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Technical Report 112

Biological and Water Quality Characteristics of Anchialine Resources in Kaloko-Honokohau National Historical Park

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SUMMARY

This study was undertaken to examine the status of biological and water quality resources in the anchialine pools, fishponds and nearshore marine waters of the Kaloko-Honokohau National Historic Park (KAHO) over a 3-year period. The study identified 82 anchialine pools and pool complexes in and adjacent to the present Park boundaries. Routine monitoring of water quality and biota was carried out in 16 anchialine pool, 8 fishpond, 10 marine and 3 coastal well sample sites. Water chemistry studies show that the water quality in the ground, anchialine, fishpond and nearshore marine waters fronting the KAHO are typical of the West Hawaii coast. Presently, there is no evidence of water pollution from anthropogenic sources in this system using the limits of detection available to this study. However the status of native anchialine species in the pools of the KAHO is poor. Sixty-four pools were examined within the Park's boundaries. Only 21 or 33% of these pools contained the most common and characteristic anchialine species the opae'ula or *Halocaridina rubra* and only 10 or 16% of these ponds was this species consistently present during daylight hours. In contrast, a study carried out in 1972 of some of these same pools noted that 75% contained the usual array of anchialine species including *H. rubra*. Concurrent with the decrease in native anchialine species has been the increase and spread of alien fish (primarily guppies, *Poecilia reticualta*) in these ponds. The alien fish are predators on several key anchialine species including the opae'ula. *Halocaridina rubra* is a keystone herbivorous species in Hawaiian anchialine systems, maintaining the ecological balance in the benthic communities. Its removal often leads to dramatic shifts in the benthic communities, which become dominated by a few macroalgal species and resulting in a decrease in the diversity of species in the system.

The study recommends that an active management program be initiated to (1) promote a strong education program and permit limited cultural use, (2) protect existing "high value" pools and (3) undertake a pool restoration program. The restoration program would have the following elements: (1) curtail the spread of alien fish, (2) remove alien fish from selected pools, (3) restore the physical features of some pools by the removal of alien vegetation and accumulated sediments due to the input of leaf litter, (4) develop new anchialine pools in presently disturbed (bulldozed a'a) habitat but well-removed from the alien fish threat, (5) undertake the acquisition of additional anchialine resources presently outside of the Park's boundaries and (6) establish a monitoring program to insure that the management program meets its objectives.

Anchialine resources in the US are only located in the Hawaiian Islands and the majority of these are along the West Hawaii coastline. Recent ecological work on the West Hawaii anchialine pools suggests that in excess of 95% of the resource has been contaminated by the invasion of alien fish. The spread of these exotics has occurred in the last 20 years. The KAHO is one of the few national parks where anchialine resources can be protected and viewed by the public. This fact in itself should be enough of an impetus to initiate a strong program to halt and reverse the loss of these precious resources. Without such a proactive approach, anchialine resources will probably disappear within the next two decades.

BIOLOGICAL AND WATER QUALITY CHARACTERISTICS OF ANCHIALINE RESOURCES IN THE KALOKO-HONOKOHAU NATIONAL HISTORICAL PARK WITH RECOMMENDATIONS FOR THEIR MANAGEMENT

1. INTRODUCTION

1.1 Purpose of the Study

The Kaloko-Honokohau National Historical Park (KAHO) in North Kona, Hawai'i was established in the early 1970's to protect significant cultural features of the area. The Park also has significant wetland features including ancient fishponds, waterbird habitat and anchialine pools. Because this Park is situated close to ever-expanding human enterprise (i.e., Honokohau Small Boat Harbor to the south and light industry inland of the Park), the need for baseline information on the status of anchialine resources as well as water quality of ground and nearshore marine waters under the Park's jurisdiction has been identified. Such baseline information is the first step to the development of a rational management plan to protect, conserve as well as restore these resources.

The objectives of this study are to (1) establish a quantitative benchmark or baseline with respect to water quality in coastal wells, anchialine pools, fishponds and the nearshore ocean fronting the KAHO so that future changes in water quality will be identifiable, (2) determine the status of aquatic biological resources in the KAHO anchialine system, and (3) using these data, suggest management strategies for the restoration and protection of groundwater and anchialine resources under the Park's jurisdiction.

Because many resource managers are not familiar with Hawaiian anchialine systems, this study first presents an overview of these resources. This is followed by the methods and findings of the present work and discusses the present degree of disturbance to the Park's anchialine systems. The final section outlines strategies that may be of use for the management of the aquatic resources present as well as suggests some methods for the restoration and enhancement of depleted or otherwise impacted aquatic resources.

1.2 Physical Characteristics of Hawaiian Anchialine Systems

With the discovery of a number of new caridean shrimp species in the early 1960's, Holthuis (1963, 1973) drew attention to an ecologically distinct habitat in which these shrimp are found. These crustaceans reside in land-locked brackish water pools and these pools have been termed "anchialine" by Holthuis (1973) and may be characterized by a lack of surface connections to the sea, yet having measurable salinities and a damped tidal fluctuation.

Naturally occurring anchialine ponds are restricted to highly porous substrates such as recent lava or limestone adjacent to the sea. These unique habitats are widely distributed having been reported from the Sinai Peninsula in the Red Sea (Por and Tsurnamal 1973, Holthuis 1973), Entedebir near the Southern Red sea (Por 1968), Aldabra in the West Indian Ocean (Borradaile 1917, Fricke and Fricke 1979), Solomon Islands (Smith and Williams 1981), Okinawa (Suzuki 1980), Philippines (Wear and Holthuis 1977), Funafuti Atoll (Holthuis 1973) in the Western Pacific, and in the Hawaiian Islands (Holthuis 1973, Maciolek and Brock 1974, Maciolek 1983, Bailey-Brock and Brock 1993, Brock and Bailey-Brock, Accepted). This unique habitat has also been reported on Ascension Island (Chace and Manning 1972) and on the Azores Islands in the Atlantic, and on Bermuda in the Caribbean. Localities with the most numerous anchialine sites are in Fiji, the Ryukyus, and Hawaii.

Anchialine systems often support an unusual biota, with many species not found elsewhere. In the Hawaiian anchialine systems the most characteristic species is the small red shrimp, opae'ula or *Halocaridina rubra*. This species has been reported from anchialine pools on Oahu, Maui, Hawaii and Kaho'olawe Islands in the archipelago (Brock and Bailey-Brock in prep.). Other than on Maui and Hawaii Islands, anchialine pools are rare; on Maui Island there are anchialine pools on and in the vicinity of Cape Kinau but in terms of a statewide resource, Hawaii Island has the largest number of known anchialine pools. The majority of these pools are situated along the western coast of the island from Kawaihae to Kailua-Kona. Approximately 420 pools have been surveyed in this area. A conservative estimate of the number of anchialine pools in Hawaii is about 600 ponds (Brock 1985).

Basin morphologies of Hawaiian anchialine pools tend to be highly irregular due to the porous lava in which these ponds are usually found. On the Kona coast, most ponds are either in pahoehoe lava (tending towards smoother basins) or in highly fractured a'a lava which results in basins that are very irregular in shape. Because anchialine pools show damped tidal fluctuations, the apparent surface area may substantially change with the changing tides if a given pond has a shallow basin morphology. Conversely, a pond located at the bottom of a sinkhole with near-vertical sides will show essentially no change in surface area with the change in tides. In the extreme case, the exposed water surface area disappears at low tide and reappears when the tide rises. Maximum tide height measured in Hawaiian anchialine pools is about one meter. Despite the lack of water through some stages of the tide, these intermittent anchialine pools have ecological significance (see below).

Hawaiian anchialine pools have surface areas that range from no exposure at low tide to sizes in excess of 100 square meters. Maciolek and Brock (1974) noted that of more than 300 anchialine pools on the West Hawaii coast that were surveyed, about 40 percent had surface areas of less than 10 square meters, 50 percent were between 10 to 100 square meters in surface area and about 10 percent had surface areas greater than 100 square meters. Most of these ponds are shallow with depths less than 0.5m (50%), but about 40 percent of them have depths between 0.5 to 1.5m while about 10 percent have depths greater than 1.5m.

1.3 Water Chemistry of West Hawai'i Anchialine Pools

The water chemistry of West Hawai'i anchialine pools has received considerable attention over the last twenty years. A working hypothesis of most studies has been that coastal development will bring potential changes to coastal groundwater by the addition of fertilizers and pesticides to improvements such as golf courses and vegetation planted around resorts, urban and commercial settings. Once applied these materials may leach by the action of irrigation water to the seaward flowing groundwater and into anchialine pools and coastal marine ecosystems. The irrigation water is often also a source of inorganic nutrients because treated sewage effluent is diluted with low salinity coastal groundwater and is used as the primary irrigant on many of the golf courses. For example, this treated effluent comprises between 10 to 15% of the volume of irrigant applied to the two coastal golf courses present at Waikoloa.

The resort, golf course, urban and commercial development at Waikoloa started in the mid-1970's. Since the mid-1980's Waikoloa provided funds in a trust account to the University of Hawaii that established a monitoring and research program to determine the impact of coastal development on water quality and biota of anchialine systems (Brock and Kam 1990, 1994, Brock 1995, 1996, 1997). Under this program sampling of anchialine systems has been undertaken over much of the east and west coasts of Hawai'i Island. Coastal groundwater, anchialine and nearshore marine waters have been sampled as well as the anchialine biota along developed and completely undeveloped sections of the coastline. Many thousands of water quality samples have been collected and analyzed under this program and the program is probably the largest continuous monitoring effort on the West Hawai'i coast.

The results of the Waikoloa monitoring program have shown that gradients of inorganic nutrients are present in the coastal ground water table. The most inland (or mauka) sampling points (wells) are inland of the coastal development. Nutrient concentrations in the low salinity groundwater from these wells are relatively low. The concentrations increase at sampling points located within the development. Most of the anchialine pools at Waikoloa are located seaward of the majority of the development. Nutrient concentrations are elevated in the mauka anchialine pools. Sampling ponds located further seaward yields declining concentrations. Because the coastal plain is comprised of very porous lava at Waikoloa and elsewhere on the West Hawai'i coast, groundwater freely percolates to the sea and ocean water intrudes inland. Inorganic nutrient concentrations are usually very low in surface ocean waters. The relatively free movement of groundwater to the sea results in dilution of concentrations; uptake of some materials passing through the anchialine system may also occur. The result is a decreasing concentration of materials on the approach to the ocean. Concentrations of materials further decreases with samples collected out into the marine environment such at that within about 100m of the shore, concentrations are at background. Thus concentration gradients for inorganic nutrients are evident along developed coastlines.

Studies carried out under the Waikoloa program have noted several generalities with respect to inorganic nutrient concentrations. The concentration of specific nutrients may be very high at certain undeveloped locations and at others, may be quite low. Some of the highest concentrations of nutrients measured along the West Hawaii coastline have been in anchialine ponds and groundwater located far (kilometers) away from any coastal or upland development. However once measured, these concentrations do not vary much through time. Despite the concentrations of nutrients being low in the groundwater of some undeveloped sites, these concentrations may be high relative to ocean waters resulting in concentration gradients similar to those at Waikoloa. As with the situation at Waikoloa (a developed coastline), the highest concentrations of nutrients are encountered at the most inland sample points on undeveloped coastlines.

Measurement of the inorganic nutrient concentrations at Waikoloa since the mid-1980's showed them to increase and then decrease through time. The increases were most apparent with the development of a new golf course in 1989-90 and again later with an accidental spill of nitrate nitrogen in 1993. Since that time nutrient levels have declined to levels similar to those measured prior to any development at Waikoloa. Despite the elevation of certain nutrients (primarily orthophosphorus and nitrate nitrogen) at Waikoloa due to anthropogenic activities, these concentrations are within the range encountered at other completely natural (undeveloped) control sample sites on the West Hawaii coast. Naturally occurring nutrient concentrations on the West Hawai'i coast may appear to be high relative to many temperate settings but in other insular locations, naturally occurring concentrations in coastal groundwater may be greater (Marsh 1977, Johannes 1980). Mean measured concentrations of coastal groundwater at undeveloped West Hawaii sites have found the two biologically important nutrients of nitrate nitrogen in the range from 20 to 200μM and orthophosphorus in the range of 0.2 to 6.5 μM (Brock and Kam 1990, 1994, Brock 1995, 1996, 1997).

Annual sampling for pesticides is also carried out at Waikoloa as well as in an undeveloped control area. This sampling focuses on products that have either been in use for some time at Waikoloa or were used in relatively large quantities. Since many materials will bind with sediments, sampling of sediments and water is routinely carried out. These studies have not detected any pesticides at either Waikoloa or the undisturbed control site. Additionally, a one time sampling effort of tissues from a long-lived (greater than 10 years) anchialine species (the shrimp, *Halocaridina rubra*) was undertaken where a search was made for more than 40 different products. Shrimp were collected from a pool no more than 20m from a golf course and from an undeveloped control site. No pesticide products were found in any sample. The explanation for the negative results with respect to pesticides is that most of the products allowed by the U.S. Environmental Protection Agency for use on golf courses and elsewhere has short half-lives. These products are effective upon application but rapidly breakdown in the environment. Problems with pesticides in most Hawaiian setting are usually with the older products which characteristically had long (ca. many years to decades) half-lives (chlorodane, etc.).

Despite changes in groundwater chemistry with the development at Waikoloa, the organisms in the anchialine system have not been affected. The aquatic species found in the groundwater and anchialine pools of the West Hawai'i coast appear to be completely insensitive to changes in inorganic nutrient concentrations in the ranges observed at Waikoloa up to this point in time. This insensitivity is probably due to these species having evolved in a system where inorganic nutrients are not limiting as they are in most aquatic systems; thus changes in concentrations in the ranges measured on the Kona coast have no impact. At Waikoloa there were no statistically significant changes in the abundance of monitored anchialine species up through 1995; in 1996 there was a significant increase in the abundance of the most characteristic anchialine species, the opae'ula or *Halocaridina rubra*. These data support the contention that the changes in nutrient chemistry of the coastal groundwater at Waikoloa due to the development have had no significant impact to the native aquatic species.

1.4 Biological Attributes of Hawaiian Anchialine Pools

As noted above, anchialine pools harbor a distinct assemblage of organisms, some of which are found nowhere else. Anchialine pool organisms fall into two classes, i.e., epigeal and hypogeal species (*sensu* Maciolek 1983). The epigeal fauna is comprised of species that require the well-illuminated (sunlit) portions of the anchialine system. Most of these species are found in other Hawaiian habitats albeit individuals from anchialine systems frequently show ecotype (morphological) variations. The hypogeal organisms occur not only in the illuminated part of the system but also in the interconnected watertable below. These species are primarily decapod crustaceans, some of which are known only from the anchialine habitat.

The Hawaiian anchialine pond ecosystem is dominated by a characteristic assemblage of organisms including crustaceans (shrimps, amphipods), fishes, mollusks, a hydroid, sponges, polychaetes, tunicates, aquatic insects, algae and aquatic macrophytes. Most striking are a number of red-pigmented caridean shrimp species. These shrimps, as well as many other co-occurring faunal components, utilize the anchialine pond habitat and the rock interstices leading to the underlying brackish water table. Depending on pond depth, many of the shrimp species display a tidally linked migration, emerging from the rock interstices with the incoming tide to feed in the ponds, and later returning via the interstices to the subterranean labyrinth with the falling tide.

Seven of the twelve species of hypogeal shrimp in this group world-wide are found in Hawaiian anchialine systems; these species are *Halocaridina rubra, Halocaridina palahemo, Metabetaeus lohena, Procaris hawaiana, Antecaridina lauensis, Calliasmata pholidota* and *Vetericaris chaceorum*. Besides Hawaii, *Antecaridina lauensis* has been collected in Fiji, Mozambique and in the Red Sea (Dahlak Archipelago) and *Calliasmata pholidota* from the Ellice Islands and the Sinai Peninsula in the Red Sea. These hypogeal shrimp are usually found in waters with salinities between 2 to 30 ppt. In deeper water exposures or where wind stress and mixing is low, vertical stratification will frequently occur and these shrimp species move through these salinity gradients with impunity suggesting tolerance to changing salinities. *Halocaridina palahemo, Procaris hawaiana, Calliasmata pholidota* and *Vetericaris chaceorum* are only known from anchialine systems with higher salinities (usually above 15 ppt).

More life history information is available for *Halocaridina rubra* (or opae'ula) than for any of the other species. Opae'ula feed on detritus, benthic diatoms, phytoplankton, filamentous algae, vascular plant tissue (Wong 1975), and, when available, animal tissue. *Halocaridina rubra* feed by plucking the substratum with bristled chelae; mid-water and surface film feeding is accomplished by using the chelae and bristles as plankton filters (Bailey-Brock and Brock 1993). Opae'ula have been maintained in small sealed containers for years. Presumably, under these conditions they are capable of utilizing bacterial films.

The embryogenesis and larval development of *H. rubra* has been documented (Couret and Wong 1978). Opae'ula have a low fecundity with the female carrying 10 to 16 eggs for at least 38 days. Evidently darkness is necessary to induce oviposition; females remain in dark seclusion until after eclosion and the offspring emerge into the open water as juveniles (Maciolek 1983). This author notes that ovigerous females (those carrying eggs on the abdomen) have not been seen in nature among the thousands of individuals observed or hundreds collected. However 12 to 42 percent of the females may have eggs visible within the carapace, which suggests that reproduction is not rare. Our observations show that with the simple routine addition of food, captive opae'ula will easily reproduce in the laboratory. However, it appears that an individual female probably does not reproduce more than twice a year. Individual *Halocaridina rubra* maintained in the laboratory have remained alive for periods in excess of twelve years suggesting that this species is relatively long-lived. Long life spans and a low fecundity make this species vulnerable to over harvesting.

Halocaridina rubra is the most abundant of the Hawaiian hypogeal shrimps. It frequently occurs in concentrations exceeding hundreds of individuals per square meter in a given pond on a rising tide; at other nearby anchialine pools it may be scarce. The apparent abundance of opae'ula in a given pond or pond system can be quite variable and misleading for little is known of the population size of these hypogeal shrimp in subterranean interstitial waters. Our limited observations in caves suggest that the abundance may be as low as one individual per hundred cubic meters of water.

Much less information is available for the remaining Hawaiian hypogeal caridean shrimp species. *Antecaridina lauensis* and *Metabetaeus lohena* have been found in salinities ranging from 2 to 36 ppt. *Metabetaeus lohena* is an active predator on other shrimp (principally *H. rubra*) and other pond invertebrates (Holthuis 1973). *Calliasmata pholidota* feeds on crustaceans and polychaetes (Maciolek's observation in Holthuis 1973), while *Procaris hawaiana* has been observed feeding on moribund shrimp (Maciolek 1983). This author further notes that *Procaris hawaiana* feeds by encounter (it has no chelae); this is a primitive, non-specialized method. Nothing is known about *Vetericaris chaceorum* other than it is known from one locality and no more than five individuals were seen (Kensley and Williams 1986).

The work of Bailey-Brock and Brock (1993) suggests that there is considerable variation in the morphological characters of *H. rubra* and *H. palahemo* with location. Sampling anchialine habitats in the vicinity of the only known locality of *H. palahemo* has resulted in the collection of *H. rubra* with variations in key morphological traits intermediate to *H. palahemo* suggesting that the latter species may be invalid.

Four other shrimp species are encountered in the Hawaiian anchialine habitat. These species are all epigeal and include the opae'huna (*Palaemon debilis*) a species common to many other brackish habitats in Hawaii, *Macrobrachium grandimanus* or opae oeha'a which is known from Hawaii and the Ryukyu Islands and whose usual adult habitat is in high island freshwater streams, *Macrobrachium lar* which is a recent introduction to Hawaii that, again, is usually found in streams and *Palaemonella burnsi* a clear shrimp known from three pools on Cape Kinau, Maui and from Kaloko Pond in the Kaloko-Honokohau National Historic Park. Life history information is not available for *P. burnsi.*

Algae are an important component of the anchialine ecosystem. Wong (1975) lists 144 species of macroalgae, microalgae and diatoms in the Cape Kinau, Maui pools. However, only a few species or species complexes of algae and aquatic plants are dominant. In the Kona coast ponds is the cyano-bacterial, carbonate producing mat or crust comprised of an actively growing matrix of plants, (including *Schizothrix, Lyngbya, Oscillatoria* and *Scytonema* spp.), bacteria, diatoms, and protozoans as well as *Rhizoclonium* sp., *Cladophora* spp. and the aquatic phanerogam, *Ruppia maritima*. Probably the most unique aspect of the anchialine pond flora is the cyano-bacterial mat which is orange to yellow in color and one of the most obvious components of many West Hawaii anchialine pools. This crust forms a white precipitate on the bottom of the pond basin that is comprised of silicon, magnesium, calcium and phosphorus (Bailey-Brock and Brock 1993).

