 for regions surveyed. Table from Kay (1986).

	Tidepool	Inlet	Coast	Subtidal
COELENTERATES				
Pocillopora damicornis	x			
Pocillopora meandrina var. *nobilis*				x
Porites sp.	x			
Dendrophyllia manni	x			
Cyphastrea ocellina	x			
PORIFERA				
Spirastrella keaukaha	x			
Black Sponge	x			
ANNELIDS				
Terebellid	x			
Eurythoe sp.	x			
MOLLUSCA				
Gastropods				
Bursa bufonia	x			
Cerithium nesioticum	x			
Conus abbreviatus	x			
Conus distans	x			
Conus hebraeus	x	x		x
Conus imperialis	x			
Conus lividus	x			x
Conus nanus	x	x		
Conus rattus	x			
Conus vermiculatus	x			x
Cymatium chlorostoma	x			
Cymatiun gemmatum	x			
Cymatium pileare	x			
Cypraea caputserpentis,	x			
Cypraea isabella	x			
Cypraea moneta	x			
Cypraea reticulata	x			
Drupa morum			x	
Drupa ricina			x	
Helcioniscus exaratus			x	
Littorina pintado	x	x		

APPENDIX B (cont.). Marine biota observed in 1957 in PUHO intertidal and nearshore subtidal zones. See Figure 14 for regions surveyed. Table from Kay (1986).

	Tidepool	Inlet	Coast	Subtidal
MOLLUSCA (cont.)				
Gastropods (cont.)				
Melanella cumingi midpacifica	x			
Mitra litterata	x			
Morula ochrostoma		x		
Morula tuberculata		x		
Natica macrochiensis	x			
Nerita picea	x	x		
Peristernia chlorostoma	x			
Phenacolepas sp.		x		
Rhizochilus madreporum	x			
Siphonaria sp.		x		
Strombus maculatus	x			
Thais harpa	x	x		
Turris sp.	x			
Vexilla taeniata	x			
Opisthobranchs				
Haminoe crocata	x			
Hexabranchus sp.	x			
Hydatina amplustre	x			
Micromelo guamensis	x			
Lamellibranchs				
Anomya nobilis	x			
Brachidontes cerebristriatus	x			
Ctena belIa	x			
Isognomon costellatum	x			
Isognomon incisum	x			
Periglypta edmonsoni	x			
Spondylus hawaiensis	x			x
ECHINODERMATA				
Asteroids				
Asterope carinifera	x			
Linkia multiflora	x			
Unidentified small red sp.	x			
Echinoidea				
Centrechinus paucispinus	x			x
Echinometra mathaei mathaei	x		x	x
Echinometra mathaei oblonga	x			x

APPENDIX B (cont.). Marine biota observed in 1957 in PUHO intertidal and nearshore subtidal zones. See Figure 14 for regions surveyed. Table from Kay (1986).

	Tidepool	Inlet	Coast	Subtidal
ECHINODERMATA (cont.)				
Echinoidea (cont.)				
Eucidaris metulari	x			
Heterocentrotus mammillatus	x			x
Lytechinus verraculatus	x			
Podophora atrata			x	
Tripneustes gratilis	x			x
Holothuria				
Actinopyga mauritiana	x			x
Chiridota rigida	x			
Holothuria atra	x			x
Ophiodesoma spectabilis	x			
Stichopus sp.	x			
Ophiuroidea				
Ophiocoma erinaceus	x			x
Ophiocoma pica	x			x
ARTHROPODA				
Crustacea				
Carpiloides bella	x			
Grapsus grapsus		x		
Leander debilis	x			
Leptodius sanguinensis	x			
Leptodius sp.	x			
Pachygrapsus minutus	x			
Platypodia eydouxi	x			
Pseudosquilla ciliata	x			
Stenopus hispidus	x			
Cirripedia				
Cthalamus hembeli			x	
Unidentified purple sp.		x		
BRYOZOA				
Loxosoma sp.	x		x	
FISHES				
Abudefdef abdominalis	x			x
Acanthurus triostegus	x			x
Aprion virescens				x
Bothus sp.	x			
Cantherines sandwichensis				x

APPENDIX B (cont.). Marine biota observed in 1957 in PUHO intertidal and nearshore subtidal zones. See Figure 14 for regions surveyed. Table from Kay (1986).

	Tidepool	Inlet	Coast	Subtidal
FISHES (cont.)				
Chaetodon fremblii	x			x
Dascyllus albisella	x			
Myripristis murjan				x
Naso unicornis				x
Ostracion cubicus	x			x
Polydactylis sexfilis				x
Priacanthus cruentatus				x
Selar crumenopthalmus				x
Sphyraena helleri				x
Thalassonia umbrostigma				x
ALGAE				
Asparagopsis	x		x	
Boodlea composita	x			
Chnoospora pacifica			x	
Cladophora	x	x		
Dictyosphaeria	x			
Gracilaria	x	x		
Hydroclathrus clathratus	x			
Jania	x			
Laurencia		x	x	
Padina	x		x	
Porolithon			x	
Sargassum			x	
Sphacellaria	x		x	
Turbinaria	x		x	
Ulva			x	
Valonia	x			

APPENDIX C-1. MARINE MOLLUSKS IN HONAUNAU BAY

Checklist of marine mollusks from Honaunau Bay, circa 1957 – 1969, with comparison data from Kealakekua Bay, Hawai‘i and Poipu, Kauai. From Doty (1969).

GASTROPODS	Honaunau Bay	Kealakekua Bay	Poipu
Diodora granifra	X	X	X
Tugali oblonga		X	
Cellana exarata	X		X
Cellana sandwichensis	X	X	X
Cellana talcosa	X	X	X
Euchelus gemmatus	X	X	X
Trochus histrio	X	X	X
Gibbula marmorea	X	X	X
Thalotia rubra	X	X	X
Thalotia subangulata			X
Phasianella variabilis	X	X	X
[*1] *Leptothyra rubricincta*	X	X	X
[*2] *Leptothyra verruca*			X
Synaptocochlea concinna	X		X
Turbo argyrostoma	X	X	X
Nerita picea	X	X	X
Nerita polita		X	X
Theodoxus neglectus	X	X	X
[*3] *Theodoxus cariosa*	X		
Littorina picta	X	X	X
Littorina pintado	X	X	X
[*4] *Littorina undulata*	X		
Peasiella tantilla	X	X	X
Planaxis labiosa	X	X	X
Phenacolepas sp.	X	X	X
[*5] *Barleeia* sp.	X		X
Rissoina ambigua	X	X	X
Rissoina gracilis	X		X
Rissoina miltozona	X	X	X
Rissoina triticea	X		X
Rissoina turricula	X	X	X
Parashiela sp.	X		X
Merelina sp.		X	X
Zebina tridentata		X	X
Cyclostremiscus minutissimus	X		X
Vitrinellid sp. 1	X		
Vitrinellid sp. 2	X		
Risoella sp.	X		X
Assiminea sp.		X	X
Caecum sepimentum	X		X
[*6] *Bittium parcum*	X		X
Bittium zebrum	X	X	X
Cerithium atromarginatum	X	X	X
Cerithium interstriatum	X		X
Cerithium nesioticum	X	X	X
[*7] *Cerithium pharos*		X	
[*7] *Cerithium granifera*		X	

APPENDIX C-1 (cont.). Checklist of marine mollusks from Honaunau Bay, circa 1957 – 1969, with comparison data from Kealakekua Bay, Hawaiʻi and Poipu, Kauai. From Doty (1969).

GASTROPODS	Honaunau Bay	Kealakekua Bay	Poipu
*7 *Cerithium columna*		X	
Obtortio sp.	X		X
Scaliola sp.	X		X
Plesiotrochus souverbianus		X	X
Cerithiopsis spp.	X		X
Vanikoro sp.		X	X
Fossarus sp.	X	X	X
Modulus tectum		X	X
Dendropoma sp.			X
Serpulorbis sp.	X	X	X
Vermetus sp.		X	X
Triphora spp.	X(2)	X(10)	X
Balcis sp.		X	X
Leostraca metcalfei		X	X
Mucronalia nitidula	X		X
Stilifer mittrei		X	X
Epitonium spp.		X	
Strombus maculatus	X		X
Hipponix australis	X	X	X
Hipponix grayanus		X	X
Hipponix foliaceus	X	X	X
Hipponix pilosus	X	X	X
Cheilea equistris		X	
Crucibulum spinosum		X	
Erato sandwichensis		X	X
Cypraea fimbriata	X	X	X
Cypraea mauiensis		X	
Cypraea moneta	X		X
Cypraea poraria		X	X
Cypraea teres		X	X
Cypraea caputserpentis	X	X	X
Cypraea maculifera	X	X	X
Cypraea mauritiana	X	X	X
Cypraea tigris		X	X
Trivia insecta		X	X
Trivia edgari		X	X
Trivia rosacea		X	X
Charonia tritonis		X	X
Cymatium nicobaricum	X	X	X
Cymatium pileare	X	X	X
Bursa bufonia	X		
Cassis cornuta		X	X
Heliacus implexa		X	X
Polinices sp.		X	X
Natica marochiensis	X	X	X
Kogomea sandwichensis	X	X	X
Volvarina sp.			X
Aspella sp.	X	X	X

APPENDIX C-1 (cont.). Checklist of marine mollusks from Honaunau Bay, circa 1957 – 1969, with comparison data from Kealakekua Bay, Hawaiʻi and Poipu, Kauai. From Doty (1969).

GASTROPODS	Honaunau Bay	Kealakekua Bay	Poipu
Coralliophila sp.		X	X
Drupa morum	X		X
Drupa ricina	X	X	X
Drupa rubusidaeus		X	X
[*8] *Maculotriton serriale*			X
Morula brunneolabru	X		
Morula granulata	X	X	X
Morula ochrostoma	X	X	X
Morula uva	X		X
Provexillum fusconigra	X		X
Provexillum vexilla	X		X
Nucella harpa	X	X	X
Rhizochilus madreporarum	X		
Thais intermedia		X	
Engina iodosia			X
Euplica varians	X	X	X
[*9] *Mitrella fusiformis*	X	X	X
[*9] *Mitrella margarita*	X	X	X
Seminella varia	X		X
Columbellidae		(4 sp.)	
Peristernia chlorostoma	X		X
Latirus nodatus		X	
Buccinidae		(4 sp.)	
Turridae		(23 sp.)	
Carinapex minutissima	X		X
Daphnella interrupta			X
Iredalea exilis	X		X
Kermia harenula	X		X
Kermia pumila	X		X
Daphnella producta	X		X
Macteola segesta		X	
Mitra cancellarioides	X		
Mitra cucumerina	X		X
Mitra litterata	X	X	X
Mitra spp.		(3 sp.)	(3 sp.)
Conus abbreviatus	X	X	X
Conus catas	X		X
Conus chaldaeus	X	X	X
Conus distans	X		X
Conus flavidus	X		X
Conus lividus	X	X	X
Conus sponsalis	X	X	X
Conus ebraeus	X	X	X
Conus imperialis	X		
Conus miles		X	

APPENDIX C-1 (cont.). Checklist of marine mollusks from Honaunau Bay, circa 1957 – 1969, with comparison data from Kealakekua Bay, Hawai‘i and Poipu, Kauai. From Doty (1969).

GASTROPODS	Honaunau Bay	Kealakekua Bay	Poipu
*10 *Conus pulicarius*		X	
Conus rattus	X		X
*11 *Terebra affinis*		X	
*11 *Terebra argus*		X	
*11 *Terebra felina*		X	
*11 *Terebra guttata*		X	
*11 *Terebra inconstans*		X	
*11 *Terebra hectica*		X	
*11 *Terebra penicillata*		X	
*11 *Terebra strigilata*		X	
Siphonaria normalis	X	X	X
Melampus sp.	X	X	X
Pedipes sp.	X	X	X
Laemodonta bronni	X	X	
Atys sp.		X	
Atys semistriata		X	X
Haminea crocata	X		X
Haminea simillima	X		
Bullaria adamsi	X		X
Bullina scabra		X	X
Julia exquisite		X	X
Pyramidellid sp.			X
*12 *Otopleura mitralis*		X	
*12 *Pupa thaanumi*		X	
*12 *Pyramidella sulcata*		X	
Umbraculum		X	X
Smaragdinella calyclulata	X	X	X
Aplysia parvula		X	X
Dolabrifera dolabrifera	X	X	X
Stylocheilus longicaudus	X		X
Elysia reticulata		X	X
Glossodoris lineata		X	X
Onchidium sp.		X	X
Dendrodoris nigra		X	X
Hexabranchus sp.	X		X
Hydatina amplustre	X		X
Micromelo guamensis	X		X

BIVALVES			
Acar plicata		X	X
Hemicardium mundum		X	X
Nesobornia ovata	X	X	X
Periglypta reticulata	X	X	X
Ctena bella	X	X	X
Spondylus sp.	X	X	X
Ostrea hanleyana	X	X	X
Isognomon perna	X	X	X

APPENDIX C-1 (cont.). Checklist of marine mollusks from Honaunau Bay, circa 1957 – 1969, with comparison data from Kealakekua Bay, Hawai‘i and Poipu, Kauai. From Doty (1969).

BIVALVES	Honaunau Bay	Kealakekua Bay	Poipu
Isognomon californicum	X	X	
*13 *Pecten* sp.		X	
*13 *Pinguitellina robusta*		X	
*13 *Tellina* spp.		X	
*13 *Macoma* sp.		X	
*13 *Angulus* sp.		X	
Hormomya crebristriatus	X	X	X
Pinna muricata	X		X
Chama iostoma	X	X	X
Pinctada radiata	X	X	X
Ervilia sp.	X		X
Anisodonta angulata	X		X
Arcinella sp.	X		

AMPHINEURA			
Ischnochiton viridis	X		X

*1. *Leptothyra rubricincta* is very common at both Honaunau and Kealakekua Bays but uncommon at Poipu, Kauai.

*2. *Leptothyra verruca* is one of the dominant trochids at Poipu, Kauai but is apparently absent at both Honaunau and Kealakekua.

*3. *Theodoxus cariosa* occurs only in still brackish and freshwaters.

*4. *Littorina undulata* is one of the two dominant littorines in the Central Pacific but only rarely found in the Hawaiian Islands.

*5. *Barleeia* sp. forms 31% of the algal mat in *Padina*-dominated outer seaward tidepools at Honaunau and 41% o£ the mat in similarly placed, pools at Poipu, Kauai.

*6. *Bittium parcum* forms only 13% to 27% of the mollusks in the algal mat of seaward tidepools at Honaunau, Hawaii but up to 40% of the mat in similar tidepools on Kauai.