The remaining fauna of Hawaiian anchialine systems is primarily marine in origin. Several unidentified sponge species are known particularly from the Cape Kinau, Maui ponds; one identified species is *Tethya diploderma* (Holthuis 1973). A hydroid, *Ostromouvia horii* collected from one pond in the Kaloko-Honokohau National Historic Park (site 55, the "Queen's bath") and was considered to be quite rare. However, this species is found in some abundance in the deep recesses of marine caves around O'ahu. Polychaetes have been recorded from ponds with low salinities (2 to 6 ppt - *Namalycastis abiuma*) as well as in higher salinity pools (10 ppt or greater - *Eurythoe complanata* and *Salmacina dysteri*). Brock and Bailey-Brock (accepted) note *Vermiliopsis torquata, Ophryotrocha* sp., *Salmacina dysteri* and two unidentified syllids from a high salinity anchialine pool on Kaho'olawe. A number of molluscs occur in the anchialine pond habitat; these include *Melania* sp., *Theodoxus cariosus*, *T. vespertinus, Melampus parvulus, Nerita polita, Assiminea nitida,* and the bivalve *Isognomon californicum*. Other than the snail, *Neritilia hawaiiensis,* all of these molluscs are known from other marine or brackish habitats. Isopods, e.g., *Ligia* sp. are common around many ponds as well as an unidentified cymothoid isopod species. Barnard (1977) reported a total of 11 amphipod species (including 8 new species) from Hawaiian anchialine ponds. Besides the above-mentioned epigeal and hypogeal shrimp and amphipods, there are other decapod species found in the anchialine habitat including the crab, *Metopograpsus thukuhar*, and the alpheid, *Alpheus crassimanus* both of which are common elements in other brackish and marine ecosystems. Insects around and in anchialine ponds include unidentified beetles, mosquitoes and midges (Maciolek and Brock 1974) as well as Collembola, Hemiptera, Veliidae, Odonata, Acarina and *Trichocorixa reticulata*. Little life history information is available for the species that are found exclusively in the anchialine pool habitat.

Fishes are a part of the fauna of the Hawaiian anchialine habitat; usually their occurrence in a pond signals the lack of hypogeal shrimp. Fishes in anchialine systems fall into two broad categories -- native or alien species. Maciolek and Brock (1974) noted an inverse relationship between the presence of fish and hypogeal shrimp. Brock (1977) found 15 native marine fish species in Kona coast anchialine ponds. The most common native fishes found in the anchialine habitat include the flagtail or aholehole (*Kuhlia sandvicensis*), mullet or ama'ama (*Mugil cephalus*), convict tang or manini (*Acanthurus triostegus*), black spot sargeant or kupipi (*Abudefduf sordidus*), sleeper or o'opu akupa (*Eleotris sandwicensis*), and the goby or o'opu nakea (*Awaous stamineus*). One species that usually inhabits ponds with better connections to the sea is the rare moray eel or puhi (*Gymnothorax hilonis*). *Gymnothorax hilonis* was described for a single type specimen collected in the Hilo market in 1903 (Jordan and Evermann 1905, Gosline and Brock 1960). It was not collected again until the 1972 Maciolek and Brock (1974) study. At that time *G. hilonis* was present in ponds at Waiulua Bay (the site of the Hilton Waikoloa Hotel) and at Kapoho in water with salinities between 3 to 19 ppt (Maciolek and Brock 1974, Brock 1977). Little is known about this dark colored eel except that it obviously tolerates the anchialine habitat and it has been seen crossing the lava between pools spaced up to about 20m apart (Brock, personal observations). The status of this species is unknown at this time but it may be extinct.

Alien or nonindigeneous fishes that have invaded or been introduced into the anchialine habitat include tilapia (usually *Tilapia mossambicus*), guppies and topminnows (Family Poecillidae including *Gambusia affinis* and *Poecilia mexicana*) and koi (*Cyprinus carpio*).

There are at least two additional eel species known from the anchialine habitat. Both of these occur in a very few high salinity locations and one species appears to have a pink coloration. These fishes have been collected but as of yet have not been positively identified. Interestingly, one pond located in a large cave in Ka'u, Hawai'i is named "Puhi Ula Pond" which translates to red eel pond. Our survey of this location found a shallow low salinity pond whose basin was probably filled in by collapse of rock from the ceiling of the cave in recent generations. It is believed that at an earlier point in time, Puhi Ula was probably a deep pond with higher salinity water in the deeper portions (stratification) providing habitat for these eels.

Summarizing the information on the biota of anchialine ponds, this habitat is usually crustacean dominated, particularly by the hypogeal anchialine shrimps, *Halocaridina rubra* and *Metabetaeus lohena*. Other frequently encountered shrimps include *Palaemon debilis* and *Macrobrachium grandimanus* as well as the crab, *Metapograpsus thukuhar*, all of which are found in other habitats. Amphipods are common and most of the species are known only from the anchialine environment. Mollusc species that are frequently seen include *Theodoxus cariosa, Melania* sp. and *Assiminea nitida.* The cyano-bacterial mats as well as Cladophora sp., Ahnfeltia concinna, Rhizoclonium sp., and Ruppia maritima usually dominate Anchialine pond flora. If predatory fish are present the hypogeal shrimp are usually absent and the abundance of epigeal shrimp and amphipods may be reduced.

Species encountered in the KAHO anchialine habitat include the shrimp *Halocaridina rubra, Metabetaeus lohena, Palaemon debilis, Macrobrachium grandimanus, M. lar* (alien), the crab *Metapograpsus messor*, isopod *Ligia* sp., the molluscs *Melania* sp., *Theodoxus carisoa, T. neglectus, Melampus parvulus, Assiminea nitida*, the algae *Rhizoclonium* sp., *Cladophora* sp., the cyano-bacterial mat (which includes *Schizothrix* and many other species), and the phanerogam, *Ruppia maritima.* There are a number of unidentified amphipods as well as Collembola, Hemiptera and Odonata present in some ponds. Fishes seen include guppies (Family Poecilidae - alien), *Cyprinus carpio* (alien), *Kuhlia sandvicensis, Mugil cephalus, Neomyxus chaptalii, Eleotris sandwichensis, Awaous stamineus, Abudefduf sordidus, Acanthurus triostegus*, and *Mulloides flavolineatus.*

1.5 Functional and Ecological Relationships in Anchialine Pools

Since quantitative information (e.g., energy flow, population size and turnover in various species) is sparse for anchialine systems, the hypotheses presented below represent a synthesis of available information as well as some of our unpublished work on the functional and ecological aspects of the anchialine habitat.

Anchialine pools are indirectly connected to the sea. This is substantiated by the damped oscillation in pond water level correlated with the tides and to the presence of saline water. Hypogeal shrimp utilize resources (food and space) present in ponds and in the watertable below. Our observations suggest that the density of shrimp may be very low in the watertable beneath the anchialine system (>1 individual per 100 cubic meters) yet in the ponds, the abundance may be high (many hundreds of individuals per square meter of pond bottom). The movement of anchialine shrimp is tidally linked for some species (Fricke and Fricke 1979); shrimp emerge into the pond via interstices on the rising and high tide apparently to feed, and retreat to the subterranean labyrinth on the ebb tide.

Ponds with sufficient illumination must represent significant points of high benthic productivity relative to the watertable below. Sunlight and dissolved nutrients provide the necessary ingredients for this productivity. Many of the shrimp species appear to take advantage of these loci of food resources (ponds). With pond obliteration (as through burial) the total productivity within a given section of the coastal watertable would also be significantly reduced; this suggests that the carrying capacity of the habitat with respect to these hypogeal species would be significantly lower with such obliteration. Hypogeal species would probably not entirely disappear however, other epigeal species (crustaceans, fishes, molluscs and flora) dependent on the illuminated high productivity part of the anchialine system would not survive.

The porosity or degree of connection of a pond with the watertable not only affects the migration of shrimp to and from these loci of food resources but may affect and determine the composition of species in a given pond as well as may play a role in the life expectancy of that pond. With respect to species composition, a pond located close to the shoreline displaying strong subterranean connections to the sea may be expected to have greater colonization by marine species than a similar, more isolated inland pond.

The porosity of the pond substratum has a direct effect on the residence time of the water. In general, most anchialine pools have very clear water. Water residence times appear to be of short duration, thus retarding phytoplankton blooms. The porosity and water residence time of a pool must influence the degree to which allochthonous sedimentary material accumulates. Ponds with greater porosity and/or flushing will probably have less sediment; field observations on closely associated anchialine pools will frequently show one to have a considerable deposit of sediment while others nearby are devoid of these materials. Sediment may be generated *in situ* by the cyano-bacterial mats. If sediment accumulation is related to the degree of flushing, two ponds side by side, and identical except for depth, should have very different rates of accumulation. A greater porous surface area is present in the deeper pond so flushing should be better and accumulation lower than in the adjacent shallow pond. This contention is supported by the observation made by Wong (1975) in Cape Kinau, Maui anchialine pools where the cyano-bacterial mats in pools with lower salinities have proportionately more sediments than higher salinity pools with these mats. Lower salinity pools are those located further inland and further removed from the tidal influence which is a major driving force in the exchange of water as well as the fact that lower salinity pools are probably those with shallower basins than are the higher salinity pools.

The variability in the rate of sediment accumulation is directly related to the life expectancy of a pond. *In situ* sediment production can lead to the infilling of an anchialine pond and its eventual transformation into a marsh covered with sedges and grasses. From a geological perspective, anchialine pools are ephemeral, enduring for a relatively short period of time. In the lava flow of 1859 along the West Hawaii coast, examples of anchialine ponds in various stages of senescence may be found. Field observations suggest that under appropriate conditions this succession may occur in about 100 years at a minimum.

Many of the field observations of the behavior patterns of hypogeal shrimp indicate that they spend a considerable period of time in the watertable beneath the surface exposures. The crevicular habits of these organisms and a number of observations suggests that they can occur through much of the coastal watertable. Maciolek (1983) notes the appearance of *Halocaridina rubra* in a cased well drilled on Oahu; this also occurred on the floodplain at Kealia, Maui during well drilling. In the present study a water sample collected with a one-liter bailer in well 3 (Figure 1) yielded two *Halocaridina rubra* which suggests their presence through the coastal watertable at KAHO. With crevicular habits the determination of population sizes and the geographic extent of a given population becomes almost impossible. These attributes may, however, serve to stave off extinction; with the destruction of surface exposures, epigeal species can be expected to disappear, while those with hypogeal habits may not.

Maciolek (1983) notes that the hypogeal habits of these red shrimp can explain their disjunct known distributions. He hypothesizes that many of those species are capable of existing in submerged marine rock as well as in emergent rock (anchialine pools) of the tropical Indo-Pacific. Many species tolerate seawater and extremely low dissolved oxygen concentrations (Kensley and Williams 1986), thus could have wide (but as yet undetermined) distributions in the tropical seas. Some of the most compelling evidence to support this contention is presented by Maciolek (1983) and includes (1) the collection of *Metabetaeus lohena*, previously known only from the Hawaiian Islands, from the reef flat and outer reef face at Tulear, Madagascar and (2) the collections and sightings of *Ligur uveae* (a hypogeal shrimp known from Molucca Islands, Loyalty Islands, Aldabra Islands, Fiji Islands, and the Philippines) by SCUBA divers deep in marine caves in Hawaii and the Marshall Islands. Maciolek concludes that this broadened habitat hypothesis allows for the occurrence of shrimps in the groundwater of many islands where they have not yet been found, as well as in deep caves on shallow reefs and seamounts. Thus rarity for some species may be related to our ability to collect specimens in a largely unsampled (and difficult to sample) habitats.

Further support for Maciolek's (1983) hypothesis may be found with some of the modern genetic work that has been done with *Halocaridina rubra*. An electrophoretic analysis of the genetic composition of *H. rubra* populations from O'ahu, Maui and Hawai'i islands and *H. palahemo* from Hawai'i indicates that these shrimp all belong to the same species (M.A. Romano and L.S. Powers, unpublished manuscript on biochemical systematics of *H. rubra*, prepared for the U.S. Army Corps of Engineers, 1992).

Anchialine pools represent a rather unique habitat. Perhaps the most unique feature of this habitat is the relative degree of isolation that it has from other aquatic environments. This isolation translates into relatively few species colonizing the anchialine habitat and those that are able to do so appear to be intolerant of the competition found in most other aquatic habitats or are simply prey in those other habitats. The anchialine species complex appears to be capable of rapidly colonizing new habitats. From a geological perspective, the anchialine habitat may be relatively short-lived, being created by a lava flow, only to be covered by the next flow. Obliteration of the habitat may also occur through infilling by storm surf (carrying sand and rubble) or by the successional events as noted above. These events may occur within short time scales from years to within hundreds of years. The ephemeral nature of the habitat dictates that anchialine species be opportunistic colonizers of habitats that are suboptimal or otherwise unavailable to most other aquatic species.

1.6 Working Definition of an Anchialine Pool

Anchialine pools intersect the coastal groundwater table and are often located in larger low-lying areas. If the pools are shallow, water exposures may disappear during low tide and during high tides, adjacent water exposures in low-lying areas may coalesce. From an ecological perspective, water exposures that coalesce at high tide constitute a single pool. Because of the variability in tide height and the highly variable natural elevation of land surrounding individual water-filled basins that constitute these pools, delineating the boundaries of a pond at a given tide height other than the maximum does not make ecological sense. From an ecological perspective pools that coalesce during any given stage of the tidal cycle represent a single ecological unit. In a coalesced state, motile organisms can range freely between individual depressions and the water mixes resulting in homogeneous chemical characteristics. Because of these realities, the boundaries of anchialine pools in this study are defined by their maximum tidal and horizontal extent. In some cases individual basins are surrounded by relatively high ground and constitute a recognizable "pool". More commonly however, a cluster of individual basins at mean (zero) tide are coalesced at higher tides and are noted herein as a "complex" of anchialine habitat. Within an anchialine complex, individual basins may be recognized and are defined by the presence of standing water through all tide cycles. In some cases, the lateral extent of benthic algae help to delineate parts of particular basins in a complex although standing water may be absent from these parts during the spring low tides.

1.7 Problems Confronting Hawaiian Anchialine Systems

A number of possible causes of anchialine pool degradation have been suggested. These include (1) development that either results in pond obliteration or excessive nutrient/pesticide loading, (2) recreation in or near pools resulting in their use for fishing, bathing, or refuse receptacles, and (3) the utilization of pools for the cultivation of fishes. Several studies (Maciolek and Brock 1974, OI Consultants, Inc. 1985) have implicated several of these as sources of deterioration of specific pools and systems.

One obvious impact associated with construction activities is the obliteration of anchialine pools by infilling and burial. Hypogeal shrimp would probably survive in the water table below filled pools albeit at lower population densities. Epigeal forms (algae, molluscs, crustaceans, insects and fishes) dependent upon the well-illuminated pond and its primary productivity would locally disappear following pond burial. Today, loss of anchialine habitat by burial would probably not be allowed by the regulatory agencies. Because anchialine pools have measurable salinities, they are found close to the shoreline. Over the last 25 years many parts of the West Hawaii coastline has undergone development. With this development has come concern over possible impacts to the anchialine systems. This concern resulted in the development of several water quality/aquatic life monitoring programs including the Waikoloa Anchialine Pond Preservation Area (WAPPA) program. The WAPPA program has monitored water quality in a large coastal development that includes resorts, commercial and residential units as well as golf courses with water quality data spanning from a point in time preceding development (1977) to present. An early study (Brock *et al.* 1987) of the water quality characteristics of anchialine ponds along the Kona, Hawaii coast found that groundwater is a major source of dissolved nutrients for these systems. These groundwater sources show high spatial and temporal variability with respect to dissolved nutrients. The study did find that changes in the water quality characteristics of the Waikoloa anchialine system could be attributed to the surrounding development. The changes were, however, within the range of natural variability as measured elsewhere in anchialine pools with no surrounding development. This suggested that the perturbation at least over the first 9 years of the study were not damaging to the anchialine resource because these nutrients frequently occur naturally in excess of concentrations which would control biological processes.

In the 1991-96 period (Brock 1997) noted that the concentration of some measured water quality parameters are increasing in the Waikoloa system and attributed these increases to the development (golf courses). These increases were statistically significant but despite this, none of the concentrations approach those measured at undisturbed control sites on the Kona coast. Furthermore, this study pointed out that up to the present time the aquatic species found in the groundwater and anchialine pools on the West Hawaii coast appear to be completely insensitive to changes in inorganic nutrient concentrations in the ranges measured in this study. This insensitivity is probably due to these species having evolved in a system where inorganic nutrients are not limiting and thus changes in concentrations in the ranges measured have no impact. Indeed, the study had found that the abundance of *Halocaridina rubra* has statistically increased at Waikoloa in 1996 over previous years lending further support that changes in water quality have not negatively impacted the anchialine system.

Brock (1997) has over the last ten years, searched for pesticides used at Waikoloa on the golf courses and grounds; this search has focused on water, sediment and the tissues of *H. rubra*. Up to this point in time, there has been no evidence of any pesticide contamination in the anchialine ecosystem from any of the development at Waikoloa. The water quality data suggest that (1) coastal groundwater quality at undisturbed sites may be quite variable and in some cases specific nutrient concentrations may be relatively high, (2) changes in coastal groundwater quality may occur with coastal development but the changes seen thus far are within the ranges encountered at undisturbed sites and (3) unlike most aquatic species, anchialine species appear to be insensitive to the changes water quality in the ranges encountered thus far probably because these species have evolved in a habitat where nutrient concentrations may be quite variable and frequently in excess of biological needs.

High benthic, algal standing crops or low water transparency (suggesting high phytoplankton activity) is apparent in some West Hawaii anchialine pools. Some of these are found near human habitation. For example, the pond at Weliweli was very turbid (green water) at the time of the 1972 survey (Maciolek and Brock 1974); this condition continued to be apparent in a 1985 revisit to this site. Toilet facilities were noted as being about 6 m inland of this pond during the 1972 survey and this may provide a potential nutrient source for the plant growth within the pond. Also present were predatory fish (aholehole or *Kuhlia sandvicensis*) which could serve to deter the presence of phytoplankton feeding shrimp.

Field observations suggest that in most instances environmental degradation of anchialine resources directly due to development of the surrounding terrain is minimal. However the increased access that occurs with development may indirectly result in degradation of anchialine habitats. Increased access improves recreational opportunities that may negatively impact anchialine resources. The completion of the Queen Ka'ahamanu Highway linking Kawaihae with Kailua-Kona in 1975 made much of the North Kona - South Kohala coastline more accessible. Today, people may drive or hike to much of the coastline that was formerly quite inaccessible. Utilization of these areas is primarily for recreation: fishing, swimming, or camping. Fishing may occur in some of the larger anchialine pools. Brock (personal observations) found a number of recently hooked and moribund specimens of the rare moray eel, *Gymnothorax hilonis* at Waiulua Bay, Anaehoomalu in 1972. He attributes the catching of these eels to fishermen seeking threadfin or moi (*Polydactylus sexfilis*) present in one of the more marine pools. Access was gained by a road that had been recently bulldozed to the site. It is the author's opinion that this eel may now be extinct. Thus fishing may directly impact some of the native fish species found in anchialine systems.

Anchialine pools are also used as bath pools by hikers and campers. Having low salinity waters, they provide a refreshing stop for hikers. Evidently anchialine pools have been subjected to this use for a long time. Pools were sometimes modified with stone walling, steps to the water, etc. by the ancient Hawaiians for bathing. There are no known negative impacts to pond biota directly due to this activity. However, the recent introduction of soaps and shampoos could be of potential concern. OI Consultants, Inc. (1985) noted the presence of shampoo containers and soap wrappers around one anchialine pool adjacent to a popular swimming beach, but did not attribute any degradation in the biota to this activity. Of concern with use of anchialine pools as bathing receptacles is the possible spread of bacterially-mediated disease between the humans via shedding using the pools.

A more obvious example of environmental degradation of the anchialine resources occurs when the pools are used as refuse pits. The practice is not new; nearly filled rubbish pits (former ponds) containing datable refuse about 100 years old have been found on the West Hawaii coast. Some refuse (e.g., bottles, cans, etc.) appears not to have any real short-term negative impact on the fauna. However, the dumping of used oil, grease, and oil filters in a pool adjacent to Honokohau Harbor resulted in the disappearance of *H. rubra* from that pool (Brock, personal observations).

Perhaps one of the greatest impacts to the biota of anchialine pools comes through the introduction (accidental or intentional) of exotic or alien fishes to these systems. Intentional introduction of an alien fish may be for its later harvest as fish bait, food or to control mosquitoes; accidental introduction can occur when one pool in a system is intentionally stocked and the introduced species colonizes other pools in the complex under its own impetus. Alien species involved include members of the family Poeciliidae (probably *Gambusia affinis* and *Poecilia mexicana*) and the tilapia (*Tilapia mossambica*). The most obvious impact resulting from the colonization of anchialine pool systems by these and other fish species is their predation on resident crustaceans, particularly the shrimps. Maciolek (1984) reviewed the impact of alien fishes in Hawaiian and other insular ecosystems. He states that adverse effects of these introductions centers on changes in natural ecosystems induced by aliens particularly on native species. These effects may be direct as through competition and predation or indirect, e.g., the introduction and transmission of parasites and disease. Furthermore, this author notes that while some adverse effects are self evident, they are often difficult to quantify and as a result, few studies have been made.

Unlike native fishes, established aliens are able to complete their lifecycles in the anchialine habitat. These fishes prey on and exclude native hypogeal shrimp that are usually a dominant faunal component (Brock 1985, Bailey-Brock and Brock 1993). The working hypothesis is that the introduction of exotic fishes into an anchialine system may initiate a change in ecological succession (Brock 1985, Brock *et al.* 1987, Bailey-Brock and Brock 1993). Predation soon reduces and eliminates hypogeal shrimp from the lighted portions of the pools. Subsequently, a slow succession of macroalgae establish and grow epiphytically on the distinctive benthic cyanobacterial crust. With herbivorous hypogeal shrimp present (*Halocaridina rubra*), these epiphytes never come to dominate the benthos. Without this characteristic shrimp species, overgrowth by macrophytes leads to the demise of the cyanobacterial crust. With this change in pond flora, comes a major change in the appearance of the pond system from one that has "anchialine" attributes (i.e., clear well-flushed basins, cyanobacterial crusts and a fauna dominated by hypogeal shrimp) to a system characterized by a mud substratum, poor water exchange, floating chlorophyte mats and exotic fishes. Such changes may speed up the infilling and pond senescence. Qualitative observations and experimental studies (Brock, Bailey-Brock and Kam, unpublished) support these hypothesized changes.

Maciolek and Brock (1974) found alien fishes in 15% of the pools surveyed in 1972; 13 years later OI Consultants, Inc. (1985) noted alien fishes in 46% of the ponds examined and more recently unpublished surveys by M.T. Lee (US Army Corps of Engineers) and R. Brock suggest that outside of the Waikoloa pond preserve, less than 10% of the anchialine pool resources on the West Hawaii coast remain free of alien fish. The continued spread of alien species that apparently impact the ecological balance and succession in anchialine pools provides a bleak outlook for the perpetuation of this unique resource on the West Hawaii coastline.

2.0 GOALS AND OBJECTIVES

The overall goal of this study is to develop management strategies that will preserve, protect, and enhance the groundwater and anchialine resources present in the KAHO. The objectives of this three-year study are:

1. To review extant literature as it pertains to coastal water quality and anchialine resources of the West Hawaii coastline;

2. Inventory the biological resources of the anchialine pools and quantitatively assess the populations of key hypogeal species under the Park's jurisdiction;

3. Ascertain the quality and status of coastal ground and nearshore marine waters through a program sampling coastal wells, anchialine pools and nearshore marine waters in and adjacent to the KAHO;

4. Recommend a protocol for the restoration of anchialine pools in the park that have been degraded by unwanted alien species;

5. Develop recommendations and alternatives for the long-term management of the Park's anchialine resources.

3.0 METHODS

The literature review included a perusal of biological and water quality information for the West Hawaii coastal groundwater and anchialine pools. This literature review covered published sources, "gray" literature sources as well as unpublished data from both our files and those of others working in the field. This review considered the present status of coastal ground and nearshore water resources as well as the condition of anchialine biological resources. Where possible the review identified changes that have occurred over the last twenty years and highlight areas where further research is needed.

The inventory of anchialine biological and water quality resources was carried out with the goal of determining their status as well as ascertaining whether the aquatic community structure or water quality indicates any possible pollution or contamination. Any identified problems will be related to changes to land use and human activities occurring in and outside of the Park's boundaries where possible.

The field work commenced with a mapping of each anchialine pool/complex found in the Park's boundaries. This was accomplished by approximately positioning each pool/complex on a base map as well as in some cases using a hand-held ground positioning system to determine latitude and longitude. The dimensions of each pool/complex were roughly measured and drawn on a separate data sheet that was established for each pool/complex. Pools/complexes were numbered and where possible related to past surveys of the anchialine resources in the KAHO.

The Kaloko Industrial Area is located inland and upslope of the Park. This area could possibly be serving as a source of pollutants via the groundwater to the anchialine, fishpond and marine waters fronting the Park. If materials are emanating from the industrial area via the seaward flowing coastal groundwater, the delineation of these materials may be made by sampling any access points to the groundwater (wells and anchialine pools) from inland to seaward locations. The relatively porous lava coastline of West Hawaii allows seawater to intrude and mix with the seaward flowing groundwater under the coastal plain. An inland point source of materials being carried in a seaward direction by groundwater flow will be mixed and diluted by both the groundwater as well as by the intruding seawater which results in a gradient of concentration. Sampling inland wells, anchialine pools and nearshore marine waters for these materials provides a means of delineating these gradients and demonstrating the fate of these materials on moving to the sea.

Water quality sampling focused on two inland-seaward (mauka-makai) transects to delineate any gradients present. The transect locations were selected following preliminary sampling of most water exposures located within Park boundaries. Once established, sampling was carried out in all wells, pools, and fishponds along the mauka-makai transects and out into the ocean as well as in selected anchialine pools along the coastline to provide a picture of water quality characteristics along the coast of KAHO.

Water chemistry parameters of interest are those specified by the Department of Health and include nitrate+nitrite nitrogen, ammonia nitrogen, total nitrogen, orthophosphorus, total phosphorus, chlorophyll-*a*, turbidity, salinity, dissolved oxygen concentration, temperature and pH. Because of its use as a tracer of groundwater, silica was also monitored. Concentrations are presented in micromoles per liter (µM) unless otherwise noted. The limits of detection for these parameters is as follows: orthophosphorus = 0.02µM, total phosphorus = 0.03µM, nitrate+nitrite nitrogen = 0.03µM, ammonia nitrogen = 0.03µM, total nitrogen = 0.04µM, silica = 0.20µM, total organic carbon = 0.02 mg/l, chlorophyll-*a* = 0.020 µg/l, turbidity = 0.01 NTU, salinity = 0.003°/oo, dissolved oxygen = 0.01 mg/l, pH = 0.01 units and temperature = 0.1°C. DON refers to dissolved organic nitrogen and is obtained by subtracting nitrate and ammonia nitrogen from the total nitrogen value of a given sample. Similarly, DOP or dissolved organic phosphorus is obtained by subtracting orthophosphorus from total phosphorus for a given sample.

The sampling procedures follow the West Hawaii Coastal Monitoring Task Force (1992), Brock *et al.* (1987), and Brock and Kam (1990). Samples were handled as per Standard Methods (1985) and for nutrient analyses, were filtered in the field, placed on ice and returned to the laboratory for analyses. Analyses followed Standard Methods (1985) with modifications as given by Grasshoff (1983) and Strickland and Parsons (1972). The analyses were carried out by the School of Earth Science and Technology, University of Hawaii Analytical Services Laboratory. The Analytical Services Laboratory is primarily a water chemistry laboratory which specializes in the analyses of water quality parameters in samples provided by marine, coastal, groundwater and oceanic researchers at the University and is an U.S. Geological Survey approved laboratory. Data are presented below using a simple mixing model (Dollar and Atkinson 1992, Brock and Kam 1994) which allows one to differentiate "sources" and "sinks" of materials in the system.

Pesticide samples were collected as sediment samples from Aimakapa'a Fishpond and from the tissues of two adult grey mullet or ama'ama (*Mugil cephalus*) and two milkfish or 'awa (*Chanos chanos*) in March 1997. The sediment samples were taken from the middle of the pond, removing the sediment to a depth of about 10cm by pushing a precleaned sample jar into the substratum. Tissue samples were taken from the major organs (muscle, intestines, liver, gonads) of each fish and an aggregated or homogenized sample again placed in a precleaned sample jar. These samples were frozen and shipped to an EPA approved laboratory in California for analysis. Because the costs of pesticide analyses are relatively high, the samples were processed for four "screens": volatile organics using EPA method 8240, organophosphorus pesticides using EPA methods 614 and 8140, chlorinated pesticides using EPA methods 608 and 8080 and acid/base/neutral extractables using EPA method 8270. The limits of detection for each sampled parameter are given with the data under the Results section.

Sediment samples for metal analyses were collected from Aimakapa'a Fishpond in March 1994 and again in March 1997. The March 1997 series of samples were collected and handled as given above. Besides the analysis of sediment for metals, homogenized tissue samples were also taken from the same mullet and milkfish as above. The sediment samples collected in March 1994 were taken at two locations: along the ocean or makai side of the fishpond and close to the inland side of the pond. These samples were taken using a simple precleaned cylinder pushed into the sediment obtaining a short core. Samples for analysis were taken at the surface of the core (i.e., 2-6cm depth), at a depth of 9 to 13cm and in one core at a depth of 15to 19cm. All of the metal samples were processed at the University of Hawaii's Atomic Spectroscopy Laboratory using accepted standard techniques. This laboratory participates in the U.S. Geological Survey round robin sample testing program is laboratory is approved by that agency.

Routine monitoring of anchialine biota noted the presence of all diurnally exposed "macro" species (i.e., greater than 3 mm in some dimension). Quantitative information on coverage by native benthic algae and submerged vascular plants as well as counts of native motile fauna was gathered using 0.1 square meter quadrats placed on the different substrates present in each pool. Benthic cover was estimated as percent cover by the various species and motile fauna were censused in these quadrats. The methods for monitoring anchialine biota follow those outlined in West Hawaii Coastal Monitoring Task Force (1992) and focus most of the quantitative effort on native and/or endemic species. Exotic or alien species were only to be qualitatively noted. Quantitative biological data was compared to available information from other West Hawai'i anchialine systems (e.g., Waikoloa). Use of other semiquantitative methods to sample the motile biota (e.g., kick nets) were suggested but due to the extremely delicate nature of the cyanobacteria mat present in many undisturbed anchialine pools, this method was not used because it would be too destructive insofar as the benthic communities are concerned.

Establishing a program that samples water quality and biota at the same sites through time will allow one to determine if a "steady state" conditions exists as well as determine rates of change(s) if they are occurring. These data are necessary to the development of any restoration/conservation program for the groundwater and anchialine resources under the Park's jurisdiction. Data generated by the monitoring studies were used to identify the best and most cost-effective strategies for the management of the Park's anchialine resources. The primary objectives of the management plan are (1) the restoration of degraded anchialine/coastal groundwater resources, (2) protection of significant anchialine resources that may be present, (3) implementation of educational program(s) for the public. The plan must be able to identify and mitigate any new sources of impacts that could occur to the Park's groundwater and anchialine pool resources.

4.0 RESULTS AND DISCUSSION

4.1 Distribution of Anchialine Resources

Besides the classical definition of an anchialine pool (i.e., a body of water having a measurable salinity and showing tidal fluctuations but no surface connections to the sea), the working definition of an anchialine pool used here is that it is isolated from other adjacent bodies of water at the highest tides. If adjacent pools show surface connections on high tides, they are considered to be part of a pool complex. A complex may have a number of depressions or basins, which through lower tides may appear as individual pools but coalesce, at higher tides.

Field reconnaissance surveys found a number of individual anchialine pools and pool complexes both within and outside of the Park's boundaries. Some field work was carried out north of the Park's present boundary along the coast to a point just south of Wawahiawa'a Point ("Pine Trees"). In total, 82 pools and easily identifiable basins were noted in this study; eighteen of these were mapped north of the Park's northern boundary and the remainder were found within the Park. Some depressions in association with Aimakapa and Kaloko Fishponds were not differentiated as ponds in this study because of their physical connection to the fishponds and hence invasion by nonnative biota from the fishponds. More emphasis in this study was placed on those ponds that appeared to have the usual complement of native biota (i.e., crustaceans, etc.) or are physically separated from other pools. Additionally, pools that had been habitat for anchialine species but had otherwise degraded (i.e., relatively isolated but invaded by alien species, filled in, etc.) were also considered because of their potential for restoration. Six known anchialine pools at the south end of the Park (near 'Ai'opio Fishtrap) were not surveyed because of interference by residents in the area. These ponds were surveyed by Maciolek and Brock (1974) but had little native biota at that time; their present biological or water chemistry status is unknown.

Figure 1 is a map of the coastline surveyed in this study. In total, about 4.7 km of coastline was covered; about 26% or 1.2 km of this shoreline is now outside and north of the Park's present northern boundary. The maps available to us from the US National Park Service depict coastal boundaries that encompass this northern area (e.g., see Figure 1), thus it was examined here. Because most anchialine pools are small and tend to be clustered together along the coast, more detailed maps were prepared to better delineate the distribution of anchialine resources in portions of the Park at a larger scale. In total, there are nine larger scale maps and the approximate areas covered by these maps are also given in Figure 1 (marked A through I) and

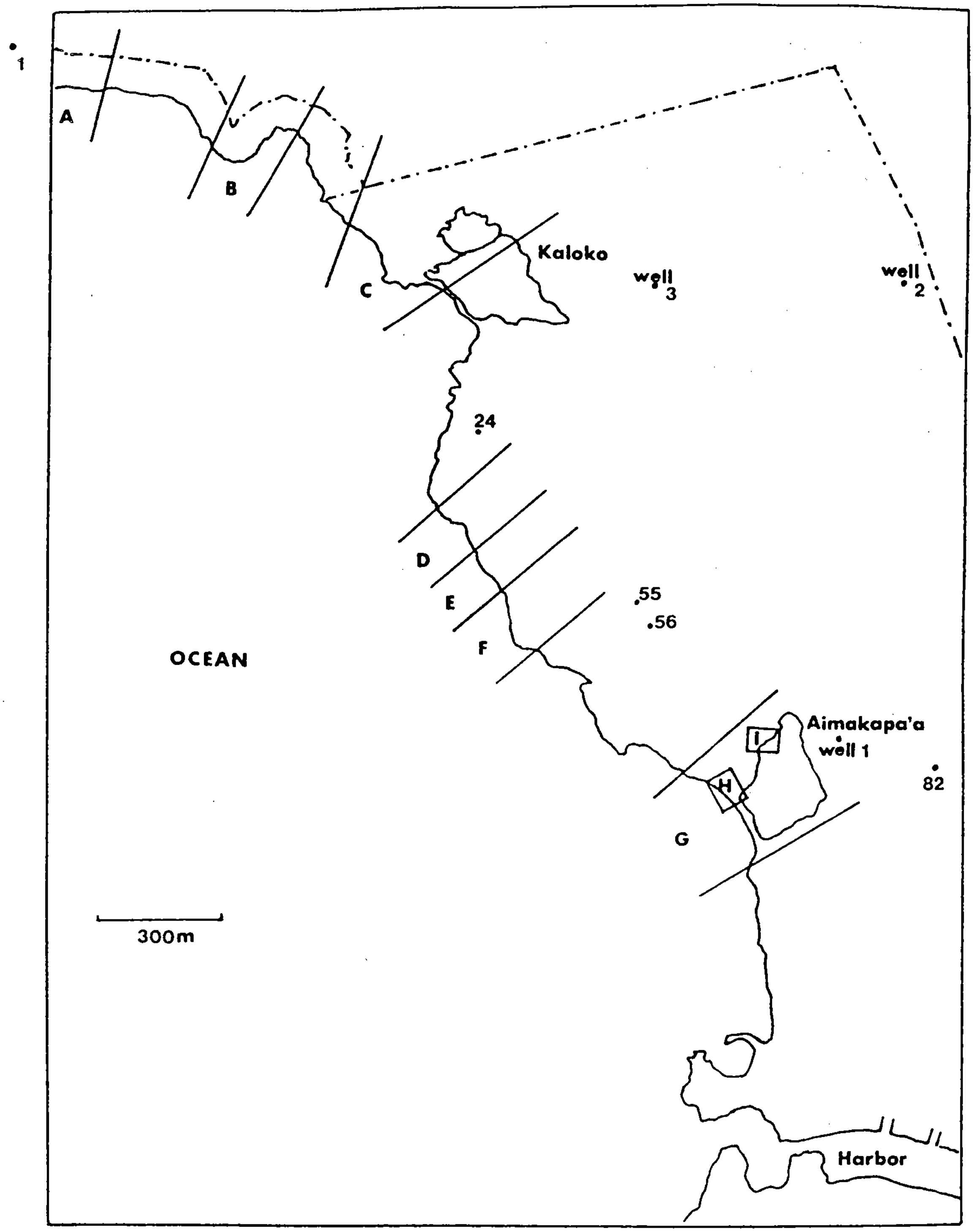


FIGURE 1. Map of the Kaloko-Honokohau National Historic Park showing the boundaries, Kaloko and Honokohau Fishponds, some of the more isolated sample sites as well as the approximate boundaries of more detailed maps that are presented in Appendix 1.

these maps are presented in Appendix 1. Information about pond location to easily identifiable points as well as in some cases latitude and longitude (taken by hand-held GPS), basin size, surrounding vegetation, and biota are given for each anchialine pool in Appendix 2. Where possible, we have also related each pond to numbers given to ponds in past surveys and this is also in Appendix 2.

The features of most anchialine pond basins such as size, shape and depth vary with tidal state. The shape of most pools is highly irregular because of the character of the porous lava in which they occur. Generally pools in pahoehoe tend towards roundness except for pools at the bottom of cracks or fissures; most irregular are the pools found in recent a'a flows. Pools with shallow, flat basins display the greatest variation in relative areal extent which is directly related to the state of the tide at the time of sampling. At the extreme are depressions that contain water only on high tidal stages. These intermittent pools are ecologically significant because they serve as habitat for desiccation resistant species such as some snails and algae during low tides and is habitat for many motile hypogeal species during high tides.

Most of the anchialine pools examined in this study may be characterized as being small (with surface areas less than $10m^2$), and shallow (less than 0.5m in depth). Maciolek and Brock (1974) found that 42% of the pools they examined were similarly small and 53% were equally as shallow. Classifying the pools examined here we note that 68% were small, 27% were intermediate in size (i.e., with surface areas between 10 to $100m^2$), and 5% were large (i.e., greater than $100m^2$ in surface area). With respect to depth, this study found that 93% of the pools surveyed were less than 0.5m in depth and 7% were between 0.5 to 1.5m in depth. The Maciolek and Brock (1974) study found that 38% of the pools they examined on the Kona coast were moderate in depth (i.e., between 0.5 to 1.5m) and 9 percent were greater than 1.5m in depth. By way of summary, the pools in the KAHO typically have very irregular basins, are small and are shallow.

We suspect that if some of the pools under the Park's jurisdiction were cleared of encroaching vegetation and excess sedimentary materials removed, many would have depths greater than 1.5m. A case in point is Pond 82. This pool was dug in the early 1970's by the construction crews building the Queen Ka`ahumanu Highway as a source of water for dust control. Maciolek and Brock (1974) surveyed this pool and noted that it was deep (greater than 1.5m). Today the apparent depth is 1m or less probably due to infilling by leaf litter, *in situ* algal production and breakdown as well as by wind borne dust.

Fully 51% of the pools examined in this study have little or no surrounding vegetation, hence have full diurnal exposure to the sun. These pools are primarily located in recent a'a flows here vegetation has not become extensively established. Eighteen percent of the pools are under a thick canopy of trees. These trees and shrubs include milo *(Thespesia populnea*), Christmas berry (*Schinus terebenthifolius*), beach naupaka (*Scaevola taccada*), hau (*Hibiscus tiliaceus*), heliotrope (*Messerschmidia argentea*), kiawe (*Prosopis pallida*), Indian pluchea (*Pluchea* *indica*) and occasionally noni (*Morinda citrifolia*). The most common canopy encountered in this study is comprised of kiawe, Christmas berry and Indian pluchea. Four percent of the pools were under a partial tree canopy and 16% of the ponds are being encroached upon by salt tolerant plants including pickleweed (*Batis maritima*), akulikuli (*Sesuvium portulacastrum*), makaloa (*Cyperus laevigatus*), makai (*Scirpus maritimus*) and ahu'awa (*Cyperus javanicus*; note that the latter two species have not been fully identified) and about 11% of the pools in this study have both a vegetative overstory as well as encroaching vegetation. The status of vegetation around and in each pool is summarized in Appendix 2.