*7. *Cerithium pharos, C. granifera,* and *C. columna* are sand-dwelling mollusks, usually found at depths of 10 feet or more.

*8. The absence of the muricid *Maculotriton serriale* both at Honaunau and Kealakekua is interesting; it is a very common species at Poipu, Kauai.

APPENDIX C-2. MARINE MOLLUSKS IN PUHO TIDEPOOLS

Distribution of marine mollusks in tidepools on Puʻuhonua Point (Figure 15) in 1969. X = present, XXXX = abundant. From Doty (1969).

	KEAWEWAI				SEAWARD POOLS	
	I Brackish	II Upper algal mat	III Lower algal mat	IV Outer Reaches	A *Padina* Pool	B *Boodlea* Pool
Bittium parcum	XX	XXXX	XXXXX	XX	XXX	XX
Cerithium atromarginatum	X	X	XX	X	XXX	X
Risoella sp.	XXXXX	XXX	XX		X	X
Theodoxus neglectus	XXXXX	XX				
Isognomon californicum	XXXXX					
Planaxis labiosus	XXX					
Morula granulata		X	X	X	X	X
Isognomon perna		X	X	X	X	
Dolabrifera dolabrifera		X	X	XX		
Morula ochrostoma		X	X	X		
Mitrella fusiformis		X	X	X		
Ervilia sp.		X	X		X	
Cyclostremiscus minutissimus		X			XX	XX
Merelina sp.		X			X	X
Pyramidellid sp.		X			X	X
Kogomea sandwichensis		X			X	
Parashiela sp.		X			X	
Provexillum fusconigra		X				
Epitonium sp.		X				
Conus ebraeus			X	XX	X	X
Rissoina ambigua			XX	XXX	XX	
Trochus histrio			X	X		
Rissoina triticea			X	X		
Haminea crocata			X		X	
Caecum sepimentum			X		X	
Triphora cingulifera			X		X	
Cerithium interstriatum			X			
Rissoina gracilis				X	X	X
Rissoina miltozona				X	X	X
Serpulorbis sp.				XX	XX	XX
Carinapex minutissiums				X	X	X
Stylocheius longicaudus				X	X	
Mitrella margarita				X	X	
Rissoina tridentata				X		
Hipponix spp.				X		
Vermetus sp.				X		
Cypraea fimbriata				X		
Euplica varians				X		
Seminella varia				X		
Cymatium nicobaricum				X		
Peristernia chlorostoma				X		
Morula brunneolabrum				X		
Morula ova				X		

APPENDIX C-2 (cont.). Distribution of marine mollusks in tidepools on Puʻuhonua Point (Figure 15) in 1969. X = present, XXXX = abundant. From Doty (1969).

	KEAWEWAI				SEAWARD POOLS	
	I Brackish	II Upper algal mat	III Lower algal mat	IV Outer Reaches	A *Padina* Pool	B *Boodlea* Pool
Provexillum vexillum				X		
Mitra cancellaroioides				X		
Mitra cucumerina				X		
Kermia harenula				X		
Daphnella producta				X		
Acar plicata				X		
Ostrea hanleyana				X		
Arcinella sp.				X		
Nesobornia ovata				X		
Ischnochiton viridis				X		
Hiloa variabilis					X	XX
Chama iostoma					XX	XX
Conus catus					X	X
Conus flavidus					X	X
Conus lividus					X	X
Conus rattus					X	X
Conus sponsalis					X	X
Gibbula marmorea					X	
Kermia pumila					X	
Diodora granifera					X	
Hormomya crebristriatus					X	
Cerithium nesioticum					X	
Rissoina turricula					X	
Vitrinellid sp. 1					X	
Vitrinellid sp. 2					X	
Barleeia spp.						XXX
Obtortio sp.						X
Scaliola sp.						X
Cerithiopsis sp.						X

APPENDIX D. FISH OBSERVED ON TRANSECTS IN HONAUNAU BAY IN 1969

Fish species, number, length and weight observed on transects 6 and 7 (Figure 17) by Doty (1969). Modified from Doty 1969 Tables 33 – 40.

1. Transect 6-1: 6/5/1968, 1112 to 1137 hours. Transect begins at 30 feet and ends at 25 feet. 48 species , 275.55 pounds of fish per acre.

COMMON NAME	SCIENTIFIC NAME	No. fish, 1ength in inches	Weight (lbs)	
			Transect	per acre
U'u	*Myripristis berndti*	34 – 5, 10 - 4	3.716	5.40
Red weke	*Mulloidichthys auriflamma*	1 - 6	.095	.14
Manu	*Parupeneus bifasciatus*	1 - 6	.108	.16
Moano	*P. multifasciatus*	3 - 8, 1 - 6, 3 - 5, 2 - 4	1.194	1.73
Moana kea	*P. chryserydros*	1 - 7	.182	.26
Mu	*Monotaxis grandoculis*	2 - 8	.573	.83
Potter's angel	*Centropyge potteri*	7 – 4 , 3 - 5	.913	1.33
Longnose butterfly	*Forcipiger longirostris*	2 - 5 , 22 - 4	.780	1.13
Blue stripe	*Chaetodon fremblii*	3 - 4	.182	.26
Orange striped	*C. ornatissimus*	3 - 3 , 20 - 5 , 21 - 4	4.553	6.61
	C. lunula	2 - 5	.273	.40
	C. quadrimaculatus	3 - 5	.356	.52
	C. multicinctus	11 - 4 , 5 - 6	1.855	2.69
Maomao	*Abudefduf abdominalis*	25 - 5	3.375	4.90
Yellow eye damsel	*Pomacentrus jenkinsi*	7 - 3 , 10 - 5	1.353	1.96
Aloiloi	*Dascyllus albisella*	1- 3 , 5 - 4	.406	.59
White tail	*Chromis leucurus*	67 - 3	2.135	3.10
Blue damsel	*Chromis ovalis*	7 - 4 , 5 - 3 , l - 5	.594	.86
Hinalea lauwili	*Thalassoma duperreyi*	23 - 5 , 24 – 4, 14 - 6, 10 - 7	5.215	7.57
Hinalea luahine	*T. ballieui*	4 – 6	.518	.75
Birdfish	*Gomphosus varius*	1 - 4	.020	.03
Opule	*Anampses cuvieri*	2 – 5	.150	.22
Labroides	*Labroides phthirophagus*	1 – 3	.012	.02
	Novaculichthys taeniourus	1 – 5	.094	.14
Omaka	*Stethojulis axillaris*	2 - 3	.028	.04
Poou	*Cheilinus rhodochrous*	1 – 6	.121	.18
	Pseudocheilinus octotaenia	1 – 4	.035	.05
Uhu	*Scarus dubius*	2 – 3	.041	.06
Band snout	*S. perspicillatus*	1 – 18	4.607	6.69
Kihikihi	*Zanclus canescens*	12 – 5	1.830	2.66
Pakuikui	*Acanthurus achilles*	4-3 , 1-6	.279	.41
White-banded maiko	*A. leucopareius*	8 – 6	1.348	1.96
Maiko	*A. nigroris*	13 – 4	.566	.82
Naenae	*A. olivaceus*	3-6 , 3-4 , 6-5	1.082	1.57
Manini	*A. sandvicensis*	3 – 3	.068	.10
Palani	*A. dussumieri*	4 – 6	.631	.92
Pualu	*A. xanthopterus*	1 – 8 , 6 – 6	1.447	2.10
Kole	*Ctenochaetus strigosus*	142 – 4, 25 – 3	9.178	13.33
Yellow manini	*Zebrasoma flavescens*	189 – 4	10.644	15.46
Kala	*Naso unicornis*	16 – 18 , 6 – 12, 1 - 6	66.494	96.55

1. Transect 6-1 (cont.).

COMMON NAME	SCIENTIFIC NAME	No. fish, 1ength in inches	Weight (lbs)	
			Transect	per acre
Kala	*N. lituratus*	25-12 , 36-4 , 23-8	57.853	84.00
Black kole	*Ctenochaetus hawaiiensis*	1 – 6	.203	.29
Sailfin tang	*Zebrasoma veliferum*	3 - 8	1.352	1.96
Humuhumu	*Balistes bursa*	5 – 5	.556	.81
Humuhumu’ele'ele	*Melichthys buniva*	3 – 6 , 3 – 4	.924	1.34
Oili uwiwi	*Pervagor spilosoma*	5 – 4	.243	.35
Moa	*Ostracion lentiginosus*	2 – 2	--	--
Keke	*Arothron hispidus*	1 –12	1.585	2.30

2. Transect 6-2: 8/14/1968, 0950 to 1023 hours. Transect begins at 20 feet and ends at 18 feet. 57 species, 273.93 pounds of fish per acre.

COMMON NAME	SCIENTIFIC NAME	No. fish, 1ength in inches	Weight (lbs)	
			Transect	per acre
Trumpet fish	*Aulostomus chinensis*	3 – 8, 1 - 12	.196	.29
Alaihi	*Holocentrus xantherythrus*	1 - 4	.039	.06
U'u	*Myripristis berndti*	17 – 6	2.791	4.05
Kahala	*Seriola dumerilii*	1 – 12	1.037	1.51
Red weke	*Mulloidichthys auriflamma*	15 – 5	.825	1.20
Malu	*Parupeneus pleurostigma*	1 – 5	.056	.08
Moano	*P. multifasciatus*	10 – 7, 2 – 12	3.650	5.30
Moana kea	*P. chryserydros*	4 – 6	.458	.67
Mu	*Monotaxis grandoculis*	1 – 6	.121	.18
Potter's angel	*Centropyge potteri*	6 - 3	.180	.26
Longnose butterfly	*Forcipiger longirostris*	35 - 5	2.056	2.99
Blue stripe	*Chaetodon fremblii*	3 - 5	.356	.52
Orange striped	*C. ornatissimus*	4 - 8" 5 - 5	3.101	4.50
	C. lunula	1 - 6	.235	.34
	C. quadrimaculatus	10 - 5	1.188	1.73
	C. multincinctus	27 - 4	1.797	2.61
	Hemitaurichthys zoster	1 - 4	.065	.09
Pilikoa	*Paracirrhites cinctus*	1 - 6	.160	.23
Pilikoa	*P. forsteri*	2 - 5	.175	.25
Pilikoa	*P. arcatus*	4 - 6	.631	.92
Poo-paa	*Cirrhitus alternatus*	1 - 6	.173	.25
	Pomacentrus jenkinsi	41 - 5	4.818	7.00
Aloiloi	*Dascyllus albisella*	30 - 5	4.388	6.37
White tail	*Chromis leucurus*	65 - 3	2.071	3.01
Black damsel	*C. verater*	133 - 5	16.126	23.42
Blue damsel	*C. ovalis*	54 - 5	5.670	8.23
Hinalea lauwili	*Thalassoma duperreyi*	89 - 5	5.340	7.75
Birdfish (hinalea i'iwi)	*Gomphosus varius*	7 – 4, 2 - 8	.471	.68
Labroides	*Labroides phthirophagus*	8 - 3	.097	.14
Ohua	*Stethojulis alboyittata*	6 - 5	.405	.59
Uhu	*Scarus dubius*	17 - 6	2.754	4.00
Band snout	*S. perspicillatus*	1 – 24	10.921	15.86
Limu teeth	*Scarops jordani*	1 - 12	1.296	1.88
Sleeping uhu	*Calotomus sandvicensis*	1 – 6	.175	.25
Kihikihi	*Zanclus canescens*	14 – 4	1.093	1.59
Surf maiko	*Acanthurus guttatus*	21 – 6, 1 - 12	7.830	11.37
Pakuikui	*A. achilles*	6 – 5	.645	.94
White-banded maiko	*A. leucopareius*	32 – 7	8.561	12.43
Maiko	*A. nigrofuscus*	1 – 6	.140	.20
Maiko	*A. nigroris*	7 – 4	.305	.44
Naenae	*Acanthurus olivaceus*	3 – 7	.700	1.02
Manini	*A. sandvicensis*	9 – 5	.945	1.37
Palani	*A. dussumieri*	1 – 12	1.261	1.83
Pualu	*A. mata*	31 – 5	2.906	4.22
Kole	*Ctenochaetus strigosus*	154 – 4	9.265	13.45
Hawaiian kole	*C. hawaiiensis*	1 – 5	.118	.17
Yellow manini	*Zebrasoma flavescens*	186 – 6	35.355	51.34

2. Transect 6-2 (cont.).

COMMON NAME	SCIENTIFIC NAME	No. fish, 1ength in inches	Weight (lbs)	
			Transect	per acre
Kala	*Naso hexacanthus*	3 – 5	.203	.30
Kala	*N. unicornis*	1 – 15	2.160	3.14
Kala	*N. lituratus*	5 – 10, 37 – 5	9.721	14.12
Humuhumu	*Balistes bursa*	3 – 6	.577	.84
Humuhumi-mimi	*B. capistratus*	1 – 6	.214	.31
Humuhumu-uli	*Melichthys vidua*	1 – 12	1.901	2.76
Humuhumu-ele'ele	*M. buniva*	17 – 5	2.338	3.40
Oili uwiwi	*Pervagor spilosoma*	5 – 4, 2 – 6	.571	.83
Moa	*Ostracion lentiginosus*	7 – 3	--	--
Awa	*Chanos chanos*	1 – 6	27.994	40.65

3. Transect 6-3: 10/30/1968, 1625 to 1650 hours. Transect begins at 20 feet and ends at 18 feet. 69 species, 603.07 pounds of fish per acre.

COMMON NAME	SCIENTIFIC NAME	No. fish, 1ength in inches	Weight (lbs)	
			Transect	per acre
Lizard fish	*Synodous variegatus*	1 – 5	.040	.06
Trumpet fish	*Aulostomus chinensis*	2 – 16	.492	.71
Alaihi	*Holocentrus xantherythrus*	4 – 5	.305	.44
U'u	*Myripristis berndti*	30 – 5	3.325	4.83
	M. multiradiatus	1 – 5	.110	.16
Introduced Roi	*Cephalopholis argus*	1 – 10	.500	.73
Upapalu	*Apogon snyderi*	1 – 4	.040	.06
Omilu	*Caranx melampygus*	5 – 10	3.200	4.65
Uku	*Aprion virescens*	1 – 10	.600	.87
Gurutsu	*Aphareus furcatus*	1 – 10	.600	.87
Spot weke	*Mulloidichthys samoensis*	1 – 7	.165	.24
Red weke	*M. auriflamma*	9 – 6	.855	1.24
Manu	*Parupeneus bifasciatus*	12 – 8	3.072	4.46
Moano	*P. multifasciatus*	33 – 7	5.999	8.71
Moana kea	*P. chryserydros*	1 – 6	.115	.17
Mu	*Monotaxis grandoculis*	4 – 7, 6 – 12	6.574	9.55
Potter's angel	*Centropyge potteri*	30 – 4	2.131	3.09
Longnose butterfly	*Forcipiger longirostris*	83 – 5	4.876	7.08
Blue stripe	*Chaetodon fremblii*	33 – 4	2.006	2.91
Orange striped	*C. ornatissimus*	19 – 6	4.761	6.91
	C. lunula	7 – 6	1.648	2.39
	C. multicinctus	70 – 4	4.659	6.77
	C. quadrimaculatus	22 – 4	1.338	1.94
Pilikoa	*Paracirrhites cinctus*	4 – 6	.639	.93
Pilikoa	*P. forsteri*	2 – 6	.302	.44
Pilikoa	*P. arcatus*	6 – 3	.118	.17
Maomao	*Abudefduf abdominalis*	16 – 4	1.106	1.61
Kupipi	*A. sordidus*	1 – 5	.079	.12
	Pomacentrus jenkinsi	66 – 4	3.971	5.77
Aloiloi	*Dascyllus albisella*	117 – 4	8.761	12.72
	Chromis dimidiatus	1 – 2	.009	.01
White tail	*C. leucurus*	100 – 4	7.552	10.97
Black damsel	*C. verater*	21 – 6	4.400	6.39
Blue damsel	*C. ovalis*	1 – 4	.054	.08
Hinalea lauwili	*Thalassoma duperreyi*	63 – 5	3.780	5.49
Hinalea lauhine	*T. ballieui*	8 – 8	2.458	3.57
Birdfish (hinalea i'iwi)	*Gomphosus varius*	19 – 5	.760	1.10
Hinalea lolo	*Coris gaimardi*	4 – 7	.604	.88
Opule	*Anampses cuvieri*	2 – 6	.259	.38
	A. rubrocaudatus	1 – 3	.012	.02
Labroides	*Labroides phthirophagus*	1 – 4	.029	.04
Poou	*Cheilinus rhodochrous*	1 – 8	.287	.42
Uhu	*Scarus dubius*	1 – 14, 13 – 8	7.050	10.24
Band snout	*S. perspicillatus*	2 – 18	9.215	13.38
	S. sordidus	7 – 8	2.688	3.90
Kihikihi	*Zanclus canescens*	127 – 5	19.368	28.12
Surf maiko	*Acanthurus guttatus*	73 – 7	31.299	45.45

3. Transect 6-3 (cont.).

COMMON NAME	SCIENTIFIC NAME	No. fish, 1ength in inches	Weight (lbs)	
			Transect	per acre
White-banded maiko	*A. leucopareius*	40 – 8	15.974	23.19
Maiko	*A. nigrofuscus*	62 – 4	2.579	3.75
Maiko	*A. nigroris*	98 – 4	4.265	6.19
Naenae	*A. olivaceus*	2 – 8	.696	1.01
Manini	*A. sandvicensis*	29 – 5	3.045	4.42
Palani	*A. dussumieri*	12 – 10	8.760	12.72
Pualu	*A. xanthopterus*	15 – 6	2.592	3.76
Pualu	*A. mata*	8 – 6	1.296	1.88
Kole	*Ctenochaetus strigosus*	372 – 5	43.710	63.47
Yellow manini	*Zebrasoma flavescens*	246 – 5	27.060	39.29
Sailfin tang	*Z. veliferum*	1 – 7, 1 – 4	.358	.52
Kala	*Naso hexacanthus*	100 – 6	11.664	16.94
Kala	*Naso unicornis*	25 – 19	109.744	159.35
Kala	*N. lituratus*	19 – 7	6.582	9.56
Humuhumu	*Balistes bursa*	12 – 6	2.307	3.35
Humuhumi-mimi	*B. capistratus*	1 – 6	.214	.31
Humuhumu-ele'ele	*Melichthys buniva*	5 – 5	.688	1.00
Oili uwiwi	*Pervagor spilosoma*	4 – 3	.082	.12
Moa	*Ostracion lentiginosus*	11 – 3	---	---
Blenny	*Cirripectus obscurus*	1 – 4	---	---
	Iso hawaiiensis	2,000,000 – 1	20.00	29.04

4. Transect 6-4: 2/13/1969, 1117 to 1140 hours. Transect begins at 25 feet and ends at 20 feet. 54 species, 599.41 pounds of fish per acre.

COMMON NAME	SCIENTIFIC NAME	No. fish, 1ength in inches	Weight (lbs)	
			Transect	per acre
Trumpet fish	*Aulostomus chinensis*	1 – 18	.350	.51
	Holocentrus scythrops	1 – 7	.213	.31
U'u	*Myripristis berndti*	7 – 6	1.149	1.67
Gurutsu	*Aphareus furcatus*	1 – 8	.307	.45
Red weke	*Mulloidichthys auriflamma*	1 – 6	.095	.14
Malu	*Parupeneus pleurostigma*	2 – 6	.194	.28
Moano	*P. multifasciatus*	42 – 8	13.025	18.91
Mu	*Monotaxis grandoculis*	2 – 10	1.120	1.63
Potter's angel	*Centropyge potteri*	27 – 4	1.918	2.79
Longnose butterfly	*Forcipiger longirostris*	65 – 5	3.819	5.55
Blue stripe	*Chaetodon fremblii*	7 – 4	.426	.62
Orange striped	*C. ornatissimus*	43 – 7	17.109	24.84
	C. multicinctus	79 – 4	5.258	7.64
	C. unimaculatus	6 – 4	.365	.53
	C. lunula	16 – 6	3.767	5.47
	C. quadrimaculatus	16 – 5	1.900	2176
Pilikoa	*Paracirrhites cinctus*	1 – 4	.047	.07
	P. forsteri	1 – 7	.240	.35
	P. arcatus	3 – 3	.059	.09
Maomao	*Abudefduf abdominalis*	7 – 4	.484	.70
	A. imparipennis	52 – 2	.262	.38
	Pomacentrus jenkinsi	17 – 4	1.023	1.49
Aloiloi	*Dascyllus albisella*	32 – 5	4.680	6.80
White tail	*Chromis leucurus*	20 – 3	.669	.97
Blue damsel	*C. ovalis*	21 – 3	.476	.69
Hinalea lauwili	*Thalassoma duperreyi*	66 – 5	3.960	5.75
Birdfish (hinalea i'iwi)	*Gomphosus varius*	18 – 5	.720	1.05
Hinalea lolo	*Coris gaimardi*	18 – 5	.990	1.44
Labroides	*Labroides phthirophagus*	7 – 3	.085	.12
	Novaculichthys taeniourus	1 – 4	.048	.07
Uhu	*Scarus dubius*	33 – 7	8.489	12.33
Band snout	*S. perspicillatus*	2 – 14, 1 – 18	8.943	12.99
	S. sordidus	18 – 8	27.648	40.15
Kihikihi	*Zanclus canescens*	56 – 5	8.540	12.40
Surf maiko	*Acanthurus- guttatus*	67 – 8	42.880	62.26
Pakuikui	*A. achilles*	29 – 8	12.769	18.54
White-banded maiko	*A. leucopareius*	76 – 10	59.280	86.08
Maiko	*A. nigrofuscus*	70 – 5	5.688	8.26
	A. nigroris	125 – 5	10.625	15.43
Naenae	*Acanthurus olivaceus*	10 – 7	2.332	3.39
Manini	*A. sandvicensis*	3 – 5	.315	.46
Palani	*A. dussumieri*	5 – 10	3.650	5.30
Pualu	*A. mata*	21 – 5	1.969	2.86
Kole	*Ctenochaetus strigosus*	215 – 5	25.263	36.68
Yellow manini	*Zebrasoma flavescens*	230 – 5	25.300	36.74
Sailfin tang	*Z. veliferum*	2 – 8	.901	1.31
Kala	*Naso hexacanthus*	42 – 7	7.779	11.30

4. Transect 6-4 (cont.).

COMMON NAME	SCIENTIFIC NAME	No. fish, 1ength in inches	Weight (lbs)	
			Transect	per acre
Kala	*N. unicornis*	34 – 13	47.807	69.42
	N. lituratus	95 – 6, 20 – 10	40.925	59.42
Humuhumu	*Balistes bursa*	16 – 6	3.076	4.47
Humuhumu-ele'ele	*Melichthys buniva*	5 – 8	2.816	4.09
	Xanthichthys ringens	2 – 5	.250	.36
Moa	*Ostracion lentiginosus*	2 – 3	--*	--*
Nenue	*Kyphosus cinerescens*	2 – 8	.758	1.10

5. Transect 7-1: 6/5/1968, 0940 to 1017 hours. Transect begins at 80 feet and ends at 20 feet. 47 species, 323.60 pounds of fish per acre.

COMMON NAME	SCIENTIFIC NAME	No. fish, 1ength in inches	Weight (lbs)	
			Transect	per acre
U'u	*Myripristis berndti*	36 – 4, 28 – 6	6.347	9.22
	Priacanthus cruentatus	3 – 7	.576	.84
Upapalu	*Apogon snyderi*	3 – 6	.408	.59
Spot weke	*Mulloidichthys samoensis*	8 – 4, 1 – 6	.350	.51
Red weke	*M. auriflamma*	50 – 8	11.264	16.36
Kumu	*Parupeneus porphyreus*	4 – 8, 20 – 4	1.897	2.75
Moano	*P. multifasciatus*	18 – 6, 10 – 5	2.724	3.96
	Monotaxis grandoculis	1 – 8	.287	.42
Black-white angel	*Holacanthus arcuatus*	4 – 4	.284	.41
Potter's angel	*Centropyge potteri*	6-4 , 27 – 3	1.235	1.79
Longnose butterfly	*Forcipiger longirostris*	60-4 , 10-5	2.393	3.47
Orange striped	*Chaetodon ornatissimus*	202 – 5	29.290	42.53
	C. multicinctus	64 – 4	4.260	6.19
Pilikoa	*Paracirrhites forsteri*	3 – 4	.134	.20
Yellow eye damsel	*Pomacentrus jenkinsi*	33 – 3	.838	1.22
Aloiloi	*Dascyllus albisella*	426 – 4	31.899	46.32
White tail	*Chromis leucurus*	36 – 3	1.147	1.67
Black damsel	*C. verater*	5 - 4 , 23 – 5	3.099	4.50
Blue damsel	*C. ovalis*	186 – 3 , 3 – 4	4.379	6.36
Hinalea lauwili	*Thalassoma duperreyi*	70 – 5 , 13 – 6	5.548	8.06
Hinalea luahine	*T. ballieui*	9 – 6	1.166	1.69
Bird fish (hinalea i'iwi)	*Gomphosus varius*	4 – 4	.082	.12
Hilu	*Coris flavovittata*	2 – 6	.186	.27
Opule	*Anampses cuvieri*	5 – 5	.375	.55
Labroides	*Labroides phthirophagus*	1 – 3	.012	.02
Poou	*Cheilinus rhodochrous*	13 – 6	1.572	2.28
	Pseudocheilinus octotaenia	1 – 4	.035	.05
Uhu	*Scarus dubius*	22 – 8	8.448	12.27
Band snout	*S. perspicillatus*	1-18 , 1 – 9	5.183	7.53
	S. sordidus	5 – 8	1.920	2.79
Kihikihi	*Zanclus canescens*	10 – 4	.781	.93
Pakuikui	*Acanthurus achilles*	3-4 , 5 – 3	.281	.41
White-banded maiko	*A. leucopareius*	2 – 6	.337	.49
Maiko	*A. nigroris*	16 – 4	.696	1.01
Naenae	*A. olivaceus*	5 – 8 , 1 – 12	2.916	4.23
Manini	*A. sandvicensis*	16 – 5	1.680	2.44
Palani	*A. dussumieri*	110 – 5, 2 – 18	18.553	26.94
Pualu	*A. xanthopterus*	3 – 4	.154	.22
Kole	*Ctenochaetus strigosus*	269 – 4	16.183	23.50
Yellow manini	*Zebrasoma flavescens*	258 – 4, 6 – 9	18.380	26.69
Kala	*Naso hexacanthus*	3 – 4 , 4 – 10, 100 – 6	13.928	20.22
Kala	*Naso lituratus*	4 – 10	4.04	5.87
Humuhumu	*Balistes bursa*	5-8 , 13-4 , 4-6	3.787	5.50
Humuhumu-uli	*Melichthys vidua*	5 – 4 , 6 – 5	1.177	1.71
Humuhumu-ele'ele	*M. buniva*	34 – 6 , 63 – 4	12.513	18.17
Sharp nose puffer	*Canthigaster rivulatus*	1 – 6	.229	.33
Blenny	Blennidae	1 – 6	--	--

6. Transect 7-2: 8/12/1968, 1700 to 1725 hours. Transect begins at 60 feet and ends at 20 feet. 49 species, 138.03 pounds of fish per acre.