4.2 Chemical Characteristics of Ground, Anchialine, Fishpond and Nearshore Marine Waters at KAHO

Once the distribution of most anchialine pool resources were known, a number of locations were selected as permanent sampling sites. Anchialine pools are coastal features as are the two fishponds under the Park's jurisdiction and provide access to seaward flowing groundwater prior to its entry into the sea. Additionally, three coastal wells drilled by the U.S. Geological Survey for their study of the groundwater resources at KAHO, offer another sampling point used in this study. Water chemistry sample sites were selected in pools and wells to define any north-south variation in coastal groundwater passing through the Park. Two locations were selected to sample through any inland-seaward (mauka-makai) gradients that may exist at those points. These mauka-makai sampling transects incorporated both of the fishponds (Aimakapa'a and Kaloko) in the Park.

In total, there were 16 anchialine pool sites, 8 locations in the two fishponds, 10 marine sites and three well locations sampled for water quality characteristics in this study. The locations of these sampling points are given in Figure 2. Along the coast the most northerly sample location was just south of Wawahiwa'a Point to Aimakapa'a Fishpond on the south, thus encompassing more than 3.5 km of coastline. Where sufficient depth occurred, water quality samples were taken about 20cm below the water's surface otherwise they were taken just under the surface. Several fishpond and marine samples were taken at depth (in most cases about 1m above the bottom). In the fishponds, these samples were F-3 at a depth of 1.5m in the middle of Kaloko Fishpond just beneath F-2, and F-7 at a depth of 75cm in the middle of Aimakapa'a Fishpond just beneath F-6. Marine bottom samples were taken offshore of Kaloko Fishpond at station M-3 about 100m offshore at a depth of 1.6m just beneath M-2 and M-5 which is located about 200m offshore at a depth of 8m just beneath M-4. In the waters offshore of Aimakapa'a Fishpond, station M-8 was established about 75m offshore at a depth of 1.6m just beneath M-7 and M-10 was located about 200m offshore at a depth of 5m just beneath M-9.

The results of the water chemistry sampling effort are presented in their entirety in Appendix 3. In total, there were six sampling periods commencing on 3 March 1994 and finishing on 18 October 1996. Table 1 presents a summary of these data as grand means with standard deviations. Several trends are apparent in these data. First, the measured concentrations of nutrients in the anchialine pools are in the usual range for undisturbed West Hawaii coastal groundwater. Secondly, concentration gradients are apparent for nitrate, total nitrogen, orthophosphorus, total phosphorus, silica and salinity relative to sample site location. Other than salinity, these gradients are due to the naturally greater concentration of these constituents in groundwater relative to marine waters. Figures 3A and B graphically demonstrate these gradients for nitrate nitrogen and orthophosphorus at sample sites commencing mauka of Kaloko Fishpond (wells 2 and 3), through this pond (F-1, F-2, and F-4) and out into the ocean (M-1, M-2, M-3, M-4). A similar situation exists for the data from Aimakapa'a Fishpond. The concentrations of nitrate and orthophosphate at site M-1 are elevated relative to sites in the fishpond or seaward of it. The reason for this "spike" is that site M-1 samples a groundwater spring that flows directly out of the pahoehoe and into the ocean at the shoreline just south of the main rock wall of Kaloko Fishpond. This groundwater must be flowing to the sea coming either from directly beneath the fishpond or from the area to the south of it. This groundwater is isolated from the water being sampled on this inland-to-seaward (mauka-makai) transect; this is evident in Figure 3C where mean salinity is plotted for these same sample sites. The lower salinity, higher nitrate, orthophosphorus and silica at site M-1 relative to stations inland or seaward of it demonstrates the isolation of this groundwater source. Such anomalies in the flow of groundwater to the sea are common on the West Hawaii coast.

With respect to the mean concentrations of measured nutrients one site appears anomalous. Data from the USGS Well no. 1 inland of Aimakapa'a Fishpond appear to be very unusual. Nitrate nitrogen, total nitrogen, orthophosphorus, total phosphorus, silica and dissolved oxygen concentrations are relatively low. Low nutrient levels suggest nutrient depletion that could possibly be due to uptake at some earlier point. Salinity is somewhat elevated and this with the low silica concentrations, suggests some greater than usual connection with marine waters especially for such an inland location. Ammonia nitrogen is elevated. The low dissolved oxygen concentrations measured at this site suggest anoxic conditions that may allow for the conversion of nitrate to ammonia. Our working hypothesis is that the water sampled by USGS Well no. 1 is connected to and part of the interstitial waters of the bottom sediments of Aimakapa'a Fishpond and that the sampled water at USGS Well no. 1 is not rapidly exchanging with the ocean probably because of local geology. Brock's (1991) study of Ku'uali'i Fishpond at Anaehoomalu, North Kona demonstrated that the Loko Pu'oune type of fishpond (i.e., a fishpond behind a sand berm such as Aimakapa'a is; see Kikuchi and Belshe 1971) is a nutrient "sink" where the incoming relatively low salinity, high nutrient brackish groundwater is stripped of most nutrients by the high standing crop of phytoplankton and benthic algae resident to the pond. The phytoplankton and algae grow, accumulating nutrients which, on death, are sequestered in the bottom sediments of the pond. Thus these ponds are sinks for nutrients. Like Ku'uali'i, Aimakapa'a Fishpond has a relatively deep sediment layer, relatively poor water exchange with the ocean and appears to function in a similar way. The bottom sediments of the pond are anoxic; water in association with these sediments will have the chemical characteristics similar to those noted for USGS Well no. 1.

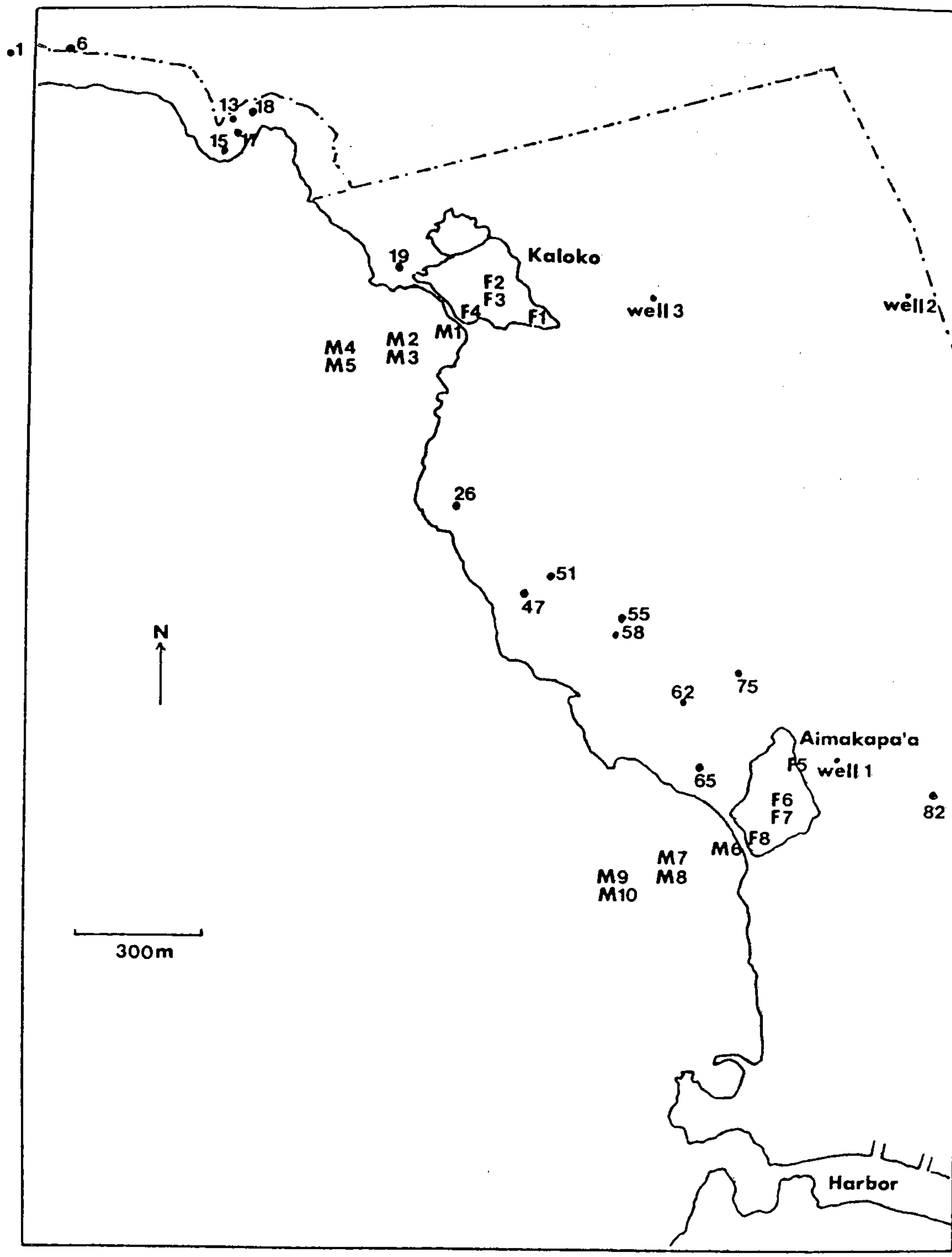


FIGURE 2. The approximate locations of 16 anchialine pools, 8 fishpond sites, 10 marine sites and 3 coastal wells sampled to characterize the status of water chemistry in and adjacent to the Kaloko-Honokohau National Historic Park.

TABLE 1. Means and standard deviations of measured water chemistry parameters at 37 sample sites in KAHO. Sample sites include 3 wells (prefix as Well-), 16 anchialine pools (given as numbers), 8 fishponds sites (prefix with F-) and 10 marine locations (prefix with M-). All anchialine pool, fishpond and marine sites sampled on 6 occasions spanning the period from 3 March 1994 through 18 October 1996. Note that site 18 was only sampled on 3 occasions and site 27 on one occasion. Since the coastal wells were completed after commencement of this study, they were sampled on 4 occasions. In the body of the table are given the means±SD; concentrations are given in μM unless otherwise noted.

Site		NO_3	NH_4	Total N	PO_4	Total P	Silica	Total Organic C	S°/oo	Turb NTU	Chl-*a*	Temp °C	Oxy mg/l	pH
Anchialine Ponds:														
1	mean	6.66	2.38	23.37	0.47	0.82	439.66	0.66	16.167	0.47	7.341	27.5	3.05	7.62
	±SD	3.60	1.67	2.94	0.28	0.20	68.80	0.27	1.133	0.41	8.059	2.4	1.43	0.34
6	mean	38.32	2.61	49.01	1.99	2.28	563.54		12.352	0.31	0.389	23.9	3.30	7.31
	±SD	4.87	2.07	2.84	0.15	0.13	49.13		0.426	0.13	0.206	1.3	0.52	0.08
13	mean	40.76	2.78	53.62	2.76	3.12	554.26		11.621	0.40	0.629	22.5	5.87	7.35
	±SD	10.13	1.62	8.69	0.47	0.56	42.51		0.345	0.47	0.409	1.8	3.26	0.40
15	mean	62.30	0.28	67.94	2.90	3.07	584.91		11.192	0.17	0.111	20.0	6.77	7.68
	±SD	3.04	0.16	4.54	0.26	0.12	37.38		0.356	0.09	0.121	0.8	0.73	0.09
17	mean	51.79	1.06	59.06	2.99	3.25	573.13	0.27	11.648	0.22	0.492	22.2	5.82	7.29
	±SD	8.00	0.56	5.84	0.30	0.15	41.43	0.25	0.705	0.07	0.498	1.5	0.90	0.13
18	mean	53.88	1.12	58.75	2.91	3.11	561.08		11.552	0.16	0.167	21.7	4.93	7.33
	±SD	5.16	1.02	2.80	0.23	0.14	24.60		0.422	0.03	0.124	0.2	0.14	0.13
19	mean	35.69	1.30	46.53	2.36	2.59	483.06	0.63	15.069	0.75	1.490	24.9	6.56	7.51
	±SD	13.30	0.53	9.23	0.45	0.34	76.85	0.0	0.833	0.98	1.774	2.3	3.08	0.36
26	mean	64.72	0.21	69.11	3.25	3.35	548.55		12.748	0.22	0.036	22.1	7.18	7.91
	±SD	1.80	0.11	4.06	0.16	0.19	40.15		0.377	0.21	0.024	0.9	0.95	0.05
27		63.83	0.05	64.60	3.43	3.43	525.75		12.773	0.06	0.006	22.0	8.16	7.89
47	mean	60.64	1.04	65.44	3.16	3.26	539.39		12.670	0.36	0.188	22.2	6.81	7.79
	±SD	2.89	0.64	4.58	0.06	0.08	33.89		0.197	0.39	0.057	0.4	1.25	0.04

TABLE 1. Continued.

Site	NO_3	NH_4	Total N	PO_4	Total P	Silica	Total Organic C	S°/oo	Turb NTU	Chl-*a*	Temp °C	Oxy mg/l	pH
51 mean	67.25	0.58	71.56	3.42	3.48	559.64	0.25	11.274	0.10	0.077	22.1	7.26	7.83
±SD	3.21	0.36	4.81	0.14	0.15	32.04	0.11	0.946	0.03	0.039	0.8	1.04	0.09
55 mean	75.09	0.83	80.56	3.75	3.86	591.91	0.24	9.002	0.17	0.051	22.9	7.46	7.95
±SD	3.69	0.57	6.19	0.13	0.11	40.06	0.14	0.378	0.09	0.022	1.0	0.98	0.06
62 mean	61.40	1.03	69.11	3.10	3.22	538.07	0.26	12.351	0.29	0.064	21.1	6.91	7.78
±SD	3.44	0.79	10.03	0.20	0.17	43.32	0.12	0.155	0.27	0.015	1.3	1.14	0.07
65 mean	19.57	2.68	40.44	1.31	1.79	443.29	1.53	16.959	0.55	1.894	28.2	4.79	7.44
±SD	16.04	2.89	16.33	0.64	0.57	44.78	0.0	2.029	0.19	1.650	2.4	2.24	0.16
75 mean	26.96	2.76	44.95	1.84	2.35	576.52	1.02	8.831	0.36	0.961	27.9	9.80	8.22
±SD	11.70	2.04	10.58	0.33	0.22	47.58	0.24	0.445	0.12	1.006	0.9	3.84	0.43
82 mean	35.26	4.62	48.92	2.90	3.30	600.30	0.69	8.298	0.69	1.353	22.6	5.83	7.15
±SD	16.12	3.67	12.73	1.10	1.05	45.26	0.11	0.175	0.99	1.389	1.4	2.82	0.37
Fishponds:													
F1 mean	21.44	1.36	32.23	1.33	1.63	281.15	0.58	22.274	0.50	2.053	30.5	7.01	7.94
±SD	19.27	0.70	16.47	1.16	1.12	200.44	0.09	9.055	0.22	1.874	1.8	0.74	0.28
F2 mean	0.41	0.26	11.21	0.16	0.55	85.57		31.302	0.59	2.043	28.7	6.52	8.11
±SD	0.38	0.13	2.12	0.08	0.10	43.14		1.995	0.28	0.803	0.1	0.58	0.10
F3 mean	0.10	0.28	8.66	0.15	0.52	42.93		33.054	1.06	2.615	28.5	6.52	8.12
±SD	0.11	0.14	1.41	0.08	0.10	14.40		0.709	0.72	0.839	1.0	0.62	0.04
F4 mean	0.38	0.63	9.51	0.15	0.45	57.42	0.52	32.356	0.44	0.955	28.9	6.53	8.13
±SD	0.39	0.43	2.16	0.08	0.06	25.38	0.07	1.233	0.30	0.405	1.1	0.54	0.05
F5 mean	29.37	3.37	47.52	2.30	2.72	529.73	0.66	11.773	0.39	1.636	27.6	3.98	7.58
±SD	8.97	2.18	11.56	0.61	0.50	32.44	0.14	0.719	0.16	2.794	2.1	2.08	0.29

TABLE 1. Continued.

Site	NO_3	NH_4	Total N	PO_4	Total P	Silica	Total Organic C	S°/oo	Turb NTU	Chl-*a*	Temp °C	Oxy mg/l	pH
F6 mean	3.66	0.26	21.06	0.83	1.43	519.38		11.989	1.69	7.493	27.9	8.02	8.34
±SD	4.34	0.20	4.24	0.15	0.22	40.16		0.624	0.90	2.816	1.2	1.53	0.08
F7 mean	0.91	0.17	20.63	0.72	1.33	519.79		12.010	1.54	8.413	27.9	8.04	8.33
±SD	1.56	0.14	4.35	0.16	0.18	42.23		0.610	0.59	2.444	1.3	1.45	0.09
F8 mean	1.48	0.47	22.62	0.73	1.42	510.46	0.78	12.132	1.47	6.309	28.8	7.65	7.94
±SD	2.96	0.39	2.47	0.24	0.22	38.59	0.0	0.581	1.04	2.762	1.9	1.69	0.52
Marine:													
M1 mean	43.05	0.08	47.39	2.59	2.68	448.61	0.25	17.423	0.19	0.133	21.9	6.19	7.67
±SD	2.75	0.04	3.19	0.09	0.13	55.11	0.20	0.542	0.18	0.051	0.8	0.89	0.15
M2 mean	1.74	0.40	8.32	0.27	0.55	31.43	0.16	33.436	0.17	0.146	25.5	7.13	8.14
±SD	0.86	0.16	0.41	0.05	0.07	12.17	0.0	0.452	0.06	0.069	1.2	0.51	0.07
M3 mean	1.52	0.37	7.82	0.23	0.51	28.21		33.573	0.15	0.163	25.6	7.24	8.16
±SD	0.67	0.11	1.76	0.06	0.07	11.04		0.471	0.07	0.070	1.3	0.58	0.05
M4 mean	1.66	0.37	8.01	0.23	0.50	29.58	0.14	33.495	0.18	0.127	25.6	7.01	8.09
±SD	0.89	0.11	1.37	0.06	0.06	13.12	0.07	0.488	0.11	0.054	1.3	0.70	0.13
M5 mean	0.48	0.32	6.43	0.15	0.42	8.96		34.252	0.12	0.105	25.5	6.99	8.11
±SD	0.19	0.22	1.41	0.03	0.05	2.46		0.203	0.05	0.028	1.3	0.69	0.06
M6 mean	1.84	0.48	9.31	0.34	0.61	51.65	0.30	32.534	0.64	0.504	27.6	7.10	8.13
±SD	1.00	0.16	1.72	0.10	0.10	27.51	0.0	1.297	0.41	0.292	1.6	0.70	0.11
M7 mean	1.04	0.53	8.75	0.24	0.51	37.55		33.060	0.32	0.167	27.4	7.45	8.23
±SD	0.48	0.28	2.58	0.05	0.08	21.51		0.932	0.31	0.092	1.3	0.42	0.07
M8 mean	0.64	0.38	7.23	0.20	0.48	25.56		33.500	0.24	0.230	27.4	7.32	8.23
±SD	0.32	0.16	1.35	0.06	0.05	16.96		0.827	0.21	0.165	1.5	0.53	0.07

TABLE 1. Continued.

Site	NO_3	NH_4	Total N	PO_4	Total P	Silica	Total Organic C	S°/oo	Turb NTU	Chl-*a*	Temp °C	Oxy mg/l	pH
M9 mean	0.43	0.37	7.14	0.17	0.48	19.65		33.822	0.15	0.145	27.5	7.16	8.22
±SD	0.28	0.20	1.43	0.04	0.12	13.49		0.486	0.05	0.063	1.3	0.57	0.06
M 10													
Mean	0.35	0.38	6.97	0.17	0.46	15.34		33.926	0.18	0.140	27.5	6.85	8.21
±SD	0.17	0.22	1.91	0.05	0.07	9.62		0.373	0.15	0.062	1.4	0.66	0.06
Well 1													
Mean	23.14	14.26	49.72	0.83	1.05	259.03		9.266	1.07	---*	21.3	1.27	9.19
±SD	3.70	9.59	14.60	0.50	0.47	90.35		0.439	0.81		0.4	0.20	0.81
Well 2													
Mean	82.73	0.14	89.70	4.27	4.38	682.44		4.841	0.60	---*	19.3	7.96	7.13
±SD	5.20	0.14	5.71	0.16	0.11	59.92		0.097	0.73		0.8	0.41	0.49
Well 3													
Mean	75.66	0.26	83.19	4.10	4.30	685.72		5.932	0.36	---*	20.2	7.62	6.73
±SD	3.09	0.30	6.91	0.29	0.49	59.44		0.059	0.21		0.7	0.17	0.24

*NOTE: Chlorophyll-*a* samples are not collected from wells.