COMMON NAME	SCIENTIFIC NAME	No. fish, 1ength in inches	Weight (lbs)	
			Transect	per acre
	Synodous variegatus	1 – 12	.553	.80
Puhi paka	*Gymnothorax flavimarginatus*	1 – 24	1.244	1.81
Trumpet fish	*Aulostomus chinensis*	1-6", 3-12, 2-24	1.983	2.88
Alaihi mama	*Holotrachys lima*	1 – 12	1.901	2.76
U’u	*Myripristis berndti*	86 – 6	14.118	20.50
Upapalu	*Apogon snyderi*	2 – 6	.272	.40
Spot weke	*Mulloidichthys samoensis*	30 – 6	3.110	4.52
Malu	*Parupeneus pleurostigma*	1 – 6	.097	.14
Kumu	*P. porphyreus*	1 – 6	.123	.18
Manu	*P. bifasciatus*	1 – 6	.108	.16
Moano	*P. multifasciatus*	1-8" 4 – 6	.729	1.06
Potter's angel	*Centropyge potteri*	17 – 3	.510	.74
Longnose butterfly	*Forcipiger longirostris*	40 – 4	1.203	1.75
Orange striped	*Chaetodon ornatissimus*	18 – 5	2.610	3.79
	C. lunula	1 – 4	.070	.10
	C. multicinctus	23 – 4	1.531	2.22
Pilikoa	*Paracirrhites arcatus*	1 – 4	.047	.07
	Pomacentrus jenkinsi	11 – 4	.662	.96
Aloiloi	*Dascyllus albisella*	66 – 4	4.942	7.18
White tail	*Chromis leucurus*	15 – 3	.478	.69
Black damsel	*C. verater*	150 – 5	18.188	26.41
Blue damsel	*C. ovalis*	25 – 3	.567	.82
Hinalea lauwili	*Thalassoma duperreyi*	33 – 4	1.014	1.47
Birdfish (hinalea i'iwi)	*Gomphosus varius*	9 – 4	.184	.27
Hinalea lolo	*Coris gaimardi*	2 – 6	.190	.28
Opule	*Anampses cuvieri*	3 – 4	.115	.17
	A. rubrocaudatus	2 – 4	.056	.08
	Novaculichthys taeniourus	1 – 5	.094	.14
Ohua	*Stethojulis albovittata*	1 – 5	.068	.10
	S. axillaris	2 – 4	.067	.10
Poou	*Cheilinus bimaculatus*	5 – 6	.724	1.05
Uhu	*Scarus dubius*	5 – 8	1.920	2.79
Kihikihi	*Zanclus canescens*	9 – 4	.703	1.02
Pakuikui	*Acanthurus achilles*	3 – 5	.323	.47
White-banded maiko	*A. leucopareius*	3 – 6	.505	.73
Maiko	*A. nigrofuscus*	10 – 4	.416	.60
Maiko	*A. nigroris*	5 – 4	.218	.32
Palani	*A. dussumieri*	3 – 6	.473	.69
Kole	*Ctenochaetus strigosus*	107 – 4	6.437	9.35
Hawaiian kole	*C. hawaiianensis*	3 – 4	.181	.26
Yellow manini	*Zebrasoma flavescens*	191 – 4	10.757	15.62
Kala	*Naso hexacanthus*	15 – 6	1.750	2.54
Kala	*N. lituratus*	6 – 6	1.309	1.90
Humuhumu	*Balistes bursa*	7 – 6	1.346	1.95
Humuhumu-ele'ele	*Melichthys buniva*	26 – 5, 13 - 8	10.897	15.82
	Xanthichthys ringens	1 – 5	.125	.18
Oili uwiwi	*Pervagor spilosoma*	4 – 3	.082	.12

6. Transect 7-2 (cont.).

COMMON NAME	SCIENTIFIC NAME	No. fish, 1ength in inches	Weight (lbs)	
			Transect	per acre
Moa	*Ostraction lentiginosus*	1 – 3, 1 – 5	--	--
Spotted puffer	*Canthigaster jactator*	2 – 3	.051	.07

7. Transect 7-3: 10/31/1968, 1023 to 1045 hours. Transect begins at 65 feet and ends at 20 feet. 49 species, 306.16 pounds of fish per acre.

COMMON NAME	SCIENTIFIC NAME	No. fish, 1ength in inches	Weight (lbs)	
			Transect	per acre
Cornet Fish	*Fistularia petimba*	1 – 12	.035	.05
Trumpet fish	*Aulostomus chinensis*	7 – 20	3.360	4.88
Alaihi	*Holocentrus xantherythrus*	1 – 4	.039	.06
	Holotrachys lima	1 – 14	3.018	4.38
U'u	*Myripristis berndti*	55 – 6	9.029	13.11
Upapalu	*Apogon snyderi*	1 – 4	.040	.06
Spot weke	*Mulloidichthys samoensis*	475 – 6	49.248	71.51
Red weke	*M. auriflamma*	10 – 6	.950	1.38
Kumu	*Parupeneus porphyreus*	2 – 12	1.970	2.86
Manu	*P. bifasciatus*	8 – 6	.864	1.26
Moano	*P. multifasciatus*	12 – 6	1.374	2.00
Mu	*Monotaxis grandoculis*	4 – 6	.484	.70
Potter's angel	*Centropyge potteri*	70 – 4	4.973	7.22
Longnose butterfly	*Forcipiger longirostris*	59 – 4	1.77	2.58
Blue stripe	*Chaetodon fremblii*	7 – 4	.426	.62
Orange striped	*C. ornatissimus*	38 – 5	5.510	8.00
Puka	*Chaetodon miliaris*	1 – 6	.203	.29
	C. trifasciatus	1 – 4	.065	.09
	C. lunula	4 – 6	.942	1.37
	C. multicinctus	51 – 4	3.395	4.93
Pilikoa	*Paracirrhites forsteri*	1 – 8	.358	.52
	Pomacentrus jenkinsi	48 – 4	2.888	4.19
Aloiloi	*Dascyllus albisella*	30 – 4	2.246	3.26
White tail	*Chromis leucurus*	111 – 3	3.537	5.14
Black damsel	*C. verater*	275 – 5	33.344	48.42
Blue damsel	*C. ovalis*	36 – 3	.817	1.19
Hinalea lauwili	*Thalassoma duperreyi*	121 – 5	7.260	10.54
Birdfish (hinalea i'iwi)	*Gomphosus varius*	17 – 5	.680	.99
Hinalea lolo	*Coris gaimardi*	33 – 6	3.136	4.55
	Anampses rubrocaudatus	1 – 6	.095	.14
Labroides	*Labroides phthirophagus*	8 – 3	.097	.14
Poou	*Cheilinus rhodochrous*	1 – 10	.560	.81
Uhu	*Scarus dubius*	6 – 8, 1 – 12	3.669	5.33
Band snout	*S. perspicillatus*	1 – 18, 1 – 12	5.972	8.67
Sleeping uhu	*Calotomus sandvicensis*	2 – 8	.829	1.20
Kihikihi	*Zanclus canescens*	72 – 4	5.622	8.16
Maiko	*Acanthurus nigrofuscus*	14 – 5	1.138	1.65
Maiko	*A. nigroris*	53 – 5	4.505	6.54
Pualu	*A. mata*	22 – 5	2.063	3.00
	Acanthurus thompsoni	1 – 6	.015	.02
Kole	*Ctenochaetus strigosus*	120 – 4	7.219	10.48
Yellow manini	*Zebrasoma flavescens*	300 – 4	16.896	24.53
Sailfin tang	*Z. veliferum*	3 – 5	.330	.48
Kala	*Naso lituratus*	27 – 6	5.890	8.55
Humuhumu	*Balistes bursa*	16 – 6	3.076	4.47
Humuhumu-ele'ele	*Melichthys buniva*	31 – 6	7.366	10.70
	Xanthichthys ringens	4 – 6	3.456	5.02
Oili uwiwi	*Pervagor spilosoma*	4 – 3	.082	.12

7. Transect 7-3 (cont.).

COMMON NAME	SCIENTIFIC NAME	No. fish, 1ength in inches	Weight (lbs)	
			Transect	per acre
Fairy shrimp	*Stenopus hispidus*	2 – 3	--	--

8. Transect 7-4: 2/11/1969, 0840 to 0915 hours. Transect begins at 65 feet and ends at 20 feet. 51 species, 388.24 pounds of fish per acre.

COMMON NAME	SCIENTIFIC NAME	No. fish, 1ength in inches	Weight (lbs)	
			Transect	per acre
Trumpet fish	*Aulostomus chinensis*	5 – 12	.518	.75
Alaihi	*Holocentrus xantherythrus*	6 – 4	.234	.34
U'u	*Myripristis berndti*	76 – 6	12.476	18.12
Opelu	*Decapterus pinnulatus*	300 – 10	50.000	72.60
Spot weke	*Mulloidichthys samoensis*	250 – 7, 7 – 5	41.580	60.37
Red weke	*M. auriflamma*	12 – 6	1.141	1.66
Kumu	*Parupeneus porphyreus*	4 – 9	1.662	2.41
Moano	*P. multifasciatus*	19 – 7	3.454	5.02
Mu	*Monotaxis grandoculis*	1 – 8	.287	.42
Potter's angel	*Centropyge potteri*	80 – 4	5.683	8.25
Longnose butterfly	*Forcipiger longirostris*	52 – 4	1.564	2.27
Orange striped	*Chaetodon ornatissimus*	24 – 6	6.013	8.73
	C. multicinctus	61 – 4	4.060	5.90
	C. lunula	11 – 6	2.590	1.76
	C. quadrimaculatus	1 – 4	.061	.09
Pilikoa	*Paracirrhites forsteri*	1 – 7	.240	.35
	P. arcatus	2 – 5	.183	.27
	Cirrhitoides bimacula	1 – 3	.014	.02
	Pomacentrus jenkinsi	72 – 4	4.332	6.29
Aloiloi	*Dascyllus albisella*	26 – 5	3.803	5.52
White tail	*Chromis leucurus*	65 – 3	2.071	3.01
Black damsel	*C. verater*	75 – 5	9.094	13.21
Blue damsel	*C. ovalis*	72 – 5	7.560	10.98
Hinalea lauwili	*Thalassoma duperreyi*	60 – 5	3.600	5.23
Hinalea lauhine	*T. ballieui*	1 – 7	.206	.30
Birdfish (hinalea i'iwi)	*Gomphosus varius*	5 – 5, 1 – 2	.202	.29
Hinalea lolo	*Coris gaimardi*	9 – 5	.495	.72
Labroides	*Labroides phthirophagus*	5 –2	.018	.03
	Novaculichthys taeniourus	2 – 6	.324	.47
Poou	*Cheilinus rhodochrous*	3 – 8	.860	1.25
Uhu	*Scarus dubius*	7 – 8, 3 – 15	10.282	14.93
Band snout	*S. perspicillatus*	2 – 12, 1 – 15	5.396	7.84
Kihikihi	*Zanclus canescens*	15 – 4	1.171	1.70
Pakuikui	*Acanthurus achilles*	4 – 5	.430	.62
White-banded maiko	*A. leucopareius*	12 – 5	1.170	1.70
Maiko	*A. nigrofuscus*	10 – 4	.416	.60
	A. nigroris	10 – 4	.435	.63
Naenae	*Acanthurus olivaceus*	1 – 8	.348	.51
Palani	*A. dussumieri*	2 – 10	1.460	2.12
Pualu	*A. xanthopterus*	3 – 5	.300	.44
Kole	*Ctenochaetus strigosus*	179 – 4	10.769	15.64
Yellow manini	*Zebrasoma flavescens*	151 – 5	16.610	24.12
Sailfin tang	*Z. veliferum*	1 – 5	.110	.16
Kala	*Naso hexacanthus*	23 – 5	1.553	2.26
	N. unicornis	10 – 14	17.562	25.50
	N. lituratus	10 – 8, 18 – 5	7.444	10.81
Humuhumu	*Balistes bursa*	19 – 6	3.653	5.30
	Xanthichthys ringens	15 – 5	1.875	2.72

8. Transect 7-4 (cont.).

COMMON NAME	SCIENTIFIC NAME	No. fish, 1ength in inches	Weight (lbs)	
			Transect	per acre
Oili uwiwi	*Pervagor spilosoma*	13 – 4	.632	.92
Nohu	*Scorpaenopsis cacopsis*	1 – 28	20.854	30.28
	S. gibbosa	1 – 8	.558	.81

APPENDIX E. FISH OBSERVED ON TRANSECTS IN HONAUNAU BAY IN 1975

Fish species and relative abundance observed on transects in Honaunau Bay (Figure 18) by Kimmerer and Durbin (1975). Data from transects in Kealakekua Bay also are shown for comparison. IN: inshore transect, MR: mid-reef transect, OR: outer reef transect. Relative abundance indices are 4: Dominant - over 5 percent of the fish in that habitat, 3: Common - 0.5 percent to 5 percent of the fish in that habitat, 2: Present on transects but less than 0.5 percent of the fish in that habitat, 1: Seen in the habitat but not counted on any transect.

	Honaunau			Kealakekua		
	IN	MR	OR	IN	MR	OR
Family Acanthuridae						
Acanthurus achilles	3	2		3	2	
A. dussumieri		1			1	2
A. glaucopareius		2	2	1		
A. guttatus	1			1		
A. leucopareius	2	2		2	2	
A. nigrofuscus	4	3		4	3	
A. nigroris	2	3	2	3	3	2
A. olivaceus	2	2		2	2	3
A. thompsoni		2	4		2	2
A. triostegus	3	2			2	2
A. xanthopterus				2	2	2
Ctenochaetus hawaiiensis	2	2	2	2	2	3
C. strigosus	4	4	4	4	4	4
Naso brevirostris		2	2		2	2
N. hexacanthus		2	2		2	2
N. lituratus	3	3	3	2	3	3
N. unicornis		2	2		2	2
Zebrasoma flavescens	4	4	4	4	4	4
Z. veliferum					1	
Family Apogonidae						
Apogon menesemus	2	2	2		2	2
Family Aulostomidae						
Aulostomus chinensis	2	2	3	2	2	2
Family Balistidae						
Melichthys niger	2	2		3	2	
M. vidua	2	2		2	2	
Rhinecanthus rectangulus	2				1	
Sufflamen bursa	2		2	3	3	3
S. frenatus						2
Xanthichthys mento	2		2		2	2
Family Belonidae						
unidentified sp.					1	
Family Blenniidae						
Cirripectus variolosus	2	2			2	
Exallias brevis	2	2		2	2	2
Plagiotremus rhinorhycus	2					
Family Bothidae						
Bothus sp.					1	

Appendix E (cont.)

	Honaunau			Kealakekua		
	IN	MR	OR	IN	MR	OR
Family Canthigasteridae						
Canthigaster amboinensis	2	2				
C. epilampris		2			2	2
C. jactator	3	2		2	2	
Family Carangidae						
Carangoides ferdau		1			1	
Caranx melampygus			2		1	
Decapterus pinnulatus						2
Gnathonodon speciosus					2	
Family Chaetodontidae						
Chaetodon auriga	2	2		1	2	
C. ephippium	1					
C. fremblii		2		2	2	2
C. kleini			1		2	
C. lineolatus	1				1	
C. lunula	2	2	2	3	2	2
C. miliaris	2					3
C. multicinctus		4	3	4	4	4
C. ornatissimus	3	3	3		3	3
C. quadrimaculatus	3	2			2	
C. reticulatus	1					
C. trifasciatus				2	2	
C. unimaculatus	2	2		2	2	2
Forcipiger flavissimus	2	3	3	3	3	3
F. longirostris	2	2	2	2	2	3
Hemitaurichthys thompsoni	1		1			
Heniochus acuminatus			1		1	
Family Chanidae						
Chanos chanos		2		1		2
Family Cirrhitidae						
Cirrhitops fasciatus	2	2		2	2	
Cirrhitus pinnulatus					2	
Paracirrhites arcatus	3	3		3	3	2
P. forsteri	2	2		2	2	2
Family Diodontidae						
Diodon hystrix			1			
Family Fistularidae						
Fistularia petimba	2	2			2	
Family Holocentridae						
Adioryx spinifer			1		2	
A. xantherythrus		1			2	
Flammeo sammara	2		2		2	2
Myripristis murdjan	3		2	2	2	2
Family Kyphosidae						
Kyphosus cinerascens				2	2	
Family Labridae						
Anampses chrysocephalus	2	2			2	
A. cuvieri	2					
Bodianus bilunulatus		2			2	2

Appendix E (cont.)

	Honaunau			Kealakekua		
	IN	MR	OR	IN	MR	OR
Family Labridae (cont.)						
Cheilinus rhodochrous	2	2	2	2	3	3
Coris gaimardi	2	2		2	2	2
Gomphosus varius	3	3	2	3	3	2
Halichoeres ornatissimus	3	2	2	3	2	2
Hemipteronotus leclusei						1
H. pavoninus					1	1
H. taeniouris	2				1	
Labroides phthirophagus	2	2	2	2	2	2
Leptojulis cerasinus		2				
Pseudocheilinus evanidus		2	3		2	3
P. octotaenia	2	3	2	2	3	2
P. tetrataenia	2	2	2		2	2
Stethojulis balteata	4	3	2	2	3	
Thalassoma ballieui		2			2	2
T. duperreyi	4	3	3	4	4	4
T. fuscum		2	1			
T. lutescens		2			2	
Family Lutjanidae						
Aphareus furcatus		2			1	
Aprion virescens		1		2	2	
Lutjanus kasmiri		1	1		1	
Family Monocanthidae						
Alutera monoceros		1				
Cantherhines dumerili		2	2	2	2	
C. sandwichiensis	2	2		2	2	2
Pervagor melanocephalus		2				
P. spilosoma	2	2	2	2	3	
Family Mullidae						
Mulloidichthys flavolineata		2		2	2	2
M. vanicolensis	2	2			2	3
Parupeneus bifasciatus	2	2		2	2	
P. chryserydros		2	2		2	
P. multifasciatus	2	2	2	2	2	2
P. pleurostigma		2		2	2	
P. porphyreus		2	2			
Family Muraenidae						
Gymnothorax flavimarginatus		2				
G. meleagris				2	2	
Family Ostraciontidae						
Ostracion meleagris	2	2	2	2	2	2
O. whitleyi	2	2			1	
Family Pomacanthidae						
Apolemichthys arcuatus			1		2	2
Centropyge loriculus		2			2	
C. potteri	2	3	3	3	3	3
Family Pomacentridae						
Abudefduf abdominalis	2	2		2	3	3
A. sordidus	2					

Appendix E (cont.)

	Honaunau			Kealakekua		
	IN	MR	OR	IN	MR	OR
Family Pomacentridae (cont.)						
Chromis agilis	3	4	4	3	4	4
C. hanui	2	3	2	3	3	3
Chromis ovalis		2	3			2
C. vanderbilti	3	3		3	2	2
C. verater		3	3		3	4
Dascyllus albisella		2			2	3
Eupomacentrus jenkensi	4	3		4	3	
Plectroglyphidodon imparipennis	3					
P. johnstonianus	3	3	3	3	3	3
Family Priacanthidae						
Priacanthus cruentatus		2			1	
Family Scaridae						
Calotomus spinidens	2	2	2		2	2
Scaridea zonarcha	2	2	2			2
Scarops rubroviolaceus	2	2	2	2	2	2
Scarus dubius			2		2	
S. forsteri			2		2	
S. perspicillatus						2
S. taeniourus	2	3	3	2		3
unidentified juvenile	3	2	2	2	2	2
Family Scorpaenidae						
Pterois sphex					1	
Scorpaenopsis gibbosa					2	
Family Serranidae						
Cephalopholis argus		2				
Pseudanthias sp. nov. B (Hawaii)			2			
Family Sparidae						
Monotaxis grandoculis		2				2
Family Sphyraenidae						
Sphyraena helleri						3
Family Synodontidae						
Synodus sp.	2	2	2		2	2
Family Tetraodontidae						
Arothron hispidus	2	2	1			
A. meleagris	2	2	2		2	
Family Triakidae						
Triaenodon obesus			1			
Family Zanclidae						
Zanclus cornutus	2	2	2	2	2	3

APPENDIX F. FISH OBSERVED ON TRANSECTS IN HONAUNAU BAY IN 1975-78

Fish species observed on transects in Honaunau and Alahaka Bays by Ludwig et al. (1980). See Figure 19 for transect locations. B = Boulder zone, DO = Drop-off, CR = Coral-rich zone, Recon = reconnaisance dive.

			Habitat			
Scientific Name	Hawaiian Name	Common Name	B	DO	CR	Recon
ACANTHURIDAE – Tangs or Surgeon Fish						
Acanthurus achilles	Paku'iku'I	Achilles Tang	x	x	x	
A. guttatus		Spotted Tang	x			
A. glaucopareius		Lesson's Tang	x			
A. nigrofuscus		Lavender Tang	x	x	x	
A. nigroris	Maiko	Cuvier's Tang	x	x	x	
A. leucopareius	Maikoiko	Jenkins' Tang	x	x	x	
A. olivaceus	Na'ena'e	Orange-spot Tang	x	x	x	
A. thompsoni		Thompson's Tang	x	x	x	
A. triostegus	Manini	Manini	x	x	x	
A. xanthopterus	Pualu	Yellow-finned Tang				x
Ctenochaetus strigosus	Kole	Yellow-eyed Tang	x	x	x	
C. hawaiiensis		Hawaiian Tang	x	x	x	
Naso brevirostris	Kala	Unicorn Tang	x	x	x	
N. hexacanthus		Six-spined Tang		x	x	
N. lituratus	Umaumalei	Liturate Tang	x	x	x	
N. unicornis	Kala	Large Unicorn Tang	x			
Zebrasoma flavescens	La'ipala	Yellow Tang	x	x	x	
Z. veliferum	'Api	Sail-fin Tang			x	
Zanclus cornutus	Kihikihi	Moorish Idol	x	x	x	
APOGONIDAE – Cardinal fish						
Apogon snyderi	'Upapalu	Snyder's Cardinal Fish			x	
AULOSTOMIDAE – Trumpet Fish						
Aulostoma chinensis	Nunu	Trumpet Fish	x	x	x	
BALISTIDAE – Trigger Fish						
Melichthys niger	Humu humu 'ele'ele	Black Trigger Fish		x	x	
M. vidua	Humu humu hi'ukole	Red-tailed Trigger Fish	x	x	x	
Rhinecanthus rectangulus	Humu humu nuku nuku a pua'a	Pig-nosed Trigger Fish	x			
Sufflamen bursa	Humu humu umauma lei	Green and White Trigger Fish	x	x	x	
Xanthichthys mento		Long-chinned Trigger Fish		x	x	
BELONIDAE – Needle Fish						
Strongylura gigantea	'Aha	Giant Needle Fish			x	
BLENNIIDAE – Comb-toothed Blennies						
Cirripectus variolosus		Common Blenny	x	x	x	
Exallias brevis	Pao'o kauila	Short-bodied Blenny	x	x	x	
Istiblennius gibbifrons		Hump-headed Blenny				x
I. zebra	Pao'o	Rock Skipper				x
Plagiotremus goslinei		Sabre Tooth Blenny	x	x	x	

Appendix F (cont.)

Scientific Name	Hawaiian Name	Common Name	Habitat B	DO	CR	Recon
BOTHIDAE - Left-eyed Flounders						
Bothus pantherinus		Spotted Flounder		x		
CANTHIGASTERIDAE - Sharp-nosed Puffers						
Canthigaster amboinensis	Pu'u ola'i	Amboina Puffer	x	x		
C. epilampra	Pu'u ola'i	Rare Kihei Puffer		x	x	
C. jactator		White-spotted Puffer	x	x		
C. rivulata	Pu'u ola'i	Schlegel's Puffer		x		
CARANGIDAE - Jacks						
Carangoides ferdau	‘Omilu	Forskal's Jack		x		
Caranx melampygus	Blue Ulua	Blue Jack			x	
Caranx sp.				x		
Decapterus pinnulatus	'Opelu	Mackerel Scad			x	
Seriola dumerili	Kahala	Amberjack		x		
CHAETODONTIDAE - Butterfly Fish						
Chaetodon auriga	Lau hau	Golden Butterfly Fish	x	x	x	
C. ephippium		Saddleback Butterfly Fish				x
C. fremblii	Lau hau	Blue-lined Butterfly Fish	x	x		
C. lineolatus	Kika kapu	Lined Butterfly Fish	x		x	
C. lunula	Kapu hili	Racoon Butterfly Fish	x	x	x	
C. miliaris		Millet Seed Butterfly Fish	x	x	x	
C. multicinctus		Pebbled Butterfly Fish	x	x	x	
C. ornatissimus	Kika kapu	Ornate Butterfly Fish	x	x	x	
C. quadrimaculatus		Four-spotted Butterfly Fish	x	x	x	
C. reticulatus		Reticulated Butterfly Fish				x
C. tinkeri		Tinker's Butterfly Fish				x
CHAETODONTIDAE - Butterfly Fish (con't.)						
Chaetodon trifasciatus	Kapu hili	Three-banded Butterfly Fish				x
C. unimaculatus	Lau hau	One-spot Butterfly Fish	x	x	x	
Forcipiger flavissimus	Lau wiliwili nukunuku ‘oi‘oi	Common Long-nosed Butterfly Fish	x	x	x	
F. longirostris		Rare Long-nosed Butterfly Fish	x	x	x	
Hemitaurichthys polylepis		Pyramid Butterfly Fish				x
H. thompsoni		Thompson's Butterfly Fish		x		
Heniochus acuminatus		Poor Man's Moorish Idol				x
CHANIDAE - Milk Fish						
Chanos chanos	Awa	Milk Fish				x
CIRRHITIDAE - Hawk Fish						
Amblycirrhitus bimacula		Two-spot Hawk Fish				x
Cirrhitops fasciatus	'O'opu kai	Banded Hawk Fish	x	x	x	
Cirrhitus pinnulatus	Po'o pa'a	Hard-headed Hawk Fish		x	x	
Paracirrhites arcatus	Piliko'a	Small Hawk Fish	x	x	x	
P. forsteri	Piliko'a	Forster's Hawk Fish	x	x	x	
CONGRIDAE - Conger Eels						
Conger cinereus	Puhi uha	White Eel				x
DIODONTIDAE - Porcupine Fish						
Diodon hystrix	‘O‘opu hue	Spiny Puffer		x		

Appendix F (cont.)

			Habitat			
Scientific Name	Hawaiian Name	Common Name	B	DO	CR	Recon
FISTULARIIDAE - Cornet Fish						
Fistularia petimba	Nunu Peke	Cornet Fish	x	x	x	
GRAMMISTIDAE - Soap Fish						
Pseudogramma polyacanthus						x
HOLOCENTRIDAE - Squirrel Fish						
Adioryx microstomus		Small Mouth Squirrel Fish	x			
A. spinifer	'U'u kane pou	Spined Squirrel Fish	x			
A. xantherythrus		Yellow-red Squirrel Fish		x	x	
Flammeo sammara		Blood-spot Squirrel Fish				x
Myripristis kuntee	‘U‘u	Cuvier's Squirrel Fish			x	
M. murdjan	‘U‘u	Forskal's Squirrel Fish		x	x	
Myripristis sp.	‘U‘u			x	x	
Plectrypops lima		Rough-scaled Squirrel Fish				x
KUHLIIDAE - Flag-tail Fish						
Kuhlia sandvicensis	Aholehole	Hawaiian Flag-tail Fish				x
KYPHOSIDAE - Rudder Fish						
Kyphosus cinerescens	Nenue	Rudder Fish				x
LABRIDAE - Wrasses						
Anampses chrysocephalus		Golden Head Wrasse	x	x	x	
A. cuvier	‘Opule	Spotted Wrasse	x	x		
Bodianus bilunulatus	A‘awa	Black-spot Wrasse		x		
Cheilinus rhodochrous	Po‘ou	Rose-colored Wrasse	x	x	x	
Cheilio inermis	Kupou	Spindle Wrasse	x		x	
Cirrhilabrus jordani		Flame Wrasse				x
Coris gaimardi	Hinalea ‘akilolo	Clown Wrasse	x	x	x	
C. venusta		Elegant Wrasse	x			
Gomphosus varius	Hinalea nuku ‘i‘iwi	Bird Wrasse	x	x	x	
Halichoeres ornatissimus	Pa‘awela	Christmas Tree Wrasse	x	x	x	
Hemipteronotus niveilatus	Lae nihi	White-side Razor Wrasse				x
Hemipteronotus sp.	Lae nihi			x		
Labroides phthirophagus		Cleaner Wrasse	x	x	x	
Macropharyngodon geoffroyi	Hinalea ‘akilolo	Geoffroy’s Wrasse		x	x	
Pseudocheilinus evanidus		Small Wrasse	x	x		
P. octotaenia		Eight-lined Wrasse	x	x	x	
P. tetrataenia		Four-lined Wrasse	x	x	x	
Stethojulis balteata	Ohua	Green Wrasse	x	x	x	
Thalassoma ballieui	Hinalea luahine	Ballieu’s Wrasse			x	
T. duperrey	Hinalea lau wili	Saddle Back Wrasse	x	x	x	
T. fuscum	‘Awela	Brown Wrasse	x			x
T. lutescens		Yellow Wrasse				x
LUTJANIDAE - Snappers						
Aphareus furcatus		Fork-tailed Snapper		x		
Lutjanus fulvus	Toau (Tahiti)	Red and Green Snapper		x		
L. kasmira	Taape	Blue-lined Snapper				x
MOBULIDAE - Manta Rays						
Manta alfredi	Hahalua	Alfred's Manta Ray				x

Appendix F (cont.)