4.2.1. Hydrographic Mixing Model Analysis

A characteristic feature of West Hawaii is its diffuse groundwater discharge at the shoreline (Cox *et al.* 1969). This discharge is the result of the island's geologically young lava; estimates of this discharge range from less than one to more than four million gallons/day per mile of coastline (U.S. Army Corps of Engineers 1985). The high porosity of these young lava will not support water contained above sea level near the shoreline (Cox *et al.* 1969), resulting in a system where groundwater moves rapidly through the lava towards the sea and seawater readily intrudes. Seawater is typically very low in inorganic nutrients and groundwater usually shows some elevation of these components resulting in gradients of nutrient concentrations as groundwater moves towards the sea. A simple dilution model has been proposed to explain these gradients (Officer 1979, Smith and Atkinson 1993). In its simplest form, the model plots the concentration of a dissolved chemical species as a function of salinity or other conservative tracers. Comparison of the curves produced by such plots with conservative mixing lines provides an indication of the origin and fate of the material in question.

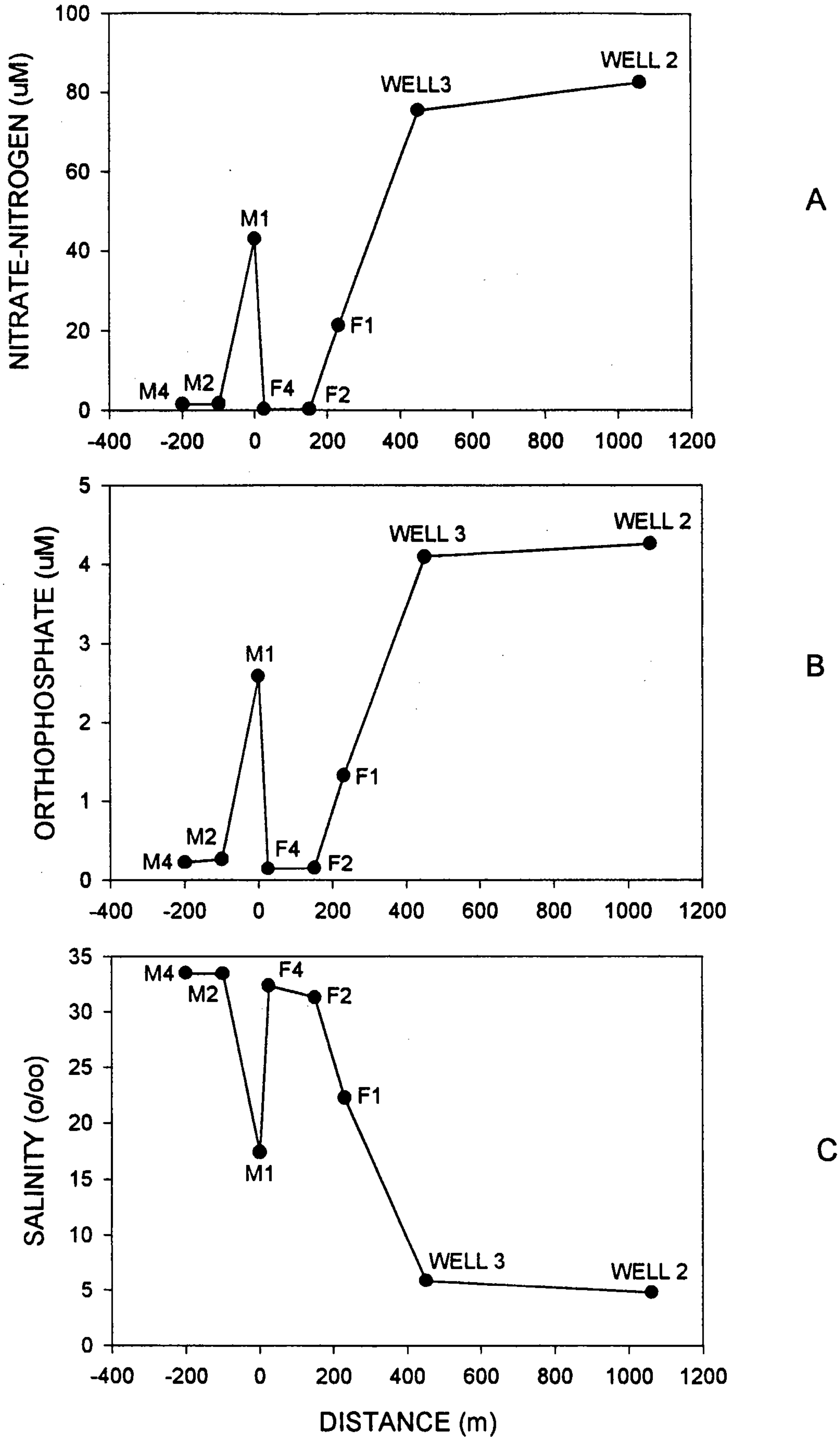
The dilution model is based on the premise that mixing two waters with differing compositions will yield straight lines on two-dimensional plots (see Smith *et al.* 1987, Dollar and Smith 1988). Straight lines will result if the differing waters are composed of conservative (i.e., non-reactive) constituents and if the waters are not physically impeded (i.e., that the lava fields adjacent to the shore have high porosity). Both salinity and silica are conservative and the resulting plot of these two species is linear (Figure 4). The conservative mixing line is constructed for each nutrient by connecting the endpoint concentrations of open ocean water and uncontaminated groundwater from sources inland of any anthropogenic inputs. Deviation from the straight line implies an additional source (i.e., points above the line) or sink (i.e., points below the line) of material, or the presence of some physical barrier to movement. Dissolved silica represents a check on the model as this material occurs in high concentration in undisturbed groundwater but is low in seawater and in developed areas is not a major component of fertilizer. Silica is used by organisms (diatoms principally) but is not otherwise rapidly assimilated by biological activity in nearshore waters. Thus a plot of silica against salinity (Figure 4) shows the data points fall reasonably close to the theoretical conservative (linear) mixing line (except for the anomalous USGS Well no. 1; see discussion above) suggesting that the mixing model and the assumptions used in developing it are an accurate reflection of the system under study. The linear relationship of the salinity/silicate plot (Figure 4) also suggests that the lava fields through which the water flows at KAHO does not materially impede the flow of water either towards the land or sea.

The plots of salinity (conservative) against nitrate nitrogen (Figure 5) and orthophosphate (Figure 6) show that most points fall either on the conservative mixing line or below this line. Points below this line suggest that some uptake is occurring (and or in the case of nitrate,

FIGURE 3. A. Concentration gradient of nitrate nitrogen with distance from the ocean (n=40). Zero on the abscissa represents the shoreline and negative numbers, the distance offshore. Note that site M-1 samples a groundwater spring flowing directly into the sea just south of the Kaloko Fishpond, thus explaining the elevation of nitrate at the shoreline.

FIGURE 3. B. Concentration gradient of orthophosphorus with distance from the ocean (n=40). Zero on the abscissa represents the shoreline and negative numbers, the distance offshore. Note that site M-1 samples a groundwater spring flowing directly into the sea just south of the Kaloko Fishpond, thus explaining the elevation of orthophosphorus at the shoreline.

FIGURE 3. C. Salinity gradient with distance from the ocean (n=40). Zero on the abscissa represents the shoreline and negative numbers, the distance of sample sites offshore. Note the depression of salinity at the M-1 station situated on the shoreline. This site samples a groundwater spring flowing directly into the sea just south of Kaloko Fishpond, thus explaining the lower mean salinity at this location.



NITRATE-NITROGEN (uM)
WELL 2
WELL3
M1
F1
M4
M2
F4
F2
A
ORTHOPHOSPHATE (uM)
WELL 3
WELL 2
M1
F1
M2
M4
F4
F2
B
SALINITY (o/oo)
M4
M2
F4
F2
F1
M1
WELL 3
WELL 2
C
DISTANCE (m)

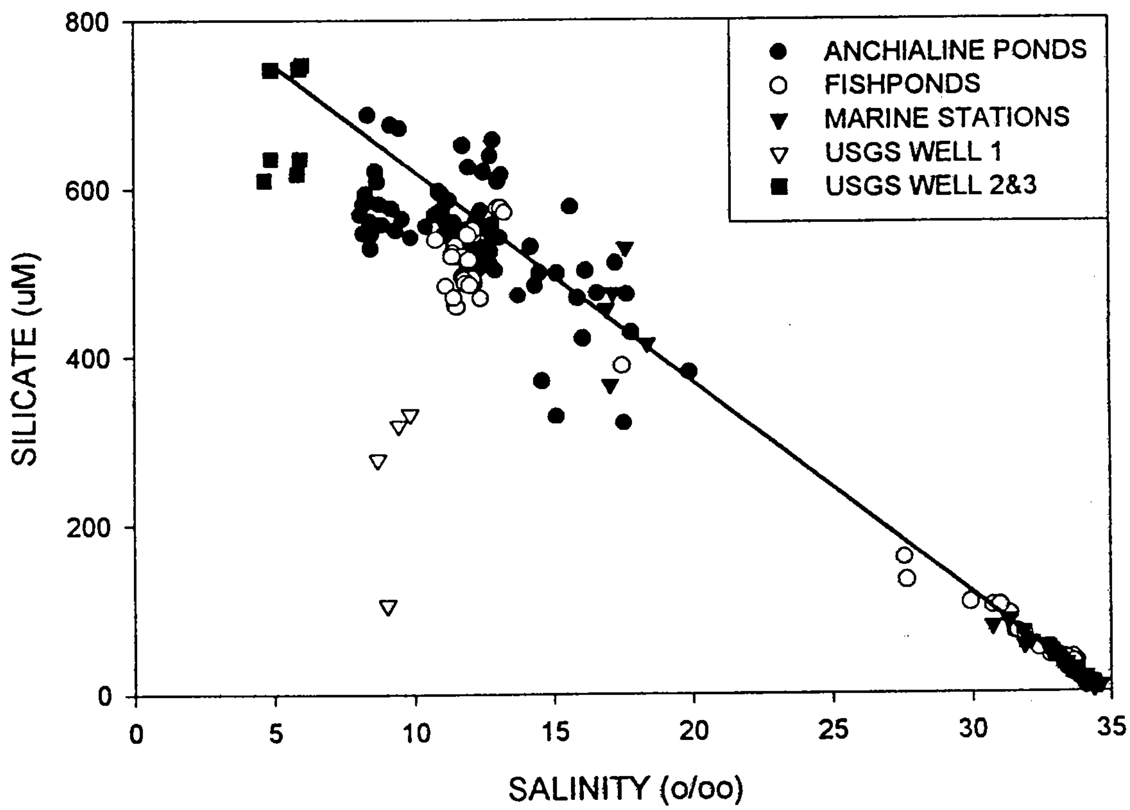


FIGURE 4. Plot of measured salinity and silica concentrations at all sample sites in this study. In total, these data are from 16 anchialine pool, 8 fishpond, 10 marine and three well sites. Note that different sites are shown with different symbols and that USGS Well no. 1 is shown separately (open triangles). Also shown is the conservative mixing line; these data demonstrate the conservative nature of silica in the system.

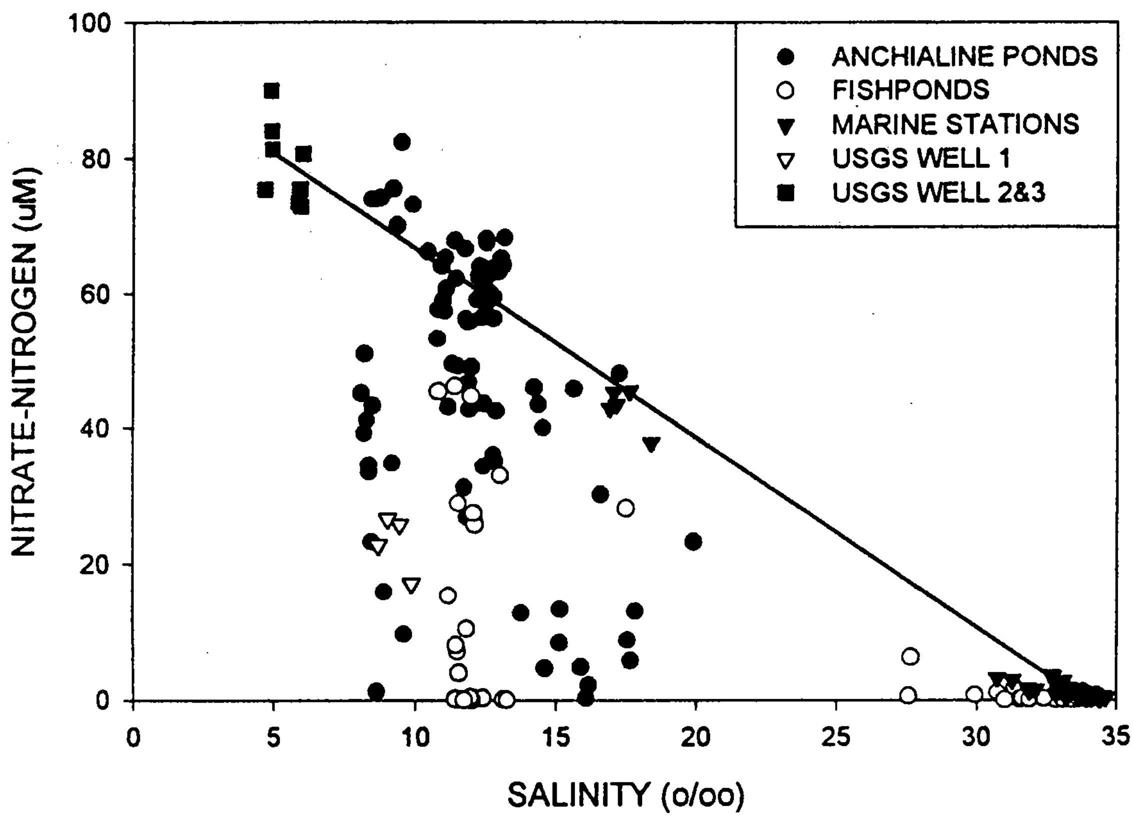


FIGURE 5. Plot of the measured salinity and nitrate nitrogen concentrations at all sample sites in this study. In total, these data are from 16 anchialine pool, 8 fishpond, 10 marine and three well sites. Note that different sites are shown with different symbols and that USGS Well no. 1 is shown separately (open triangles). Also shown is the conservative mixing line; points above the line suggest allochthonous input of nitrate to the system and points below the line indicate uptake of nitrate in the system.

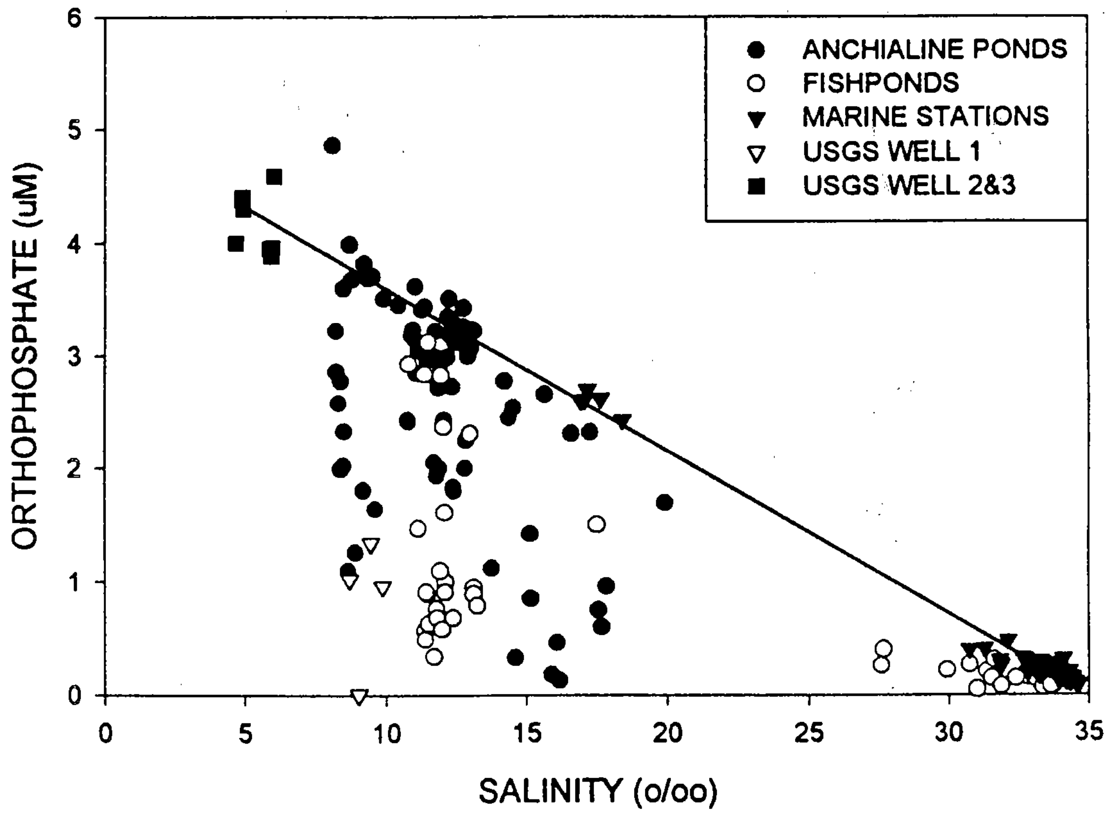


FIGURE 6. Plot of the measured salinity and orthophosphorus concentrations at all sample sites in this study. In total, these data are from 16 anchialine pool, 8 fishpond, 10 marine and three well sites. Note that different sites are shown with different symbols and that USGS Well no. 1 is shown separately (open triangles). Also shown is the conservative mixing line; points above the line suggest allochthonous input of orthophosphorus to the system and points below the line indicate uptake of this nutrient in the system.

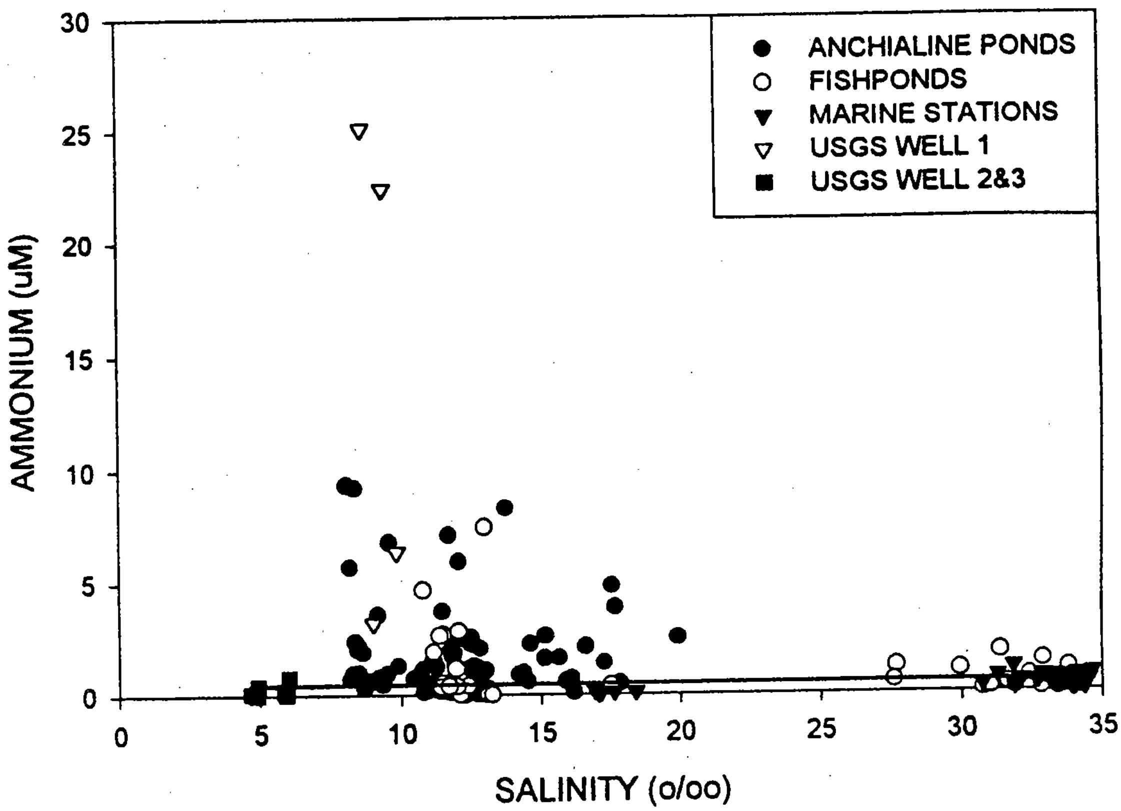


FIGURE 7. Plot of the measured salinity and ammonia nitrogen concentrations at all sample sites in this study. In total, these data are from 16 anchialine pool, 8 fishpond, 10 marine and three well sites. Note that different sites are shown with different symbols and that USGS Well no. 1 is shown separately (open triangles). Also shown is the conservative mixing line for ammonia nitrogen. The spread of points suggests no relationship of ammonia nitrogen with salinity. Because groundwater and ocean water have ammonia nitrogen at similar concentrations, a "flat" mixing line results. Points above the line suggest an input to the system.

denitrification) as the high nutrient groundwater passes through the sampled anchialine pool/fishpond systems. The relatively high concentration of nitrate and orthophosphate in the inland (undisturbed) well water appear to be a natural part of the West Hawaii coastal groundwater (see above).

Ammonia nitrogen or ammonium is the other form of dissolved inorganic nitrogen. Ammonium shows no relationship with the conservative mixing line (Figure 7). This is not unexpected in that the concentration of ammonium is about the same in both the inland groundwater and nearshore marine waters which results in a line with little or no slope. The lack of correlation in the concentration of ammonium nitrogen with salinity with many points falling above the conservative mixing line suggests *in situ* generation of this nutrient at KAHO. Ammonia nitrogen may be produced by biological activity and the production may be elevated in some of the anchialine pools and marine waters where biological activity is often high. Also as noted above, ammonia nitrogen may also be formed under anoxic conditions by the conversion of nitrate to ammonia. This process may be occurring with samples from USGS Well no. 1 (note the two points of elevated ammonia nitrogen in Figure 7 are from Well no. 1).

4.2.2. Compliance with Department of Health Water Quality Standards

The Hawaii State Department of Health has developed specific criteria for different classes of water in the state (e.g., as for harbors, streams and marine waters). The waters fronting the KAHO are classed as "open coastal waters" and are to remain "...in their natural pristine state with an absolute minimum of pollution or alteration of water quality from any human-caused source or action" (Hawaii Administrative Rules, Chapter 11-54-01). The most stringent standards have been set for open coastal waters. There are no standards set for anchialine pools, fishponds or coastal brackish water wells, thus the focus here is on the marine water samples collected during this study of KAHO.

As noted above there are ten marine sites and samples were collected on 6 occasions. The geometric means for the sampled parameters are given in Table 2 and the standards for open coastal waters are presented in Table 3. The standards are established on the basis of the volume of local freshwater input either as surface runoff or as groundwater. "Dry" conditions in the standards are defined as those coastal waters that receive less than three million gallons of freshwater discharge per day per shoreline mile and "wet" coastline are those with greater input. To our knowledge there are no estimates of groundwater efflux to the ocean at KAHO. At Waikoloa about 36 km north of KAHO early estimates (Kanehiro 1977) placed the groundwater efflux in the range of 0.97 to 3.97 million gallons of groundwater discharge per day per mile of shoreline. Recent estimates are higher; presently the groundwater discharge in the Waikoloa area is estimated to be in the range of 6 million gallons per day per shoreline mile (Tom Nance Water Resources Engineering, Honolulu, personal communication). An estimate of groundwater flow to the sea was made for a proposed development at O'oma (about 2.8km north of the KAHO).

This estimate was about 2 million gallons of groundwater discharge per shoreline mile per day (Nance 1991). Since the groundwater efflux is highly variable and site dependent, we have assumed that the more stringent "dry" standards apply to the marine samples in this study.

Inspection of Table 2 shows that none of the marine stations were in compliance for dry standards with respect to nitrate nitrogen and all but one station were out of compliance for ammonia nitrogen. Half of the sampling sites were out of dry standards compliance for total nitrogen and for the parameters of total phosphorus, turbidity and chlorophyll-*a*, some stations were out of compliance with the dry standards. Examination of marine water quality samples from coastal areas with little or no hinterland development (South Kohala, North Kona, South Kona, Lana'i, etc.) reveals that samples often do not meet state standards for open coastal waters. The usual reason for noncompliance with most nutrients is groundwater input; for ammonia nitrogen it may be related to the metabolism of the diverse biological communities in shallow waters. Thus for many localities the standards represent criteria imposed on natural systems that may never be in compliance. The Department of Health has recognized this problem and has initiated studies in which we are participating to determine if ecologically-based standards may replace the present absolute standards.

4.2.3. Pesticide and Heavy Metal Analyses

Sediment samples from three locations in Aimakapa'a Fishpond were examined for metals and pesticides. Aimakapa'a Fishpond was selected as the primary sample site for this aspect of the study due to (1) its proximity to the inland Kaloko Industrial area, and (2) because this pond appears to be a major sink for materials entering it. Two adult grey mullet or ama'ama (*Mugil cephalus*) and two milkfish or 'awa (*Chanos chanos*) were captured using a gill net in Aimakapa'a Fishpond on 18 March 1997 for pesticide/heavy metal accumulation in the tissues. The standard lengths of the mullet were 30 and 33cm; the standard lengths of the milkfish were 38 and 45cm respectively. Tissue samples were collected from the major organs (intestinal tract, liver, gonads and muscle) of each fish and samples for each species were combined as a single composite for analysis.

Sediment samples were first collected in March 1994 using a precleaned core and sample jars. Subsamples were taken from two depths in one core (surface and 9-13cm deep) and in the second, from three depths (surface, 9-13cm, and 15-19cm). One sample was taken close to the inland (mauka) bank of Aimakapa'a Fishpond and the second close to the seaward (makai) bank. These sediment samples were analyzed for metals and trace elements. In March 1997 an additional sediment sample was collected from the middle of the fishpond sampling the surface layer of the sediment. This sample was split and analyzed for both metals as well as pesticides. All samples were collected in precleaned containers and all were handled according to standard protocols.

Because the costs of analysis are relatively high, four pesticide screens were performed on the single midpond sediment sample and the two composite mullet and milkfish samples. These

TABLE 2. Summary of the geometric means of marine samples collected at ten sites on 6 occasions. The sample sites are divided into surface ("S") or bottom ("B") locations. In the body of the table are given the geometric means for each site combined through time. At the foot of the table are given the grand geometric means for all stations and sample dates combined. All data are in micromoles per liter (μM) unless otherwise noted. Underlined means exceed the Department of Health water quality standards for "Dry" coastlines.

Site	NO_3	NH_4	Total N	PO_4	Total P	Silica	S°/oo	Turb NTU	Chl-*a*	Temp °C	Oxy mg/l	pH
M-1-S	42.98	0.07	47.28	2.59	2.68	445.18	17.415	0.14	0.121	21.9	6.14	7.67
M-2-S	1.59	0.37	8.31	0.26	0.55	29.45	33.432	0.16	0.133	25.4	7.11	8.14
M-3-B	1.35	0.35	7.58	0.22	0.50	25.19	33.570	0.13	0.147	25.5	7.22	8.15
M-4-S	1.43	0.35	7.86	0.22	0.50	26.85	33.492	0.15	0.116	25.5	6.97	8.09
M-5-B	0.44	0.26	6.27	0.15	0.42	8.68	34.251	0.11	0.100	25.5	6.96	8.11
M-6-S	1.53	0.44	9.14	0.33	0.60	42.11	32.508	0.53	0.398	27.5	7.06	8.13
M-7-S	0.87	0.45	8.39	0.24	0.51	28.63	33.047	0.23	0.138	27.4	7.44	8.23
M-8-B	0.54	0.34	7.10	0.19	0.48	19.25	33.489	0.18	0.189	27.4	7.29	8.23
M-9-S	0.33	0.31	6.98	0.16	0.47	15.67	33.819	0.14	0.130	27.5	7.13	8.21
M-10-B	0.30	0.30	6.70	0.16	0.45	12.61	33.924	0.15	0.128	27.4	6.82	8.21
Grand Mean	1.09	0.30	8.81	0.26	0.57	27.20	31.693	0.17	0.148	26.1	7.02	8.12

TABLE 3. Specific criteria specified by the Department of Health water quality standards for open coastal waters as amended in 1988. Nutrient standards are presented in micromoles per liter (μM).

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value
Total Nitrogen (μM)	10.71* 7.85**	17.86* 12.86**	25.00* 17.86**
Ammonia Nitrogen (μM)	0.25* 0.14**	0.61* 0.36**	1.07* 0.64**
Nitrate + Nitrite (μM)	0.36* 0.25**	1.00* 0.71**	1.79* 1.43**
Total Phosphorus (μM)	0.65* 0.52**	1.29* 0.97**	1.94* 1.45**
Chlorophyll-*a* (μg/l)	0.30* 0.15**	0.90* 0.50**	1.75* 1.00**
Turbidity (NTU)	0.50* 0.20**	1.25* 0.50**	2.00* 1.00**

* "Wet" criteria apply when the open coastal waters receive more than three million gallons per day of fresh water discharge per shoreline mile.

** "Dry" criteria apply when the open coastal waters receive less than three million gallons per day of fresh water discharge per shoreline mile.

Applicable to both "Wet" and "Dry" conditions:

Salinity - shall not vary more than 10 percent from natural or seasonal changes considering hydrologic input and oceanographic factors.

Orthophosphate was eliminated from the list of requirements in the revised 1988 document but because of its biological importance, it was measured in this study. The old "wet" criterion was 0.23uM and the "dry" standard was 0.16uM.

screens were for chlorinated pesticides (screens for 26 compounds), organophosphate pesticides (looks for 21 compounds), volatile organic compounds (examines the sample for 53 compounds) and acid/base/neutral extractables which screens the sample for 59 different compounds. In total, these screens examined each sample for different 159 compounds. The results of these screens are presented in Appendix 4. In no case were any of these compounds detected in any of the three samples analyzed here at the limits of detection as given in the appendix.

Elemental analyses of the three sediment and two composite tissue samples are presented in Table 4. Also presented are the results from running a bovine standard with certified values from the National Institute of Science and Technology which was run alongside of the fish tissue samples to provide an indication of the precision of the laboratory analyses. Both the tissue and sediment data in Table 4 are reported as dry weights. Several points may be made regarding the elemental analysis for the sediment samples. First, there are large differences in the concentrations of most elements when comparing the March 1994 series of samples to the single March 1997 sample. All of these samples were taken from Aimakapa'a Fishpond and all sampled the pond sediment. Different analysts at the University of Hawaii performed the analyses and the differences may be related to this and the use of different equipment. At this point, we do not know why the single recent sample is so different. However in all of the sediment samples the dominant elements are calcium, magnesium and silica. In the March 1994 sediment samples these three elements account for 94.3% to 96.6% of the total weight of each sample; in the March 1997 sediment sample they account for 83.7% of the total weight supporting the contention that these sediments are biogenic in origin. The relatively high calcium values are related to the magnesium carbonate (aragonite) in the samples which is probably derived from carbonate production in the pond. Again these data suggest biological origin of much of the sequestered materials. In general, the concentration of iron increases with depth through a sample suggesting that much of the materials sampled in the pond are organic in origin. Copper has a uniform distribution through sample 1 suggesting that the form encountered here is organically complexed. Zinc is a good measure of anthropogenic contamination and in these samples is about 100 times less than commonly found in uncontaminated Hawaiian soils, again suggesting that much of the sampled material is organic in origin.

The proximity of an active volcano and the geologically young age of the West Hawaii lava are potential sources for the observed concentrations of some elements in the sediment samples analyzed in this study. It has been well-established that active volcanism is a source for atmospheric mercury (Siegel and Siegel 1987). During the 1977 volcanic event at Kilauea, Hawaii, mean measured total atmospheric mercury measured in proximity to a vent was $40{,}800 \pm 4{,}680$ ng/m^3. In the vicinity of these volcanic sources total fallout may be as high as 800 ug/m^2/day (Siegel and Siegel 1978). These volcanic sources may lead to bioaccumulation of mercury in tissues; pelagic billfish caught offshore of the West Hawaii coast (many kilometers distant from the volcanic sources) have total mercury accumulations from 0.29 to 13.45 ppm in various tissues (Shultz and Crear 1976). Thus the presence of mercury in the tissue samples from fish collected in Aimakapa'a Fishpond is not surprising and is probably related to inputs from natural volcanic sources.

TABLE 4. Summary of the metal analyses of two sediment samples collected in Aimakapa'a Fishpond in March 1994 (nos. 1 and 2), a single sediment sample collected in March 1997 (no. 3) as well as a mullet and a milkfish composite tissue samples collected in March 1997. Sample 1 was collected along the inland side of the pond in water about 70cm deep, sample 2 was collected along the ocean or makai side of the pond in water about 50cm deep and sample 3 was taken in the middle of the pond where the water depth is approximately 1m. Both the mullet and milkfish tissue samples are composites of livers, gonads, intestinal tract and muscle of two adult fish of each species. All values for sediments are given in mg/kg (dry weight); values for fish tissues and bovine standard are in µg/gm (dry weight) The limits of detection are given in µg/gm for sediment and fish tissue samples; the reference standards for the bovine tissue from the National Institute of Standards and Technology (NIST) are also given in µg/gm. Table continued on the next page.

SAMPLE DATE: March 1994

	Sample Number and Sediment Depth				
Element	**No.1: 2-6cm**	**No.1: 9-13cm**	**No.1: 15-19cm**	**No.2: 2-6cm**	**No.2: 9-13cm**
Fe	2104.01	3135.97	6242.80	2167.44	1998.23
Mn	130.45	195.77	239.43	138.10	131.33
Ba	1.26	2.78	11.41	2.30	0.79
Cu	50.50	51.24	41.24	41.72	44.95
Co	3.16	5.68	10.15	2.11	3.28
Ni	11.47	14.98	20.68	11.99	10.64
P	2203.95	1740.19	1227.25	1879.73	2071.81
Ca	16043.07	47734.45	69197.30	16255.79	15963.16
Mg	87526.80	84592.70	102040.95	55240.92	55701.25
Al	968.90	1607.26	5089.51	796.01	699.66
Si	41501.59	94018.74	91636.28	57015.15	85080.27
Sr	124.14	280.36	413.68	132.35	131.33
Ti	87.95	190.94	754.65	82.19	61.36
Zn	12.73	14.86	19.68	10.45	13.70
V	784.80	980.07	1729.93	765.32	866.09

TABLE 4. Continued.

SAMPLE DATE: March 1997

Element	Sediment Sample 3 2-6cm depth	Sediment Limits of Detection	Mullet Composite	Milkfish Composite	Tissue Limits of Detection	Bovine Reference Material	NIST Bovine Reference Standard
Fe	34300±4500	1.2	68±3.3	36.3±1.8	1.2	173±184	184
Mn	476±63	1.2	1.03±0.21	0.89±0.14	0.17	11±10.5	10.5
Ba	91±10	7.5	0.46±0.37	0.03±0.16	0.17	0.35	
Cu	50±3	4.7	4.95±0.72	2.52±0.43	0.6	141±160	160
Co	35±4	3.2	1.54±1.20	1.85±0.35	0.17	2.00±0.25	0.25
Ni	64±9	2.4	0.59±1.50	0.03±0.59	0.17	1.70	
Ca	211000±17000	11	465±21	740±121	1.2	121±116	116
Mg	38900±2800	0.3	1004±412	882±34	0.17	556±601	601
Al	25500±5800	15	0.20±4.80	1.22±7.48	0.6	1.80±3.00	3
Si	109000±4000	40	72±26	84±35	1.2	9.30	
Sr	1690±100	0.3	7.83±4.90	2.56±0.40	0.17	0.10±0.136	0.136
Ti	4890±680	2.0	0.29±0.35	0.24±0.12	0.17	0.20	
As	2.0	0.5	0.37	0.41	0.01	0.24±0.005	
Hg	>1.0	1.0	0.15	0.09	1.0	0.12±0.003	

Naturally occurring arsenic concentrations may be greater in insular volcanic and limestone soils than in continental settings. Kabata-Pendais and Pendais (1984) note that naturally occurring arsenic in sandy soils is in the range of 1 to 30 mg/kg, in soils overlying volcanic rocks it ranges from 2.1 to 11 mg/kg with a mean of 5.9 mg/kg, in soils overlying limestone arsenic will range from 1.5 to 21 mg/kg with a mean of 7.8 mg/kg and in basalts the range is from 0.6 to 2.0 mg/kg. Strontium has been reported at a naturally occurring concentration of 118 mg/kg in sandy soil and in food plants ranging from 10 to 1500 mg/kg. Manganese in sandy soils occurs in the range from 900-1000 mg/kg and mercury occurs in the range from 0.03 to 0.101 mg/kg in volcanic soils (all dry weights, Kabata-Pendais and Pendais 1984).

An analysis of trace elements naturally occurring in lava from Hawaii Island noted that barium occurs in the range from 57-186 mg/kg, mean = 120 mg/kg; copper = 43-86 mg/kg, mean = 55 mg/kg; cobalt = 23-47 mg/kg, mean = 39 mg/kg; nickel = 39-96 mg/kg, mean = 72 mg/kg and strontium = 188-507 mg/kg, mean 346 mg/kg (Tilling *et al.* 1987). Other than the biologically active strontium, these values are similar to those found in the sediment samples analyzed in this study. Major soil elements are often expressed as percent by weight. Soils from Kawaihae on the West Hawaii coast have the following characteristics: silica makes up to close to 15% of the weight of a soil sample, iron = 14%, aluminum = 8%, magnesium = 4%, titanium = 3%, calcium = 2.4% and manganese = 0.23% (Halbig *et al.* 1985). Other than calcium all of the percent by weight values for Kawaihae soils are similar in sediment sample no. 3 analyzed in this study (Table 4). The high calcium level is related to biological activity in the fishpond (e.g., calcium accretion).

At the limits of detection used in this study the metal analyses of the sediment and tissue samples do not suggest any unusual inputs to the groundwater and Aimakapa'a Fishpond from the inland area at this time.

4.3 Biological Characteristics of the Anchialine Resources at KAHO

As noted above, we have identified 82 pools and or pool complexes in this study. Eighteen of these pools are presently outside of the Park's boundaries and were sampled but six additional pools at the southern end of the Park were not sampled because of interference by area residents. Thus under the Park's present jurisdiction there are minimally 70 pools and/or pool complexes and at least 18 more ponds/complexes to the north that may, at some later point in time, come under the Park's jurisdiction.

This study did not exhaustively sample each water exposure in carrying the biological inventory, rather efforts were made to determine the relative degree of disturbance that has or has not occurred to each pool/pool complex. Undisturbed pools will have the usual complement of native species and disturbed pools will lose certain keystone species such as *Halocaridina rubra* (see above). Thus the presence of alien fishes signals the fact that hypogeal shrimp will not usually be diurnally present and that the ecological balance in the benthic community of the pond is or probably will be shifted to favor a few macrophyte algal species. Ponds containing alien fishes do not provide the habitat necessary for the hypogeal shrimp and many other anchialine species (amphipods, etc.) due to predation by the fish. In some instances under the cover of darkness hypogeal shrimp may emerge from the watertable into a pool inhabited by alien fish because the visual acuity of these predators is lessened at night. However, relegating feeding to the night hours only may not be enough to maintain the ecological balance in the benthic community of a pool. Similarly, there are some pools in which *H. rubra* may be found in very low abundance (i.e., only a few individuals/m^2) diurnally co-occurring with small guppies. An example is the Queen's Bath pool (no. 55). Unlike the occasional invasion of a pond by native marine fish, alien fishes are able to complete their lifecycles in the anchialine habitat making their presence a permanent threat to the native anchialine species and the integrity of the habitat.

Inventories of anchialine biota may be made at night when may cryptic species usually emerge into the pool to feed. No nocturnal inventories of the anchialine pools in the KAHO were done in this study. Because the degree of disturbance due to alien fish is high in the KAHO anchialine pools, creating an exhaustive list of species seen in a undisturbed pool is not warranted, especially when exotic fish are continuing to spread in the KAHO pools. We inventoried 82 pools and/or pool complexes and 64 were within the Park's boundaries. A summary of the biological characteristics of each is given in Appendix 2. As noted above, opae'ula or *Halocaridina rubra* are a usual component of biologically undisturbed anchialine systems in Hawaii. We used the presence of *H. rubra* as a first guideline in determining the status of the habitat. As of June 1997 there are 21 pools (or 33% of the total in the Park's boundaries) with *Halocaridina rubra* present. Only ten (or 16%) of these routinely have *H. rubra* present; the remainder may diurnally have shrimp present on occasion and when if so, their abundance is very low (i.e., >1 individual/0.1m^2). The reason(s) for this low abundance in these pools are not known. Thus, 67% of the anchialine pools inventoried in this study did not have the usual array of anchialine hypogeal species. The reason(s) for their absence may be many but obvious deterrents to their presence include predatory fish (both native and nonnative). Twenty-eight (or 44%) pools contained alien fish species that lowered the value of this habitat for the suite of important hypogeal species.