			Habitat			
Scientific Name	Hawaiian Name	Common Name	B	DO	CR	Recon
MONACANTHIDAE - File Fish						
Cantherhines dumerili	‘O‘ilepa	Dumeril's File Fish	x	x	x	
C. sandwichiensis	‘O‘ilepa	Sandwich Island File Fish	x	x		
C. verecundus		Shy File Fish				x
Pervagor melanocephalus		Black File Fish	x	x	x	
P. spilosoma	‘O‘ili lepa	Fan Tail File Fish	x	x	x	
MULLIDAE - Goat Fish						
Mulloidichthys flavolineatus	Weke	Samoan Goat Fish			x	
M. pflugeri	Weke ‘ula	Pfluger’s Goat Fish	x			
M. vanicolensis	Weke	Gold-banded Goat Fish	x	x	x	
Parupeneus bifasciatus	Munu	Two-striped Goat Fish	x	x	x	
P. chryserydros	Moano	Yellow-tailed Goat Fish	x	x	x	
P. multifasciatus	Moano	Red and Black Banded Goat Fish	x	x	x	
P. porphyreus	Kumu	Purplish Goat Fish	x	x		
MURAENIDAE - Moray Eels						
Enchelynassa canina	Puhi kauila	Canine-toothed Moray			x	
Gymnothorax flavimarginatus	Puhi kapa	Yellow-margined Moray			x	
G. meleagris		White-spotted Moray		x	x	
MYLIOBATIDAE - Eagle Rays						
Aetobatus narinari	Hihimanu	Spotted Eagle Ray		x	x	
OSTRACIIDAE - Box Fishes						
Ostracion meleagris	Pahu	Speckled Box Fish	x	x	x	
O. whitleyi		Whitley's Box Fish				x
PLEURONECTIDAE - Right-eyed Flounders						
Samariscus triocellatus		Three Spot Flounder				x
PRIACANTHIDAE - Big Eyes						
Priacanthus cruentatus	‘Aweoweo	Bloody Big Eye				x
POMACANTHIDAE - Angel Fish						
Centropyge loriculus		Flame Angel Fish				x
C. potteri		Potter’s Angel Fish	x	x	x	
Holacanthus arcuatus		Black-banded Angel Fish		x		
POMACENTRIDAE - Damsel Fish						
Abudefduf abdominalis	Maomao	Green Damsel Fish	x		x	
Chromis acares (?)					x	
C. agilis		Agile Chromis	x	x	x	
C. hanui		Chocolate Chromis	x	x	x	
C. leucurus		Dark Chromis				x
C. ovalis		Oval Chromis	x	x	x	
C. vanderbilti		Vanderbilt's Chromis	x	x	x	
C. verator		Black Chromis	x	x	x	
Dascyllus albisella	Alo‘ilo‘i	White-spotted Damsel Fish	x	x	x	
Eupomacentrus fasciolatus		Yellow-eyed Damsel Fish	x	x	x	

Appendix F (cont.)

			Habitat			
Scientific Name	Hawaiian Name	Common Name	B	DO	CR	Recon
Plectroglyphidodon imparipennis		Small Damsel Fish				x
P. johnstonianus		Johnston Island Damsel Fish	x	x	x	
P. sindonis		Sindo's Damsel Fish	x			
SCARIDAE - Parrot Fish						
Scarops rubroviolaceus		Red and Violet Parrot Fish	x	x		
Scarus perspicillatus	Uhu uliuli	Big Blue Parrot Fish	x			
S. sordidus		Sordid Parrot Fish	x	x	x	
Scarus sp.			x	x	x	
SCORPAENIDAE - Scorpion Fish						
Pterois sphex		Lion Fish				x
Scorpaenopsis brevifrons		Short-browed Scorpion Fish				x
S. cacopsis	Nohu	Jenkins' Scorpion Fish		x		
Taenianotus triacanthus		Leaf Fish				x
SERRANIDAE - Groupers						
Cephalopholis argus		Argus Grouper		x	x	
Liopropoma sp. nov.						x
Anthias bicolor		Bicolor Fancy Bass				x
A. ventralis		Yellow Fancy Bass				x
SPARIDAE - Porgys						
Monotaxis grandoculis	Mu	Grand-eyed Porgy		x	x	
SPHYRAENIDAE - Barracuda						
Sphyraena barracuda	Kaku	Great Barracuda		x		
SYNODONTIDAE - Lizard Fish						
Saurida gracilis	‘Ulae	Slender Lizard Fish		x	x	
Synodus binotatus		Two-spot Lizard Fish			x	
S. variegatus	‘Ulae	Variegated Lizard Fish				x
TETRAODONTIDAE - Balloon Fish						
Arothron hispidus	‘O‘opuhue	Spiny Balloon Fish	x		x	
A. meleagris		Speckled Balloon Fish	x		x	
A. nigropunctatus		Black Spotted Balloon Fish				x
TRIAKIDAE - Smooth Dogfish Sharks						
Triaenodon obesus		White-tipped Reef Shark				x

APPENDIX G. STATE OF HAWAII WATER QUALITY STANDARDS

Water body classification and water quality standards for the State of Hawaiʻi are promulgated through Chapter 11-54 of the Hawaiʻi Administrative Rules (DOH 2004). Sections relevant to coastal water resources in PUHO are excerpted/summarized below.

§11-54-1.1 General policy of water quality antidegradation.

(a) Existing uses and the level of water quality necessary to protect the existing uses shall be maintained and protected.

(b) Where the quality of the waters exceed levels necessary to support propagation of fish, shellfish, and wildlife and recreation in and on the water, that quality shall be maintained and protected unless the director finds, after full satisfaction of the intergovernmental coordination and public participation provisions of the state's continuing planning process, that allowing lower water quality is necessary to accommodate important economic or social development in the area in which the waters are located. In allowing such degradation or lower water quality, the director shall assure water quality adequate to protect existing uses fully. Further, the director shall assure that there shall be achieved the highest statutory and regulatory requirements for all new and existing point sources and all cost-effective and reasonable best management practices for nonpoint source control.

(c) Where high quality waters constitute an outstanding national resource, such as waters of national and state parks and wildlife refuges and waters of exceptional recreational or ecological significance, that water quality shall be maintained and protected.

§11-54-2 Classification of state waters.

(a) State waters are classified as either inland waters or marine waters.

(b) Inland waters may be fresh, brackish, or saline.

(1) All inland fresh waters are classified as follows, based on their ecological characteristics and other natural criteria (n/a)

(2) All inland brackish or saline waters are classified as follows, based on their ecological characteristics and other natural criteria:

(A) Standing waters.

(i) Anchialine pools; and

(ii) Saline lakes.

(B) Wetlands.

(i) Coastal wetlands (marshes, swamps, and associated ponds).

(C) Estuaries.

(i) Natural estuaries (stream-fed estuaries and spring-fed estuaries); and

(ii) Developed estuaries.

(c) Marine waters.

(1) All marine waters are either embayments, open coastal, or oceanic waters;

(2) All marine waters which are embayments or open coastal waters are also classified according to the following bottom subtypes:

(A) Sand beaches;

(B) Lava rock shorelines and solution benches;

(C) Marine pools and protected coves;

(D) Artificial basins;

(E) Reef flats; and

(F) Soft bottoms.

§11-54-3 Classification of water uses.

(a) The following use categories classify inland and marine waters for purposes of applying the standards set forth in this chapter, and for the selection or definition of appropriate quality parameters and uses to be protected in these waters. Storm water discharge into State waters shall be allowed provided it meets the requirements specified in this section and the basic water quality criteria specified in section 11-54-4.

(b) Inland waters.

(1) Class 1. It is the objective of class 1 waters that these waters remain in their natural state as nearly as possible with an absolute minimum of pollution from any human caused source. To the extent possible, the wilderness character of these areas shall be protected. Waste discharge into these waters is prohibited. Any conduct which results in a demonstrable increase in levels of point or nonpoint source contamination in class 1 waters is prohibited.

(A) Class 1.a. The uses to be protected in class 1.a waters are scientific and educational purposes, protection of native breeding stock, baseline references from which human-caused changes can be measured, compatible recreation, aesthetic enjoyment, and other nondegrading uses which are compatible with the protection of the ecosystems associated with waters of this class;

(B) Class 1.b. The uses to be protected in class 1.b waters are domestic water supplies, food processing, protection of native breeding stock, the support and propagation of aquatic life, baseline references from which human-caused changes can be measured, scientific and educational purposes, compatible recreation, and aesthetic enjoyment. Public access to these waters may be restricted to protect drinking water supplies;

(2) Class 2. The objective of class 2 waters is to protect their use for recreational purposes, the support and propagation of aquatic life, agricultural and industrial water supplies, shipping, and navigation. The uses to be protected in this class of waters are all uses compatible with the protection and propagation of fish, shellfish, and wildlife, and with recreation in and on these waters. These waters shall not act as receiving waters for any discharge which has not received the best degree of treatment or control compatible with the criteria established for this class. No new treated sewage discharges shall be permitted within estuaries. No new industrial discharges shall be permitted within estuaries, with the exception of:

(A) Acceptable non-contact thermal and drydock or marine railway discharges within Pearl Harbor, Oahu;

(B) Stormwater discharges associated with industrial activities (defined in 40 C.F.R. Section 122.26(b)(14) and(b)(15), except (b)(15)(i)(A) and (b)(15)(i)(B)) which meet, at the minimum, the basic water quality criteria applicable to all waters as specified in section 11-54-4(a), and all applicable requirements specified in chapter 11-55, titled "Water Pollution Control"; and

(C) Discharges covered by a National Pollutant Discharge Elimination System general permit, approved by the U.S. Environmental Protection Agency and issued by the Department in accordance with 40 C.F.R. Section 122.28 and all applicable requirements specified in chapter 11-55, titled "Water Pollution Control.".

(c) Marine waters.

(1) Class AA. It is the objective of class AA waters that these waters remain in their natural pristine state as nearly as possible with an absolute minimum of pollution or alteration of water quality from any human-caused source or actions. To the extent practicable, the wilderness character of these areas shall be protected. No zones of mixing shall be permitted in this class:

(A) Within a defined reef area, in waters of a depth less than 18 meters (ten fathoms); or

(B) In waters up to a distance of 300 meters (one thousand feet) off shore if there is no defined reef area and if the depth is greater than 18 meters (ten fathoms). The uses to be protected in this class of waters are oceanographic research, the support and propagation of shellfish and other marine life, conservation of coral reefs and wilderness areas, compatible recreation, and aesthetic enjoyment. The classification of any water area as Class AA shall not preclude other uses of the waters compatible with these objectives and in conformance with the criteria applicable to them;

(2) Class A. It is the objective of class A waters that their use for recreational purposes and aesthetic enjoyment be protected. Any other use shall be permitted as long as it is compatible with the protection and propagation of fish, shellfish, and wildlife, and with recreation in and on these waters. These waters shall not act as receiving waters for any discharge which has not received the best degree of treatment or control compatible with the criteria established for this class. No new sewage discharges will be permitted within embayments. No new industrial discharges shall be permitted within embayments, with the exception of:

(A) Acceptable non-contact thermal and drydock or marine railway discharges, in the following water bodies: (n/a)

(B) Storm water discharges associated with industrial activities (defined in 40 C.F.R. Section 122.26(b)(14) and (b)(15), except (b)(15)(i)(A) and (b)(15)(i)(B)) which meet, at the minimum, the basic water quality criteria applicable to all waters as specified in section 11-54-4, and all applicable requirements specified in the chapter 11-55, titled "Water Pollution Control;" and

(C) Discharges covered by a National Pollutant Discharge Elimination System general permit, approved by the U.S. Environmental Protection Agency and issued by the Department in accordance with 40 C.F.R. Section 122.28 and all applicable requirements specified in chapter 11-55, titled "Water Pollution Control."

(d) Marine bottom ecosystems.

(1) Class I. It is the objective of class I marine bottom ecosystems that they remain as nearly as possible in their natural pristine state with an absolute minimum of pollution from any human-induced source. Uses of marine bottom ecosystems in this class are passive human uses without intervention or alteration, allowing the perpetuation and preservation of the marine bottom in a most natural state, such as for nonconsumptive scientific research (demonstration, observation or monitoring only), nonconsumptive education, aesthetic enjoyment, passive activities, and preservation;

(2) Class II. It is the objective of class II marine bottom ecosystems that their use for protection including propagation of fish, shellfish, and wildlife, and for recreational purposes not be limited in any way. The uses to be protected in this class of marine bottom ecosystems are all uses compatible with the protection and propagation of fish, shellfish, and wildlife, and with recreation. Any action which may permanently or completely modify, alter, consume, or degrade marine bottoms, such as structural flood control channelization, (dams); landfill and reclamation; navigational structures (harbors, ramps); structural shore protection (seawalls, revetments); and wastewater effluent outfall structures may be allowed upon securing approval in writing from the director, considering the environmental impact and the public interest pursuant to sections 342D-4, 342D-5, 342D-6, and 342D-50, HRS in accordance with the applicable provisions of chapter

91, HRS.

§11-54-4 Basic water quality criteria applicable to all waters.

(a) All waters shall be free of substances attributable to domestic, industrial, or other controllable sources of pollutants, including:

(1) Materials that will settle to form objectionable sludge or bottom deposits;

(2) Floating debris, oil, grease, scum, or other floating materials;

(3) Substances in amounts sufficient to produce taste in the water or detectable off-flavor in the flesh of fish, or in amounts sufficient to produce objectionable color, turbidity or other conditions in the receiving waters;

(4) High or low temperatures; biocides; pathogenic organisms; toxic, radioactive, corrosive, or other deleterious substances at levels or in combinations sufficient to be toxic or harmful to human, animal, plant, or aquatic life, or in amounts sufficient to interfere with any beneficial use of the water;

(5) Substances or conditions or combinations thereof in concentrations which produce undesirable aquatic life; and soil particles resulting from erosion on land involved in earthwork, such as the construction of public works; highways; subdivisions; recreational, commercial, or industrial developments; or the cultivation and management of agricultural lands.

(b) To ensure compliance with paragraph (a)(4), all state waters are subject to monitoring and to the following standards for acute and chronic toxicity and the protection of human health.

(1) As used in this section:

(A) "Acute Toxicity" means the degree to which a pollutant, discharge, or water sample causes a rapid adverse impact to aquatic organisms. The acute toxicity of a discharge or receiving water is measured using the methods in section 11-54-10, unless other methods are specified by the director.

(B) "Chronic Toxicity" means the degree to which a pollutant, discharge, or water sample causes a longterm adverse impact to aquatic organisms, such as a reduction in growth or reproduction. The chronic toxicity of a discharge or receiving water is measured using the methods in section 11-54-10, unless other methods are specified by the director.

(C) "Dilution" means, for discharges through submerged outfalls, the average and minimum values calculated using the models in the EPA publication, Initial Mixing Characteristics of Municipal Ocean Discharges (EPA/600/3-85/073, November, 1985), or in the EPA publication, Expert System for Hydrodynamic Mixing Zone Analysis of Conventional and Toxic Submerged Single Port Discharges (Cormix 1) (EPA/600/3-90/073), February, 1990.

(D) "No Observed Effect Concentration Observed Effect Concentration" (NOEC), means the highest per cent concentration of a discharge or water sample, in dilution water, which causes no observable adverse effect in a chronic toxicity test. For example, an NOEC of 100 percent indicates that an undiluted discharge or water sample causes no observable adverse effect to the organisms in a chronic toxicity test.

(2) Narrative toxicity and human health standards.

(A) Acute Toxicity Standards: All state waters shall be free from pollutants in concentrations which exceed the acute standards listed in paragraph (3). All state waters shall also be free from acute toxicity as measured using the toxicity tests listed in section 11, or other methods specified by the director.