The alien fish problem is spreading in the KAHO anchialine system. There are several examples where at the initiation of this study, *H. rubra* was present in a given pond but by the end of the project alien fishes had colonized the pool and the shrimp were diurnally absent. For example, *Halocaridina rubra* was seen in pond no. 19 (a sinkhole near Kaloko Fishpond) on the first visit (March 1994) but by the second visit in August 1994, guppies (*Poecilia reticulata*) had colonized this pond and the shrimp absent. The anchialine shrimp/amphipod complex has continued to be absent up to the present time (June 1997). Chai (1991) reported Pond "G" to be the most biologically diverse of those he inventoried in 1990-91. This pond (no. 28 in this report) was found to be overrun by *Poecilia reticulata* in our surveys beginning in 1994. Perhaps the worst case example is with the complex of pools (nos. 69-74). These pools are probably indirectly connected to Aimakapa'a Fishpond. They are located in an open area surrounded by a thicket of hau and milo trees in a low pahoehoe flow north of Aimakapa'a Fishpond. There is considerable ground cover of *Sesuvium* and various sedges around these pools. These pools contained many anchialine species at relatively high abundance when first inventoried and were probably the best biological example of anchialine pools in the Park's boundaries during the early phase of our study. However, by July 1996 these ponds had been colonized by guppies; the shrimp and most amphipods were absent. It is surmised that this colonization took place during spring high tides probably in the late fall of 1995 or January 1996 which may have allowed guppies from Aimakapa'a Fishpond to reach these pools. Tides in January 1996 were in excess of 76cm.

The ecological shifts that may occur in the benthic community of an anchialine pool when the keystone herbivorous *Halocaridina rubra* are driven from the lighted portions of the pool by alien predatory fish were readily apparent in pond nos. 69-74. The preliminary surveys of this pool complex noted benthic communities that were dominated by a mix of the cyano-bacterial mat (the orange *Schizothrix* mat as well as *Rhizoclonium* sp.) and the vascular pondweed *Ruppia maritima* all of which are common elements in undisturbed anchialine pools. Following the colonization of these pools by guppies, the pools became filled with the green alga, *Cladophora* sp., which choked out most of the *Ruppia* and overtopped the *Schizothrix* causing its demise (see Figure 8A and B).

A second group of pools worthy of discussion are those clustered under and around the milo thicket located in an elongated mauka-makai depression near the ATV access road (see Map F, Appendix 1, pond nos. 46-54). Many of these pools have a number of marine fish species, many of which may have colonized these pools naturally during periods of high surf. Interestingly, some of these normally more marine species such as the yellowstripe goatfish or weke (*Mulloides flavolineatus*), have successfully survived in reduced salinities (mean = 12.6°/oo). Despite the presence of fish, these ponds have retained several unique anchialine features including the limpets or hihiwai-kai (*Theodoxus cariosus* and *T. neglectus*) and glass shrimp or 'opae (*Palaemon debilis*). These ponds are unique examples of anchialine pools that contain a mix of native marine species along with several anchialine species. Other than pond nos. 52 through 54, the pools of this group all have been colonized by alien fish (guppies). Despite this, the ecological balance in the benthic communities of these ponds appears to be intact.

The limpet or hihiwai-kai (*Theodoxus cariosus*) completes its lifecycle in the anchialine system, laying demersal egg masses on the hard substratum of ponds. These limpets may display considerable morphological and color variation. These morphs appear to be area-specific, that is, a single morph may be found only in one anchialine pond or series of ponds over a small geographical area, usually to the exclusion of any other morph. Thus this species may be undergoing the first steps in evolution towards a separate species. The hihiwai-kai is collected and consumed by some ethnic groups in Hawaii. In anchialine pools, it is conspicuous during high tides when it comes out of crevices to graze on the surfaces of rocks and easily collected. The population of hihiwai-kai was monitored in Pond 51 over the course of this study. Mean abundance of *T. cariosus* was 17 individuals/0.1m^2 prior to 23 March 1995. From that date forward, the mean abundance of this species had fallen to 2 individuals/0.1 m^2. It is suspected

FIGURE 8. Photographs of portions of the complex of pools north of Aimakapa'a Fishpond (nos. 69-74) located in a clearing surrounded by hau and milo trees. Photograph at the top of the page shows a small pool in the foreground (part of pond no. 71?) surrounded by grasses, sedges and *Sesuvium* and containing the cyano-bacterial or *Schizothrix/Rhizoclonium* mat (photo taken on 31 October 1994). Bottom photo (taken on 18 March 1997) shows an adjacent anchialine pool of this complex (no. 70?) following the colonization of these pools by guppies. The bottom photo was taken during low tide so the water in the pond is not obvious; what is apparent is a complete coverage of the pool's bottom and sides by *Cladophora* sp. that has blocked the sunlight and caused the demise of the anchialine benthic community.

that the majority of the population in this pool had been harvested for consumption (all probably at one time) because there was no evidence of "fresh" empty shells which would be indicative of natural mortality. Unfortunately, this population of *T. cariosus* was one of the few remaining that we are aware of on the West Hawaii coast.

Other anchialine pools with the usual complement of native aquatic species within the Park's boundaries include pond nos. 23, 25, 26, 27, 42, 43, 44, 53, 54, 56 and 81. In a number of other pools native anchialine species such as *H. rubra* occur but at low densities. Some of these presently low density pools may provide better habitat for hypogeal anchialine species with some restoration work as discussed below.

In summary, the biological resources of most anchialine pools under the jurisdiction of the KAHO have been impacted by the introduction of alien fish species and in a few cases, impacted by collecting for human consumption. If left unchecked, many anchialine species will become extremely rare or will disappear in the future from the KAHO.

4.4 Anchialine Resources Outside of the Park's Present Boundaries

There are a considerable number of anchialine resources in the pahoehoe lava fields around Wawahiwa'a Point north of the KAHO. These resources have been surveyed and mapped in the past as part of a proposed development of those lands; at least 67 anchialine pools were noted inland and to the north of the possible Park coastal boundary extension (OI Consultants, Inc. 1986). As noted previously, since many of the maps of the KAHO show a coastal boundary extension north along the coast to Wawahiwa'a Point, we surveyed some of the anchialine resources situated close to the coastline. This boundary extension as drawn appears to be about 90m (300 feet) wide thus our inventory efforts were focused in this narrow coastal area. We noted 18 anchialine pools in this area, the approximate locations of which are given in Figure 1 and Map nos. A and B in Appendix 1. The physical and biological characteristics of these pools are given in Appendix 2.

Several ponds in this northern area retain key anchialine biota and/or are excellent examples of pools as used in the old Hawaiian culture. Pond no. 1 was used as a growout pool for mullet, aholehole and milkfish. This pond was still being tended in 1972 when we first sampled it (Maciolek and Brock 1974). It subsequently has fallen into disrepair with pickleweed encroaching and *Cladophora* sp. filling much of the water column. This pool could be cleared and restocked if it was under the Park's jurisdiction. Perhaps the premier group of pools with the normal complement of anchialine biota found in this study are pond nos. 2 through 10. These ponds are worthy of protection and should be considered for inclusion in the Park. Pond nos. 11 and 12 lie relatively far inland (perhaps outside of the 90m boundary) but are good examples of anchialine pools having the normal complement of native species. In all probability, there are more small anchialine pools in the vicinity of nos. 11 and 12 hidden in the surrounding Christmas berry/kiawe thickets but inland of the boundary. Pond nos. 17 and 18 are also good examples of anchialine pools because they retain the usual suite of anchialine species. However, pond no. 18 is threatened by pollution and has a significant chance of being colonized by alien fish because it is located adjacent to a beach camp area used by campers. This pond is surrounded by *Scaevola* and at one point in time had an outhouse built of plywood over it so that camper's wastes would directly enter the pool. The outhouse is now gone but the probability of someone releasing guppies into this pool is high because of its proximity to the campsite.

4.5 Comparative Analysis of Biological Integrity of Pools Under the Park's Jurisdiction

Over the years there have been several inventories made of the anchialine resources in the Kaloko-Honokohau area. Reviewing the status of the biological resources of the pools through time provides a sense of the changes that may have occurred.

The earliest and probably the most useful (from the perspective of the present study) work was done by Maciolek and Brock (1974) in the summer of 1972. Since we are unable to unequivocally match the Maciolek and Brock (1974) pond numbers to those of the present survey, the biological data must be considered in aggregate. Discounting the six ponds at the south end of the Park which were not surveyed in this study due to interference by residents, Maciolek and Brock (1974) reported inventorying 24 anchialine pools within the present KAHO boundaries. Of these 24 pools, 18 or 75% contained the usual array of anchialine species that includes *Halocaridina rubra*. Three pools (or 12.5% of the total) were noted as having established populations of guppies (probably *Poecilia reticulata*). It is interesting to note that the guppy problem was just around Kaloko Fishpond and this species was not present around or in Aimakapa'a Fishpond.

In 1985, OI Consultants, Inc. (1985) resurveyed many of the Maciolek and Brock pools as well as some others. In the vicinity of Kaloko Fishpond they surveyed 18 ponds. At that time, they found 2 pools (or 11% of the total) with *Halocaridina rubra* and 12 pools with guppies (or 67% of the total). In the vicinity of Aimakapa'a Fishpond, they inventoried 14 pools and 3 or 21% of the total contained *Halocaridina rubra*. Apparently, none of the ponds surveyed at this time had been colonized by guppies but one pool was noted with tilapia (*Tilapia mossambica*). Fortunately, the tilapia have not been subsequently seen in any pool surveyed by us.

Chai (1991) monitored 12 anchialine pools in the vicinity of Kaloko Fishpond in 1990. At that time *Halocaridina rubra* occurred in 10 of the 12 pools but as Chai (1991) reported "...six of the ten pools had *Halocaridina rubra* appearing only at night and in limited numbers due to the presence of predatory fish (aholehole and guppies)." Thus diurnal observations (as done in all of the other surveys including the present study) found *Halocaridina rubra* present in 4 (or 33%) of the 12 pools. With respect to pools located south of Kaloko Fishpond, Chai (1991) noted that "At present, the southern pools are only minimally degraded. Collectively these pools provide an excellent array of physical and biological diversity." The situation has changed today with guppies being present in many of these pools.

For comparative purposes, the present survey found 64 pools/pool complexes in the Park boundaries and as noted above, 21 or 33% contained *Halocaridina rubra* but in only 10 or 16% of these was this species consistently present during daylight hours. Additionally guppies (probably all *Poecilia reticulata*) were encountered in 28 or 44% of these pools. In summary, the data suggest a progression of invasion by alien fish that have had a profound impact on the abundance of native anchialine species as well as on the entire ecological balance of these pools.

5.0 PROPOSED MANAGEMENT STRATEGIES

This study has not found any evidence of gross pollutant inputs to the coastal groundwater, anchialine pools, fishponds or nearshore marine environment in the KAHO. However, it has documented a significant decline in the abundance and diversity of hypogeal anchialine species due primarily to the introduction and spread of alien fishes. Without an active management program, we expect that many of the Park's once abundant anchialine resources to disappear or become extremely rare. The management program should meet the following objectives: (1) education of the public as to the biological, cultural and physical resources in the KAHO, (2) development of a plan to protect certain pools with high biological value and are presently at risk, (3) a physical and biological restoration program for selected pools and or complexes, (4) implementation of a program to incorporate anchialine resources presently not under the control of the KAHO, and (5) development of a program to monitor the status of the resources thus insuring the long-term integrity of the system.

Any increase in management activities requires a greater funding base. In these times of fiscal austerity, obtaining more funds is very difficult. This impediment is recognized and the suggested preliminary program below has attempted to keep costs in mind. However, without some proactive action, the anchialine resources of the KAHO may soon become a part of history thus negating some of the rationale for this Park. The components of this proposed management program are given below.

5.1 Educational Program and Cultural Use

Insofar as the anchialine resources of the KAHO are concerned, one could surmise that much of the biological degradation that has occurred would not have happened if a strong educational program was in place at the time the Park was established (1970's). The primary problem has been the introduction and spread of alien fishes. The proposed educational efforts should meet two objectives: (1) convey the message of resource protection and conservation (i.e., Do Not Release Aquatic Organisms Into Ponds) as well as (2) provide educational, cultural and interpretative opportunities to the public including native Hawaiians. Given the poor condition of the anchialine resources in the KAHO, these two objectives are somewhat at odds with one another. The old culture utilized the anchialine pools as sources of bait (opae'ula), drinking and bathing water as well as for the holding of some fish. These uses should be recognized in the educational context but probably should not be practiced given the poor condition of the resource.

Some of the anchialine pools offer an excellent opportunity for interpretative exhibits, especially those ponds where remnants of their historic use may be evident. These unique features should be incorporated into an interpretative program. The interpretative program will use primarily passive techniques; these include signage at appropriate vantage points that describe the natural and historic features of interest. A brochure should be developed that outlines a self-guided tour through the Park as well as describes the scientific value and historic uses of anchialine pools.

Cultural use of the anchialine resources has until recently been overlooked in the management of these entities. As noted above, anchialine pools were used as sources of drinking water, for bathing, raising and holding of native fishes and as a source of bait. This exploitation occurred over generations and the resources survived. Today, we know little of the old management and use practices of anchialine pool resources. The Park's management plan should recognize a place for this exploitation and use. We suggest that after the resource base has been restored (i.e., pond basins restored and the populations of the primary species such as opae'ula have attained carrying capacity for the system) consideration should be given to limited and controlled use of the resources be allowed if *bona-fide* native individuals wanting to use this resource with aboriginal methods and materials are identified. If allowed to proceed, these activities should be carefully monitored to insure the integrity of the resources.

5.2 Protection of High Value Pools

As pointed out elsewhere, the alien fish problem continues to spread through the anchialine pools of the Park. The mode of colonization remains unknown but is either through natural recruitment or by active transport and release by humans into ponds. In all probability the spread of fish has been by a combination of the two mechanisms. Some pools/complexes that presently retain their native species should probably be afforded some level of protection from the possible release of fish into them by humans. This category also includes some pools that could be cleared of unwanted exotic fishes (see below) and once so cleared, may be given the same level of protection.

Some of these "high biological value" pools are probably isolated enough that they will probably not be disturbed under the present conditions. One example is pond no. 23 that is relatively distant from other anchialine pools and is situated in a thicket of kiawe. However, other biologically important pools such as the Queen's bath (pond no. 55) are readily accessible to people who use it for bathing purposes and do release fish into it. Access to this pond should be controlled and without someone continuously monitoring the pool, which is prohibitively expensive, a fence may one of the few available methods available. Perhaps signage will suffice.

High value pools are those that have (1) the usual array of native anchialine species, (2) those with unique assemblages of euryhaline and/or marine species, or (3) those with unique cultural features. Assessment of most cultural features should be made by someone with a strong background in archaeology. In this analysis, we only point out that certain pools appear to have interesting cultural modifications. However, it should be noted that any archaeologist assessing the cultural importance of modifications made to pools should be aware that these modifications may not be at all old. Over the years we have encountered individuals on the West Hawaii coast who claimed to have made modifications to specific pools for their use and that prior to their modifications, there were none present.

In their present state, some pools may be considered not to have much value as examples of biological diversity or cultural modifications but with some restoration work they could be excellent examples. Table 5 presents a summary of the status of the pools examined in this study and assigns a value to each. These "values" are "high", "intermediate", and "low" and are based on the relative suitability of the habitat for anchialine species, the degree or extent of cultural modifications, and the geological setting of each pool. It should be noted that assigning an arbitrary value to a pool is just that; it may be argued that all water exposures in the KAHO have value. The values we have assigned to these pools and/or complexes are subjective and are based on our best judgement that incorporates more than 27 years of experience of studying this resource. If financial resources are limited, priority should be given to ponds or complexes that will yield the greatest return for the funds spent. In summary considering all 82 pools and/or pool complexes, 19 ponds (or 23% of the total) are considered to be high value needing little restoration work, 16 or 20% need some restoration first but would be considered as high value pools, 14 or 17% have an intermediate value without any work and 9 or 11% will need some restoration efforts to have an intermediate value. There are 24 low value pools (or 29% of the total). If we focus on the 64 pools/pool complexes situated within the Park's present boundaries, there are 8 pools (13%) considered to be high value and needing little restoration, 15 pools or 23% requiring some restoration work before being considered as high value, 12 pools or 19% are intermediate in value and not requiring restoration, 9 pools or 14% needing restoration work to be considered as intermediate in value and 20 pools or 31% are considered to be low value.

5.3 Proposed Restoration Activities

In geological terms, anchialine pools are ephemeral and relatively short-lived. Ponds may be created by a lava flow only to be buried by the next flow that may occur within weeks to periods exceeding a century or more. Pools created close to the ocean may be buried by coral rubble and sand carried onshore during high wave events (i.e., periods of storm surf) or they may be uncovered. Anchialine pools also undergo a natural senescence over time changing from a barren rocky basin to pools with encroaching vegetation. Leaf litter will speed up the senescence process such that pools in dated historic lava flows may become marshes within 100 to 150

TABLE 5. Summary of the biological and cultural status in anchialine pools examined in this study with some suggestions as to needed restoration work. Pools are rated as high, intermediate or low in value.

Pond No.	Remarks
Outside of Present Park Boundaries:	
1	Good example of a fish grow-out pond used up to recent times. Requires clearing of pickleweed and some sediment removal. With clearing and maintenance, a high value pond showing cultural use.
2-10	Prime example of a complex of anchialine pools with normal suite of species. High biological value. High value pool complex.
11-12	Good examples of anchialine pools with usual suite of species. Intermediate value.
13-14	Heavy overgrowth of pickleweed and kiawe. Low value.
15	Good examples of a "cave" pond; biota sparse. Low value.
16	Heavy overgrowth of pickleweed and kiawe, recommend clearing and sediment removal. Low value.
17-18	Good examples of anchialine pools with usual complement of species. These pools need to be protected from the possible introduction of alien fish because of their close proximity to campers and fishermen. High value.
Inside of Present Park Boundaries:	
19	Anchialine pool at the bottom of a sinkhole. Candidate for alien fish and sediment removal. Once cleared, high value.
20	Leave as is. Low value.
21	Good example of an anchialine pool with interesting geological features. May be a candidate for alien fish removal. High value.
22	Leave as is. Low value.
23	Excellent example of an anchialine pool with normal biota. High value.

TABLE 5. Continued.

Pond No.	Remarks
24	Leave as is. Low value.
25-27	Good examples of anchialine pools situated in a'a with usual biota. Need signage to keep alien fish from being introduced. High value.
28	Excellent example of an anchialine pool. This pool is a strong candidate for alien fish removal. Encroaching Christmas berry needs to be removed. Once restored, high value.
29-36	This series of pools provides an example of anchialine pools situated in a mauka-makai a'a crack. Some pools need to be cleared of loose a'a pushed into them by a bulldozer in the early 1970's. Intermediate value; habitat supports a low diversity of anchialine species.
37-40	Shallow basins in a'a with little water; minimal anchialine habitat. Intermediate value.
41-45	Reasonable examples of pools with some cultural modifications and native biota. Some restoration work needed (i.e., removal of fallen rock, etc). High value.
46-51	Excellent examples of ponds colonized by marine and euryhaline species. These pools need some sediment removal and vegetation (milo and Christmas berry) cut back. Signage needed to reduce the harvest of hihiwai-kai. High value.
52	Good example of an anchialine pool; needs no restoration work. High value.
53-54	Good examples of pools with cultural modifications and native biota. The proximity of these pools to the ATV road/trail increases the probability of alien fish introductions. At a minimum, signage is needed. High value.
55	Excellent example of a pool with cultural modifications. This pond is a good candidate for alien fish removal due to its isolation from alien fish sources. Once completed, entry into the water and bathing should be curtailed; signage needed to reduce the chance of alien fish reintroduction. High value.
56	Example of an undisturbed anchialine pool in a'a. This pool is relatively isolated and should probably be left that way. High value.

TABLE 5. Continued.

Pond No.	Remarks
57-64	Biota in these anchialine pools is sparse for no obvious reason. Some clearing of exotic vegetation and removal of loose rock material in some pools may enhance their attractiveness to anchialine species by having water present through all tide cycles. Intermediate value.
65-68	These pools are badly degraded and probably interconnect to Aimakapa'a at high tide (a continuing source of alien fish). Removal of encroaching pickleweed and accumulating trash from the ocean recommended. Low value.
69-74	Because of the interconnection of these pools with Aimakapa'a at high tides, removal of alien fish not recommended. Suggest these pools be left as is. Low value.
75-81	Because of the interconnection of these pools with Aimakapa'a at high tides, removal of alien fish not recommended. Suggest removal of encroaching pickleweed and kiawe overhead. Pond 75 has a good example of cultural modification (walling). We suspect that once pickleweed is removed, it will be evident that several pools in this group were modified and used for the holding of fish. Low value for anchialine species but high value as an example of cultural modifications.
82	Suggest removal of the Christmas berry overhead and sediment from this pool. This pond is a candidate for alien fish removal due to its isolation. Intermediate value.

years. Other pools in prehistoric flows may remain essentially unchanged for hundreds of years. Anchialine species have evolved with this fluctuation in the availability of habitat. Thus these species are usually capable of rapidly colonizing a newly formed habitat and many species have the ability to survive in the subterranean watertable until appropriate habitat again becomes available. These characteristics have allowed many hypogeal anchialine to survive and are important considerations in the restoration of these resources.