(B) Chronic Toxicity Standards: All state waters shall be free from pollutants in concentrations which on average during any twenty-four hour period exceed the chronic standards listed in paragraph (3). All state waters shall also be free from chronic toxicity as measured using the toxicity tests listed in section 11-54-10, or other methods specified by the director.

(C) Human Health Standards: All state waters shall be free from pollutants in concentrations which, on average during any thirty day period, exceed the "fish consumption" standards for non-carcinogens in paragraph (3). All state waters shall also be free from pollutants in concentrations, which on average during any 12 month period, exceed the "fish consumption" standards for pollutants identified as carcinogens in paragraph (3).

(3) Numeric standards for toxic pollutants applicable to all waters. The freshwater standards apply where the dissolved inorganic ion concentration is less than 0.5 parts per thousand; saltwater standards apply above 0.5 parts per thousand. Values for metals refer to the dissolved fraction. All values are expressed in micrograms per liter.

	Freshwater		Saltwater		Fish
Pollutant	Acute	Chronic	Acute	Chronic	Consumption
Acenapthene	570	ns	320	ns	ns
Acrolein	23	ns	18	ns	250
Acrylonitrile*	2,500	ns	ns	ns	0.21
Aldrin*	3.0	ns	1.3	ns	0.000026
Aluminum	750	260	ns	ns	ns
Antimony	3,000	ns	ns	ns	15,000
Arsenic	360	190	69	36	ns
Benzene*	1,800	ns	1,700	ns	13
Benzidine*	800	ns	ns	ns	0.00017
Beryllium*	43	ns	ns	ns	0.038
Cadmium	3+	3+	43	9.3	ns
Carbon tetrachloride*	12,000	ns	16,000	ns	2.3
Chlordane*	2.4	0.0043	0.09	0.004	0.000016
Chlorine	19	11	13	7.5	ns
Chloroethersethy-(bis-2)*	ns	ns	ns	ns	0.44
isoprophyl	ns	ns	ns	ns	1,400
methyl(bis)*	ns	ns	ns	ns	0.00060
Chloroform*	9,600	ns	ns	ns	5.1
Chlorophenol(2)	1,400	ns	ns	ns	ns
Chlorpyrifos	0.083	0.041	0.011	0.0056	ns
Chromium_(VI)	16	11	1,100	50	ns
Copper	6+	6+	2.9	2.9	ns
Cyanide	22	5.2	1	1	ns
DDT*	1.1	0.001	0.013	0.001	0.000008
metabolite_TDE*	0.03	ns	1.2	ns	ns
Demeton	0.1	ns	0.1	ns	
Dichlorobenzenes*	370	ns	660	ns	850
benzidine*	ns	ns	ns	ns	0.007
ethane(1,2)*	39,000	ns	38,000	ns	79
ehenol(2,4)	670	ns	ns	ns	ns
propanes	7,700	ns	3,400	ns	ns
propene(1,3)	2,000	ns	260	ns	4.6
Dieldrin*	2.5	0.0019	0.71	0.0019	0.000025
Dinitroo-cresol(2,4)	ns	ns	ns	ns	250
toluenes*	110	ns	200	ns	3.0
Dioxin*	0.003	ns	ns	ns	$5.0x10_{-9}$
Diphenylhydrazine(1,2)	ns	ns	ns	ns	0.018
Endosulfan	0.22	0.056	0.034	0.0087	52
Endrin	0.18	0.0023	0.037	0.0023	ns
Ethylbenzene	11,000	ns	140	ns	1,070
Fluoranthene	1,300	ns	13	ns	18

	Freshwater		Saltwater		Fish Consumption
Pollutant	Acute	Chronic	Acute	Chronic	
Guthion	ns	0.01	ns	0.01	ns
Heptachlor*	0.52	0.0038	0.053	0.0036	0.00009
Hexachlorobenzene*	ns	ns	ns	ns	0.00024
butadiene*	30	ns	11	ns	16
cyclohexane-alpha*	ns	ns	ns	ns	0.010
beta*	ns	ns	ns	ns	0.018
technical*	ns	ns	ns	ns	0.014
cyclopentadiene	2	ns	2	ns	ns
ethane*	330	ns	310	ns	2.9
Isophorone	39,000	ns	4,300	ns	170,000
Lead	29+	29+	140	5.6	ns
Lindane*	2.0	0.08	0.16	ns	0.020
Malathion	ns	0.1	ns	0.1	ns
Mercury	2.4	0.55	2.1	0.025	0.047
Methoxychlor	ns	0.03	ns	0.03	ns
Mirex	ns	0.001	ns	0.001	ns
Naphthalene	770	ns	780	ns	ns
Nickel	5+	5+	75	8.3	33
Nitrobenzene	9,000	ns	2,200	ns	ns
Nitrophenols*	77	ns	1,600	ns	ns
Nitrosamines*	1,950	ns	ns	ns	0.41
Nitroso-dibutylamine-N*	ns	ns	ns	ns	0.19
diethylamine-N*	ns	ns	ns	ns	0.41
dimethylamine-N*	ns	ns	ns	ns	5.3
diphenylamine-N*	ns	ns	ns	ns	5.3
Pyrrolidine-N*	ns	ns	ns	ns	30
Parathion	0.065	0.013	ns	ns	ns
Pentachloroethanes	2,400	ns	130	ns	ns
benzene	ns	ns	ns	ns	28
phenol	20	13	13	ns	ns
Phenol	3,400	ns	170	ns	ns
2,4-dimethyl	700	ns	ns	ns	ns
Phthalate	esters				
dibutyl	ns	ns	ns	ns	50,000
diethyl	ns	ns	ns	ns	590,000
di-2-ethylhexyl	ns	ns	ns	ns	16,000
dimethyl	ns	ns	ns	ns	950,000
Polychlorinated biphenyls*	2.0	0.014	10	0.03	0.000079
Polynuclear aromatic hydrocarbons*	ns	ns	ns	ns	0.01
Selenium	20	5	300	71	ns

	Freshwater		Saltwater		Fish Consumption
Pollutant	Acute	Chronic	Acute	Chronic	
Silver	1+	1+	2.3	ns	ns
Tetrachloroethanes	3,100	ns	ns	ns	ns
benzene(1,2,4,5)	ns	ns	ns	ns	16
ethane(1,1,2,2)*	ns	ns	3,000	ns	3.5
ethylene*	1,800	ns	3,400	145	2.9
phenol(2,3,5,6)	ns	ns	ns	440	ns
Thallium	470	ns	710	ns	16
Toluene	5,800	ns	2,100	ns	140,000
Toxaphene*	0.73	0.0002	0.21	0.0002	0.00024
Tributyltin	ns	0.026	ns	0.01	ns
Trichloroethane(1,1,1)	6,000	ns	10,400	ns	340,000
ethane(1,1,2)*	6,000	ns	ns	ns	14
ethylene*	15,000	ns	700	ns	26
phenol(2,4,6)*	ns	ns	ns	ns	1.2
Vinyl chloride*	ns	ns	ns	ns	170
Zinc	22+	22+	95	86	ns

ns -No standard has been developed.
* - Carcinogen.
+ - The value listed is the minimum standard. Depending upon the receiving water $CaCO_3$ hardness, higher standards may be calculated using the respective formula in the U. S. Environmental Protection Agency publication Quality Criteria for Water (EPA 440/5-86-001, Revised May 1, 1987).
Note - Compounds listed in the plural in the "Pollutant" column represent complex mixtures of isomers. Numbers listed to the right of these compounds refer to the total allowable concentration of any combination of isomers of the compound, not only to concentrations of individual isomers.

§11-54-5 Uses and specific criteria applicable to inland waters. Inland water areas to be protected are described in section 11-54-5.1, corresponding specific criteria are set forth in section 11-54-5.2; water body types are defined in section 11-54-1.

§11-54-5.1 Inland water areas to be protected.

(a) Freshwaters (n/a)

(b) Brackish or saline waters (anchialine pools, saline lakes, coastal wetlands, and estuaries).

(1) Class 1.a.

(A) All inland brackish or saline waters within natural reserves, preserves, sanctuaries, and refuges established by the department of land and natural resources under chapter 195, HRS, or similar reserves for the protection of aquatic life established under chapter 195, HRS.

(B) All inland brackish or saline waters in national and state parks.

(C) All inland brackish or saline waters in state or federal fish and wildlife refuges.

(D) All inland brackish or saline waters which have been identified as a unique or critical habitat for threatened or endangered species by the U.S. Fish and Wildlife Service.

(D) All inland brackish and saline waters in Wai-manu National Estuarine Research Reserve (Hawai‘i).

(F) The following natural estuaries: Lumaha‘i and Kilauea estuaries (Kaua‘i).

(2) Class 1.b. All inland brackish or saline waters in protective subzones designated under chapter 13-5 of the state board of land and natural resources.

(3) Class 2. All inland brackish and saline waters not otherwise classified.

§11-54-5.2 Inland water criteria.

(a) Criteria for springs and seeps, ditches and flumes, natural freshwater lakes, reservoirs, low wetlands, coastal wetlands, saline lakes, and anchialine pools. Only the basic criteria set forth in section 11-54-4 apply to springs and seeps, ditches and flumes, natural freshwater lakes, reservoirs, low wetlands, coastal wetlands, saline lakes, and anchialine pools. Natural freshwater lakes, saline lakes, and anchialine pools will be maintained in the natural state through Hawai‘i's "no discharge" policy for these waters. Waste discharge into these waters is prohibited (see paragraph 11-54-3(b)(1)).

(b) Specific criteria for streams (n/a).

(c) Specific criteria for elevated wetlands (n/a).

(d) Specific criteria for estuaries.

(1) The following table is applicable to all estuaries except Pearl Harbor:

Parameter	Units	Criterion		
		GM (1)	GM 10% (2)	GM 2% (3)
TDN	µg N/l	200.00	350.00	500.00
NH4	µg NH4-N/l	6.00	10.00	20.00
NO3+NO2	µgNO3-N/l	8.00	25.00	35.00
TDP	µg P/l	25.00	50.00	75.00
Chl-a	µg/l	2.00	5.00	10.00
Turb	ntu	1.5	3.00	5.00

(1) Geometric mean not to exceed the given value
(2) Geometric mean not to exceed the given value more than 10% of the time
(3) Geometric mean not to exceed the given value more than 2% of the time

Parameter	Units	Criterion
pH	n/a	7.0 – 8.6, deviate ≤0.5 units from ambient
Dissolved Oxygen	% saturation	≥75% saturation
Temperature	°C	Deviate ≤1°C from ambient
Salinity	ppt	Deviate ≤10% from ambient
EH	mV	≥ -100 mV in upper 10 cm of sediment

§11-54-6 Uses and specific criteria applicable to marine waters.

(a) Embayments.

(1) As used in this section: "Embayments" means land-confined and physically protected marine waters with restricted openings to open coastal waters, defined by the ratio of total bay volume to the cross-sectional entrance area of seven hundred to one or greater. "Total bay volume" is measured in cubic meters and "cross-sectional entrance area" is measured in square meters, and both are determined at mean lower low water.

(2) Water areas to be protected.

(A) Class AA.

(i) Hawaiʻi: Puako Bay, Waiulua Bay, Anaehoomalu Bay, Kiholo Bay, Kailua Harbor, Kealakekua Bay, Honaunau Bay

(ii) All embayments in preserves, reserves, sanctuaries, and refuges established by the department of land and natural resources under chapter 195 or chapter 190, HRS, or similar reserves for the protection of marine life established under chapter 190, HRS.

(iii) All waters in state or federal fish and wildlife refuges and marine sanctuaries.

(iv) All waters which have been officially identified as a unique or critical habitat for threatened or endangered species by the U.S. Fish and Wildlife Service.

(B) Class A. Hawai‘i: Hilo Bay (inside breakwater), Kawaihae Boat Harbor, Honokohau Boat Harbor, Keauhou Bay

(3) The following criteria are specific for all embayments excluding those described in section 11-54-06(d).(Note that criteria for embayments differ based on fresh water inflow.)

Table 5a. Water quality criteria applicable to Honokohau Harbor. (DOH 2004).

Parameter	Units	Season (1)	Criterion		
			GM (2)	GM 10% (3)	GM 2% (4)
TDN	µg N/l	Wet	200.00	350.00	500.00
		Dry	150.00	250.00	350.00
NH4	µg NH4-N/l	Wet	6.00	13.00	20.00
		Dry	3.50	8.50	15.00
NO3+NO2	µgNO3-N/l	Wet	8.00	20.00	35.00
		Dry	5.00	14.00	25.00
TDP	µg P/l	Wet	25.00	50.00	75.00
		Dry	20.00	40.00	60.00
Chl-a	µg/l	Wet	1.50	4.50	8.50
		Dry	0.50	1.50	3.00
Turb	ntu	Wet	1.5	3.00	5.00
		Dry	0.40	1.00	1.50

(1) “Wet” and “Dry” criteria apply when average freshwater inflow to harbor is greater than, or less than, one percent of the harbor volume per day, respectively
(2) Geometric mean not to exceed the given value
(3) Geometric mean not to exceed the given value more than 10% of the time
(4) Geometric mean not to exceed the given value more than 2% of the time

Parameter	Units	Criterion
pH	n/a	7.6 – 8.6, except where freshwater influence depresses pH to 7.0 (min)
Dissolved Oxygen	% saturation	≥75% saturation
Temperature	°C	Deviate ≤1°C from ambient
Salinity	ppt	Deviate ≤10% from ambient

(b) Open coastal waters.

(1) As used in this section: "Open coastal waters" means marine waters bounded by the 183 meter or 600 foot (100 fathom) depth contour and the shoreline, excluding bays named in subsection (a);

(2) Water areas to be protected (measured in a clockwise direction from the first-named to the second-named location, where applicable):

(A) Class AA.

(i) Hawaiʻi - The open coastal waters from Leleiwi Point to Waiulaula Point;

(ii) Maui (n/a)

(iii) Kahoolawe (n/a)

(iv) Lanai (n/a)

(v) Molokai (n/a)

(vi) Oahu (n/a)

(viii) Niihau (n/a)

(ix) All other islands of the state - All open coastal waters surrounding the islands not classified in this section;

(x) All open waters in preserves, reserves sanctuaries, and refuges established by the department of land and natural resources under chapter 195 or chapter 190, HRS or similar reserves for the protection of marine life established under chapter 190, HRS, as amended; or in the refuges or sanctuaries established by the U.S. Fish and Wildlife Service or the National Marine Fisheries Service;

(B) Class A - All other open coastal waters not otherwise specified.

(3) The following criteria are specific for all open coastal waters, excluding those described in section 11-54-6(d). (Note that criteria for open coastal waters differ, based on fresh water discharge.) (n/a)

(c) Oceanic waters (n/a)

(d) Area-specific criteria for the Kona (west) coast of the island of Hawaiʻi.

(1) For all marine waters of Hawaiʻi Island from Loa Point, South Kona District, clockwise to Malae Point, North Kona District, excluding Kawaihae Harbor and Honokohau Harbor, and for all areas from the shoreline at mean lower low water to a distance 1000 m seaward:

(i) in areas where nearshore marine water salinity is greater than 32.00 parts per thousand the following specific criteria apply:

Parameter	Units	Criterion
TDN	µg N/l	100.00
NO3+NO2	µg(NO3+NO2)-N/l	4.50
TDP	µg P/l	12.50
PO4	µg PO4-P/l	5.00
NH4 (1)	µg NH4-N/l	2.50
Chl-a (1)	µg/l	0.30
Turb (1)	ntu	0.10

(1) Criterion also applicable to coastal waters with salinities less than 32.00 ppt.

Parameter	Units	Criterion
pH	n/a	Deviate ≤0.5 units from ambient except where freshwater influence depresses pH to 7.0 min.
Dissolved Oxygen	% saturation	≥75% saturation
Temperature	°C	Deviate ≤1°C from ambient
Salinity	ppt	Deviate ≤10% from ambient

(ii) If nearshore marine water salinity is less than or equal to 32.00 parts per thousand the following parameters shall be related to salinity on the basis of a linear least squares regression equation:

$Y = MX + B$
where:

Y = parameter concentration (in ug/L)
X = salinity (in ppt)
M = regression coefficient (or "slope")
B = constant (or "Y intercept").

The absolute value of the upper 95 per cent confidence limit for the calculated sample regression coefficient (M) shall not exceed the absolute value of the following values:

Parameter	Units	M
NO3+NO2	µg(NO3+NO2)-N/l	-31.92
TDN	µg N/l	-40.35
PO4	µg PO4-P/l	-3.22
TDP	µg P/l	-2.86

(iii) Parameter concentrations shall be determined along a horizontal transect extending seaward from a shoreline sample location using the following method: water samples shall be obtained at distances of 1, 10, 50, 100, and 500 meters from the shoreline sampling location. Samples shall be collected within one meter of the water surface and below the air-water interface. Dissolved nutrient samples shall be filtered through media with particle size retention of 0.7 um. This sampling protocol shall be replicated not less than three times on different days over a period not to exceed fourteen days during dry weather conditions. The geometric means of sample measurements for corresponding offshore distances shall be used for regression calculations.

(iv) pH Units - shall not deviate more than 0.5 units from a value of 8.1, except at coastal locations where and when freshwater from stream, storm drain or groundwater discharge may depress the pH to a minimum level of 7.0. Dissolved Oxygen - Not less than seventy-five per cent saturation, determined as a function of ambient water temperature and salinity. Temperature - Shall not vary more than one degree Celsius from ambient conditions. Salinity - Shall not vary more than ten per cent from natural or seasonal changes considering hydrologic input and oceanographic factors. L - liter N.T.U. - Nephelometric Turbidity Units. A comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension under the same conditions. The higher the intensity of scattered light, the higher the turbidity. ug - microgram or 0.000001 grams.

§11-54-7 Uses and specific criteria applicable to marine bottom types.

(a) Sand beaches.

(l) As used in this section: "Sand beaches" means shoreline composed of the weathered calcareous remains of marine algae and animals (white sand), the weathered remains of volcanic tuff (olivine), or the weathered remains of lava (black sand). Associated animals are largely burrowers and are related to particle grain size, slope, and color of the beach;

(2) Water areas to be protected:

(A) Class I - All beaches on the Northwestern Hawaiian Islands (n/a)

(B) Class II - All beaches not in Class I;

(3) The following criteria are specific to sand beaches:

(A) Episodic deposits of flood-borne sediment shall not occur in quantities exceeding an equivalent thickness of ten millimeters (0.40 inch) twenty four hours after a heavy rainstorm;

(B) Oxidation - reduction potential (EH) in the uppermost ten centimeters (four inches) of sediment shall not be less than +100 millivolts;

(C) No more than fifty per cent of the grain size distribution of sediment shall be smaller than 0.125 millimeters in diameter.

(b) Lava rock shoreline and solution benches.

(1) As used in this section: "Lava rock shorelines" means sea cliffs and other vertical rock faces, horizontal basalts, volcanic tuff beaches, and boulder beaches formed by rocks falling from above or deposited by storm waves. Associated plants and animals are adapted to the harsh physical environment and are distinctly zoned to the degree of wave exposure; “Solution

benches" means sea level platforms developed on upraised reef or solidified beach rock by the erosive action of waves and rains. Solution benches are distinguished by a thick algal turf and conspicuous zonation of plants and animals;

(2) Water areas to be protected:

(A) Class I - All lava rock shorelines and solution benches in preserves, reserves, sanctuaries, and refuges established by the department of land and natural resources under chapter 195 or chapter 190, HRS, or similar reserves for the protection of marine life established under chapter 190, HRS, as amended; or in refuges or sanctuaries established by the U.S. Fish and Wildlife Service or the National Marine Fisheries Service;

(B) Class II

(i) All other lava rock shorelines not in Class I;

(ii) The following solution benches: (n/a)

(3) The following criteria are specific to lava rock shorelines and solution benches:

(A) Episodic deposits of flood-borne sediment shall not occur in quantities exceeding an equivalent thickness of five millimeters (0.20 inch) for longer than twenty-four hours after a heavy rainstorm

(B) The director shall determine parameters, measures, and criteria for bottom biological communities which may be affected by proposed actions. The location and boundaries of each bottom-type class will be clarified when situations require their identification. For example, when a discharge permit is applied for or a waiver pursuant to Section 301(h) of the Federal Water Pollution Control Act (33 U.S.C. Section 1311) is required. Permanent benchmark stations may be required where necessary for monitoring purposes. The water quality standards for this subsection shall be deemed to be met if time series surveys of benchmark stations indicate no relative changes in the relevant biological communities, as noted by biological community indicators or by indicator organisms which may be applicable to the specific site.

(c) Marine pools and protected coves.

(1) As used in this section: "Marine pools" means waters which collect in depressions on sea level lava rock outcrops and solution benches and also behind large boulders fronting the sea. Pools farthest from the ocean have harsher environments and less frequent renewal of water and support fewer animals. Those closest to the ocean are frequently renewed with water, are essentially marine, and support more diverse fauna; "Protected coves" means small inlets which are removed from heavy wave action or surge;

(2) Water areas to be protected;

(A) Class I.

(i) All marine pools and protected coves in preserves, reserves, sanctuaries, and refuges established by the department of land and natural resources under chapter 195 or chapter 190, HRS, or similar reserves for the protection of marine life established under chapter 190, HRS, as amended; or in refuges or sanctuaries established by the U.S. Fish and Wildlife Service or the National Fisheries Service;

(ii) Hawaiʻi: Honaunau, Kiholo

(B) Class II. Hawaiʻi: Kalapana, Pohakuloa, Kapalaoa, Kapoho, King's Landing (Papai), Hilo, Leileiwi Point, Wailua Bay

(d) Artificial basins (n/a)

(e) Reef flats and reef communities

(1) As used in this section: "Nearshore reef flats" means shallow platforms of reef rock, rubble, and sand extending from the shoreline. Smaller, younger flats projected out as semicircular aprons while older, larger flats form wide continuous platforms. Associated animals are mollusks, echinoderms, worms, crustaceans (many living beneath the surface), and reef-building corals. "Offshore reef flats" means shallow, submerged platforms of reef rock and sand between depths of zero to three meters (zero to ten feet) which are separated from the shoreline of high volcanic islands by lagoons or ocean expanses. Dominant organisms are bottomdwelling algae. Biological composition is extremely variable. There are three types: patch, barrier, and atoll reef flats; quite different from one another structurally. The presence of heavier wave action, water more oceanic in character, and the relative absence of terrigenous influences distinguish offshore reef flats. "Protected reef communities" means hard bottom aggregations, including scattered sand channels and patches, dominated by living coral thickets, mounds, or platforms. They are found at depths of ten to thirty meters (thirty-two to ninety-six feet) along protected leeward coasts or in shallow water (up to sea level) in sheltered lagoons behind atoll or barrier reefs and in the calm reaches of bays or coves. "Wave-exposed reef communities" means aggregations, including scattered sand channels and patches, dominated by corals. They may be found at depths up to forty meters (approximately one hundred thirty feet) along coasts subject to continuous or heavy wave action and surge. Wave-exposed reef communities are dominated biologically by benthic algae, reef-building corals, and echinoderms.

(2) Water areas to be protected:

(A) Class l.

(i) All reef flats and reef communities in preserves, reserves, sanctuaries, and refuges established by the department of land and natural resources under chapter 195 or chapter 190, HRS, or similar reserves for the protection of marine life under chapter 190, HRS, as amended; or in refuges or sanctuaries established by the U.S. Fish and Wildlife Service or the National Marine Fisheries Service;

(ii) Nearshore reef flats: Hawaiʻi: Puako

(iii)Offshore reef flats: (n/a)

(iv) Wave exposed reef communities: Hawaiʻi (n/a)

(v) Protected reef communities: Hawaiʻi: Puako, Honaunau, Kealakekua, Kiholo, Anaehoomalu, Hapuna, Kahaluu Bay, Keaweula (North Kohala), Milolii Bay to Keawaiki, Kailua-Kaiwi (Kona), Onomea Bay, 1801 Lava Flow (Keahole or Kiholo), 1850 Lava Flow (South Kona), 1859 Lava Flow (Kiholo), 1919 Lava Flow (Milolii), 1926 Lava Flow (Milolii)

(B) Class II.

(i) Existing or planned harbors may be located within nearshore reef flats showing degraded habitats and only where feasible alternatives are lacking and upon written approval by the director, considering environmental impact and the public interest pursuant to section 342D-6, HRS. [Hawaiʻi: Blonde Reef (Hilo Harbor), Kawaihae Small Boat Harbor] All other nearshore reef flats not in Class I;

(ii) Offshore reef flats: (n/a)

(iii)All other wave exposed or protected reef communities not in Class I.

(3) Specific criteria to be applied to all reef flats and reef communities: No action shall be undertaken which would substantially risk damage, impairment, or alteration of the biological characteristics of the areas named herein. When a determination of substantial risk is made by the director, the action shall be declared to be contrary to the public interest and no other permits shall be issued pursuant to chapter 342, HRS.

(A) Oxidation-reduction potential (EH) in the uppermost ten centimeters (four inches) of sand patches shall not be less than +100 millivolts;

(B) No more than fifty per cent of the grain size distribution of sand patches shall be smaller than 0.125 millimeters in diameter

(C) Episodic deposits of flood-borne soil sediment shall not occur in quantities exceeding equivalent thicknesses for longer than twenty-four hours after a heavy rainstorm as follows:

(i) No thicker than an equivalent of two millimeters (0.08 inch) on living coral surfaces;

(ii) No thicker than an equivalent of five millimeters (0.2 inch) on other hard bottoms;

(iii) No thicker than an equivalent of ten millimeters (0.4 inch) on soft bottoms;

(D) The director shall determine parameters, measures, and criteria for bottom biological communities which may be affected by proposed actions. The location and boundaries of each bottom-type class shall be clarified when situations require their identification. For example, the location and boundaries shall be clarified when a discharge permit is applied for or a waiver pursuant to Section 301(h) of the Federal Water Pollution Control Act of 1972 (33 U.S.C. 1251 et seq.) is required. Permanent benchmark stations may be required where necessary for monitoring purposes. The water quality standards for this subsection shall be deemed to be met if time series surveys of benchmark stations indicate no relative changes in the relevant biological communities, as noted by biological community indicators or by indicator organisms which may be applicable to the specific site.

(f) Soft bottom communities.

(1) As used in this section: "Soft bottom communities" means poorly described and "patchy" communities, mostly of burrowing organisms, living in deposits at depths between two to forty meters (approximately six to one hundred thirty feet). The particle size of sediment, depth below sea level, and degree of water movement and associated sediment turnover dictate the composition of animals which rework the bottom with burrows, trails, tracks, ripples, hummocks, and depressions.

(2) Water areas to be protected: Class II - All soft bottom communities;

(3) Specific criteria to be applied - Oxidation-reduction potential (EH) in the uppermost ten centimeters (four inches) of sediment should not be less than -100 millivolts. The location and boundaries of each bottom-type class shall be clarified when situations require their identification. For example, the location and boundaries shall be clarified when a discharge permit is applied for or a waiver pursuant to Section 301(h) of the Act is required.

§11-54-8 Specific criteria for recreational areas.

(a) In inland recreational waters:

(1) Enterococcus content shall not exceed a geometric mean of 33 per one hundred milliliters in not less than five samples which shall be spaced to cover a period between 25 and 30 days. No single sample shall exceed the single sample maximum of 89 CFU per 100 milliliters or the site-specific one-sided 82 per cent confidence limit. Inland recreational waters in which enterococcus content does not exceed the standard shall not be lowered in quality.

(3) At locations where sampling is less frequent than five samples per twenty-five to thirty days, no single sample shall exceed the single sample maximum nor shall the geometric mean of these samples taken during the 30-day period exceed 33 CFU per 100 milliliters.

(4) Raw or inadequately treated sewage, sewage for which the degree of treatment is unknown, or other pollutants of public health significance, as determined by the director of health, shall not be present in natural public swimming, bathing or wading areas. Warning signs

shall be posted at locations where human sewage has been identified as temporarily contributing to the enterococcus count.

(b) In marine recreational waters:

(1) Within 300 meters (one thousand feet) of the shoreline, including natural public bathing or wading areas, enterococcus content shall not exceed a geometric mean of seven per one hundred milliliters in not less than five samples which shall be spaced to cover a period between twenty-five and thirty days. No single sample shall exceed the single sample maximum of 100 CFU per 100 milliliters or the site-specific one-sided 75 per cent confidence limit. Marine recreational waters along sections of coastline where enterococcus content does not exceed the standard, as shown by the geometric mean test described above, shall not be lowered in quality.

(2) At locations where sampling is less frequent than five samples per twenty-five to thirty days, no single sample shall exceed the single sample maximum nor shall the geometric mean of these samples taken during the thirty-day period exceed 7 CFU per 100 milliliters.

(3) Raw or inadequately treated sewage, sewage for which the degree of treatment is unknown, or other pollutants of public health significance, as determined by the director of health, shall not be present in natural public swimming, bathing or wading areas. Warning signs shall be posted at locations where human sewage has been identified as temporarily contributing to the enterococcus count.

As the nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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