Studies of the human-made anchialine pools at Waikoloa have demonstrated the rapidity at which anchialine organisms will colonize newly created habitat (Brock and Kam 1990). The ability of rapid colonization and formation of stable aquatic communities suggests that pool creation is a viable tool in anchialine pond management; creation of new anchialine water exposures allows the resource manager the opportunity to enhance the populations of many anchialine species by providing additional appropriate habitat. Similarly, anchialine species are very tolerant of physical modifications to anchialine pools. Thus the removal of material from the bottoms of pools to increase depth and water exchange as well as removal of encroaching vegetation improves the habitat for anchialine species and slows senescence. These techniques were practiced in the old Hawaiian culture. The ephemeral nature of the anchialine habitat and the ability to rapidly colonize appropriate habitat set the restoration and management of anchialine resources apart from many other native ecosystems. These attributes may allow the resource manager the possibility improving a resource that is rapidly disappearing.

5.3.1 Alien Fish Removal

With the colonization of many anchialine pools under the park's jurisdiction by alien fishes, much of this habitat has been lost to native anchialine species. These species still exist in the watertable below these pools but access by these species to the lighted, high-productivity part of the system has been severely curtailed because of the presence of these predators. In some cases removal of these unwanted alien fish species could be accomplished by use of rotenone. In relatively isolated pools, we have successfully removed alien fishes and have had the native anchialine shrimp reappear in the pools within hours from the completion of the fish eradication. Removal of alien fish from a pool must be complete; in no instance can a single ovigerous female guppy remain if the program is to be successful. Any remaining guppies serve to keep most shrimp out of the pool and the populations will soon increase to the pond's carrying capacity. Thus the use of biological controls on poecilid populations do not work because (1) there are always some fish remaining and (2) any predator placed in the pools to feed on the guppies will prey on the hypogeal shrimp also.

An important aspect of the proposed management program is the elimination of unwanted poecilids in some of the more isolated anchialine pools under the Park's jurisdiction. This effort should restore these pools once again making the habitat available to native anchialine species. We have spent years grappling with the problem of removing alien fishes from anchialine pools.

The only viable alternative is the use of the ichthyocide, rotenone. Rotenone is a natural product (powdered derris root) that rapidly breaks down when exposed to the elements (i.e., heat and sunlight). It is the active ingredient of "tomato dust" which is heavily used in agriculture. Our experience has been that the anchialine biota rapidly recolonize pools cleared of exotic fish. If ecological shifts have occurred in the benthic communities because of the alien fish, reversion to the original anchialine community may take a year or more to occur. Removal of exotic fish can only be successfully accomplished if the pool will not be recolonized by these exotics from elsewhere. Thus successful eradication requires that the target pool is relatively isolated which suggests that it was originally colonized by fish released directly into the pool. Additionally, eradication of fish has only been successful in smaller pools. It is very difficult to successfully spread the ichthyocide rapidly enough to expose all fish in a pool if the pool is very large (greater than $100m^2$). Exotic fish will actively avoid the ichthyocide, diving into the cracks and crevices of the substratum, which may allow them to survive. As a result, the technique should only be applied to smaller, well-isolated pools. Some candidate pools include nos. 19, 28, 55, and 82. If undertaken, someone familiar with the application of rotenone in anchialine pools should do this work.

5.3.2 Removal of Vegetation and Sediment

As noted above, the old Hawaiian culture would "improve" anchialine pools by removal of sediment and encroaching vegetation. These activities cause a transient impact to the aquatic biota during the period of time that they are occurring. However, these impacts are minor relative to the benefits incurred by these activities. Removal of sediment and emergent vegetation will improve the exchange of water in the pond and allow hypogeal better access to and from the watertable below the pool. This activity will also slow down the natural process of infilling (i.e., pond senescence), allow more light to reach the pond's surface thereby improving primary production and expose more of the hard substratum of the pool for the recruitment of the usual array of anchialine benthic species.

The removal of vegetation should probably be done by hand methods in most ponds. A problem species is pickleweed (*Batis maritima*) which is receiving attention of ecologists for its control in other Hawaiian brackish water pond systems. At this point removal by hand appears to be the temporary solution. Many of the anchialine pools under the Park's jurisdiction would benefit from a cutting back of the overstory of nonnative trees that presently block light. Removal of emergent vegetation in some pools is recommended with the acknowledgment that some species such as the makaloa (*Cyperus laevigatus*) is used in the Hawaiian culture. It is suggested that the growing of makaloa be undertaken in those pools and/or complexes where there is no solution for the removal of exotic fish (e.g., 13, 14, 16, 65-68, 69-74, 76-80). Consideration should be given to the complete removal of nonnative trees that are creating an overstory over anchialine pools. Just cutting these trees back does not solve the problem because they will just grow back.

Removal of sediment can be done by a combination of hand methods and the use of a small suction dredge. In some cases, small anchialine pools with very shallow rocky basins that "go dry" at low tides could have their basin depths increased by the simple removal of some of the loose rock material. This would allow access by hypogeal anchialine during all cycles of the tides. Other ponds have a considerable buildup of sedimentary material. These pools could be cleared by hand or dredge; consideration should be given to the placement of dredge spoils in areas where they will not create impacts. If a suction dredge is used and an additional source of water is needed for its operation, care must be given to the source of that water. There are examples where the spread of exotic fish from one pond to the next was inadvertently done by using water from a contaminated source. Again these activities should be undertaken with the guidance of personnel experienced in the anchialine pool biology. Some of the pools that may be candidates for removal of overstory include nos. 11-13, 16, 17, 21, 23, 28, 48-50, 59, 60, 63, 64, 75-82. Possible candidate pools for the removal of emergent and or encroaching vegetation include nos. 1, 13-16, 19, 28, 65-68, 69-81. There are a number of candidate pools for the removal of sediment. These include pond nos. 1, 13, 14, 16, 19, 48-50, 60, 63, 65-68, 76-82. It may be advisable to leave the sediment undisturbed in some pools for use in the growing of makaloa that requires a shallow pond usually with some overstory.

5.3.3 Development of New Anchialine Habitat

Pond no. 82 was created as a water source for dust control during the development of Queen Ka`ahamanu Highway in the early 1970's. When examined by Maciolek and Brock (1974) this isolated pool was habitat for the usual array of anchialine species. Today, it is filled with alien fish considerable fine sediment and a thick overstory of Christmas berry trees. This pond is an excellent candidate for the removal of alien fish, sediment and overstory. It may once again become a viable anchialine habitat.

Creation of new anchialine habitat is recommended for consideration in the overall management program of the KAHO. The rationale for creating new habitat is that a large proportion of the existing habitat has been irretrievably lost to alien fish in the last 25 years. As noted above, some of the more isolated pools may be cleared of the problem, but for the majority, this is not possible with the technology available today. Construction of new habitat could replace what has been lost and serve to sustain the important anchialine resources that are now rapidity disappearing at the KAHO. This construction could take place in areas well removed from sources of potential colonization by alien fish and in areas where the terrain has been previously disturbed by bulldozers, etc. One such area is in the vicinity of Pond nos. 25-33 where the a'a lava was partially leveled by the previous landowner and there is only one pool in the area (no. 28) with an alien fish problem. We recommend that Pond no. 28 is first cleared of alien fish prior to undertaking the development of more anchialine pools in the area. Even if no pools are constructed, the alien fish should be removed from Pond 28 because their presence threatens all of the existing 20 ponds in the near vicinity.

Pools should be constructed by digging a hole in the flattened a'a with a backhoe to about 30cm below mean low water. In this area it would mean removing from 40cm to 2m of overlying material. Individual ponds should be constructed to mimic nature, thus being anywhere from $2m^2$ to no more than about $25m^2$ in surface area. Pond basins should be left rugged, porous and irregular which is close to the natural situation. Construction should probably be undertaken in at least two phases where ten or so pools are dug and monitored to determine recruitment success prior to construction of additional pools in the area. Park managers may wish to find other areas for possible pool construction; if an alien fish problem arises, having all pools in close proximity to one another could be disastrous.

In summary, an education program promoting the concept of not releasing fish or other organisms in anchialine pools coupled with an effort to create new anchialine habitat well removed from pools with existing alien fish problems should assist in the perpetuation of anchialine resources in the KAHO. This, along with a program to eliminate alien fish in selected isolated pools should be a central part of the KAHO anchialine pool restoration program.

5.3.4 Acquisition of Additional Anchialine Resources

The aquatic resources in anchialine pools under the Park's jurisdiction have been severely impacted by the introduction and spread of alien fish over the last 25 years. North of the present Park boundary are a number of anchialine pools some of which have not been impacted by the exotic fish problem. South and inland of Wawahiwa'a Point are more than 28 anchialine pools, many of which are inland of the 300 foot boundary as marked on some KAHO maps. In total there are at least 67 identified anchialine pools around Wawahia'a Point in the Kohanaiki land parcel (OI Consultants, Inc. 1986). Brock (1985) has noted that the one point of commonality for all of the rarest hypogeal anchialine species is that they occur in pools with salinities above 12 to 15°/oo. The Wawahiwa'a Point pools were surveyed by OI Consultants, Inc. (1986); their study noted a mean salinity of 14°/oo which is considerably higher than the average for the West Hawaii Coast. Overall, mean salinity of West Hawaii anchialine pools is about 7°/oo. Thus the pools in the vicinity of Wawahiwa'a Point are unusual because of their relatively high salinities and could provide appropriate habitat for some of the rare hypogeal species. Any effort to expand the Park's boundaries in a north direction should attempt to include these pools which are among some of the best examples remaining on the West Hawaii coast.

As noted above, a conservative estimate is that there are about 600 anchialine pools in the Hawaiian Islands (Brock 1985). This study has identified 64 pools within the Park's boundaries and an additional 18 pools to the north along the coast. If the lands around Wawahiwa'a Point (i.e., the Kohanaiki parcel) were included in the KAHO, at least 149 anchialine pools would be under the Park's control. This would amount to about 25% of the state's known anchialine pool resources. Including the 64 anchialine pools in the KAHO, about 27% (or 162 ponds) of the statewide resource is presently under management programs that confer some degree of protection. Probably less than 5 pools are known in the Volcanoes National Park (here we estimate 5 pools), 25 pools are in the Hawaii State Natural Area Reserves System (i.e., 23 in Maui's Ahihi-Kinau Reserve and 3 in South Kona's Manuka Reserve) as well as 67 pools in the Waikoloa Anchialine Pond Preserve. If the 67 anchialine pools in the Kohanaiki parcel were also under the Park's jurisdiction, approximately 38% of the known resource would be afforded some level of protection.

However because of the invasion of alien fish, less than 10 percent of the Hawaiian anchialine resource has maintained its biological integrity. The largest group of biologically intact anchialine pools is at Waikoloa, which is surrounded by development. These pools have survived the alien fish threat due to an active management program carried out by the authors through the University of Hawaii.

The biological status of the 67 Kohanaiki anchialine pools is unknown. In 1972 Maciolek and Brock (1974) found no alien fish in the Kohanaiki anchialine pools. OI Consultants, Inc. (1986) note that both tilapia and guppies (Family Poecilidae) are present in 14 pools (or 21% of the total) but only in the most northern pools. Our limited observations in this study have found guppies also present in many of the southern pools. Despite the presence of alien fish the Kohanaiki anchialine pools are an important resource because of (1) their higher than usual salinities which is appropriate habitat for many rarer hypogeal species and (2) the relative isolation of many Kohanaiki pools from one another may improve the effectiveness of any contemplated alien fish eradication program.

With the acquisition of additional anchialine resources comes an important responsibility of resource protection. If these or any other anchialine resources were to be acquired by the U.S. National Park Service, we recommend that steps be immediately taken to (1) ascertain the status of the resources (i.e., extent of alien fish problems), (2) post signage or take other appropriate measures to curtail the further spread of any alien species in the newly ponds, and (3) include these pools in the management program herein. Because of the rapid declines that have occurred in the anchialine resources of the West Hawaii coast in the last 25 years, we strongly recommend that the U.S. National Park Service strive to acquire the lands and anchialine resources in the Kohanaiki parcel if it is or becomes available. It will only be through the concerted efforts of a governmental agency that these dwindling resources may be protected from further declines and perhaps, the habitats restored to their former status.

5.3.5 Management and Monitoring Program

The continuing development of the lands surrounding the Park may be a potential source of alteration/pollution to the groundwater that flows through the Park. This, plus the continuing threat to anchialine resources from the spread of alien fish are reasons for the proposed monitoring program as outlined here.

The restoration and maintenance of the anchialine resources under the KAHO jurisdiction will require the input of individual(s) with a strong background and understanding of anchialine pool chemistry and ecology. Without this assistance we believe that the resources and success of the program may be in question. Thus we recommend that the KAHO consider the part time services of a program manager with the appropriate background. The overall goal of the program manager will be to maintain and insure the environmental integrity of the anchialine resources in the KAHO. To achieve this goal, the program manager will meet the following objectives:

1. To assist in the development of a educational program including a brochure to be used in a self-guided tour of the Park and signage to curtail the intentional spread of alien species in the Park's anchialine pools;

2. To assist in the implementation of a program of alien fish removal in selected pools in the KAHO and to ascertain the effectiveness of this program;

3. To assist in the physical restoration (i.e., removal of vegetation and sediment) in selected anchialine pools in the Park;

4. To assist Park personnel in the development of new anchialine habitat and ascertain the effectiveness of this habitat in sustaining aquatic anchialine species;

5. To annually monitor the status and characteristics of water quality in selected pools of the Park thus insuring the integrity of groundwater quality;

6. To annually determine the status of the anchialine aquatic resources in the KAHO;

7. To develop an annual report on the status of the anchialine resources in the KAHO.

The Hawaiian Islands are the only state in the union that have anchialine resources and the KAHO is one of the few national parks where these resources can be viewed by the public. This fact in itself should be enough of an impetus to initiate a strong program to halt and reverse the loss of these precious anchialine resources.

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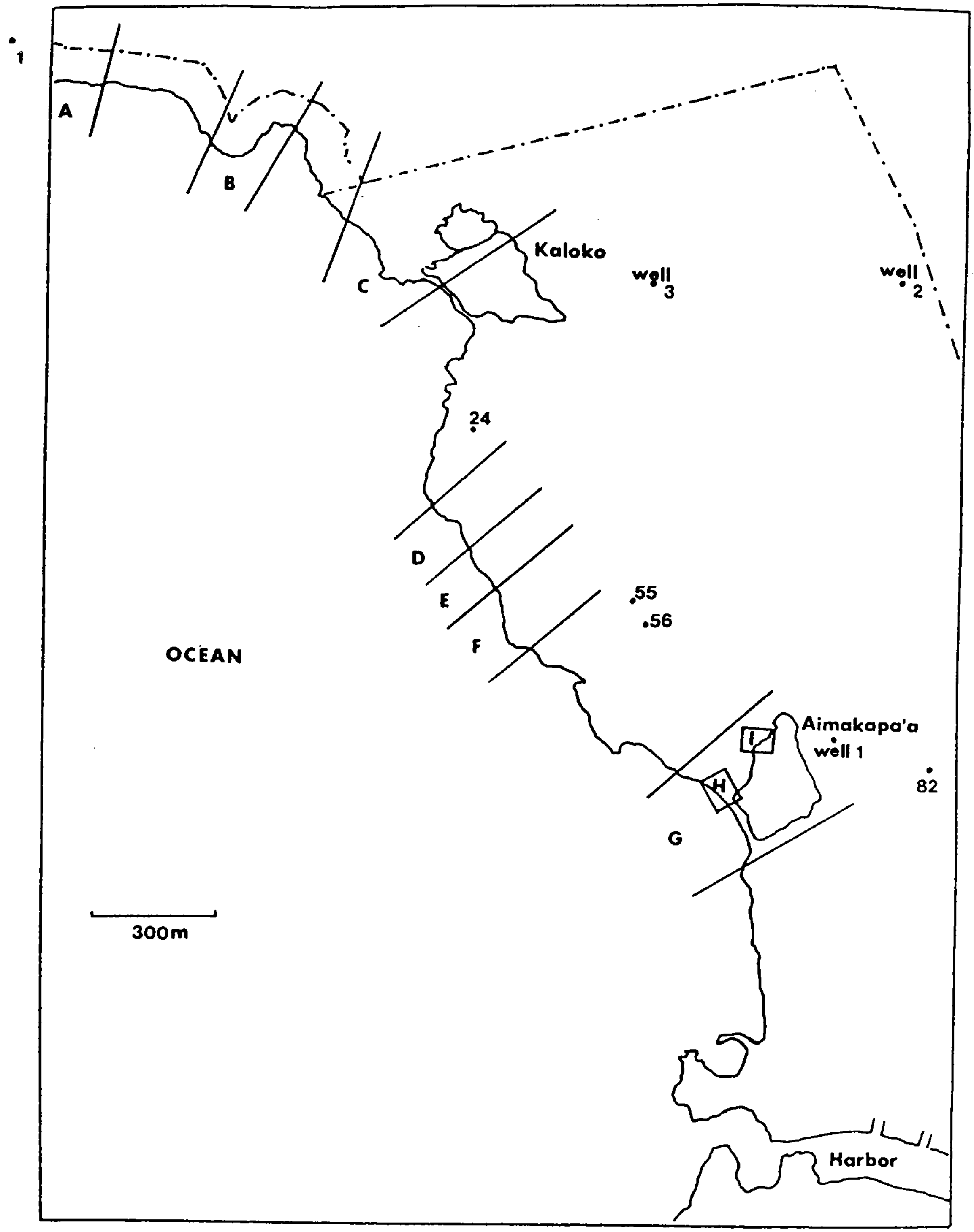
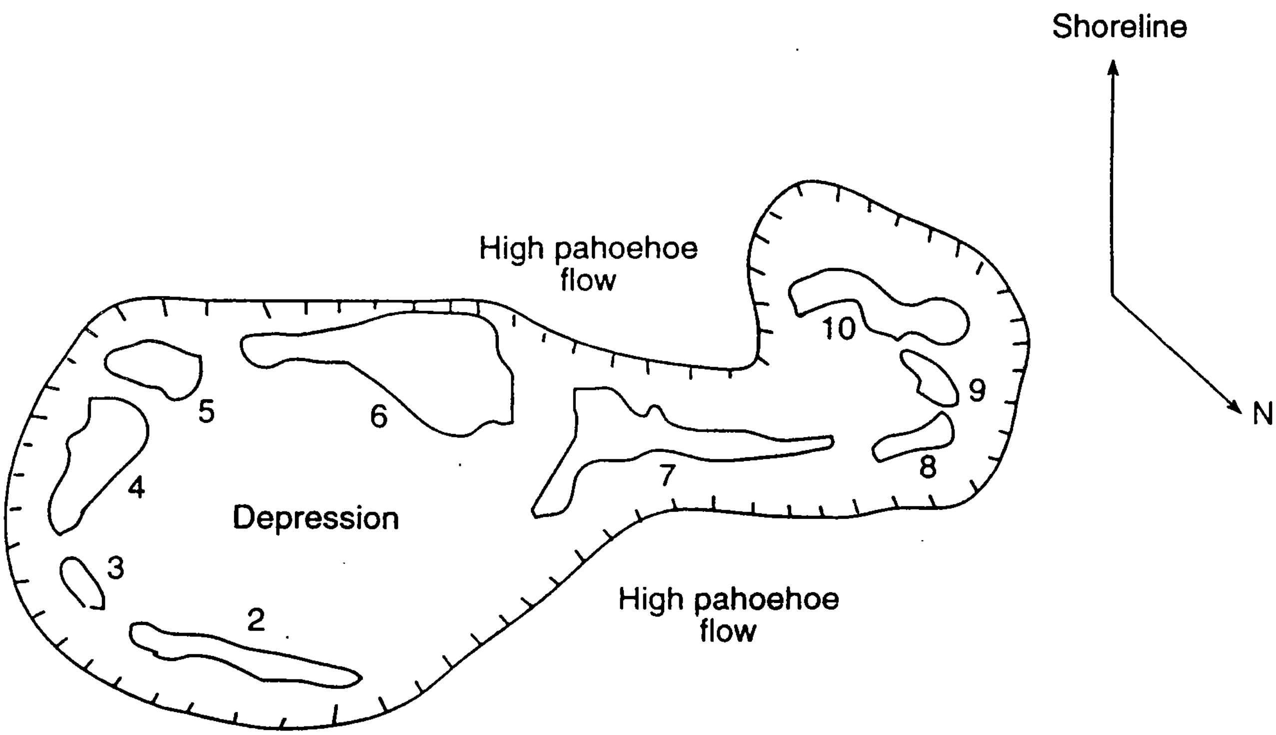
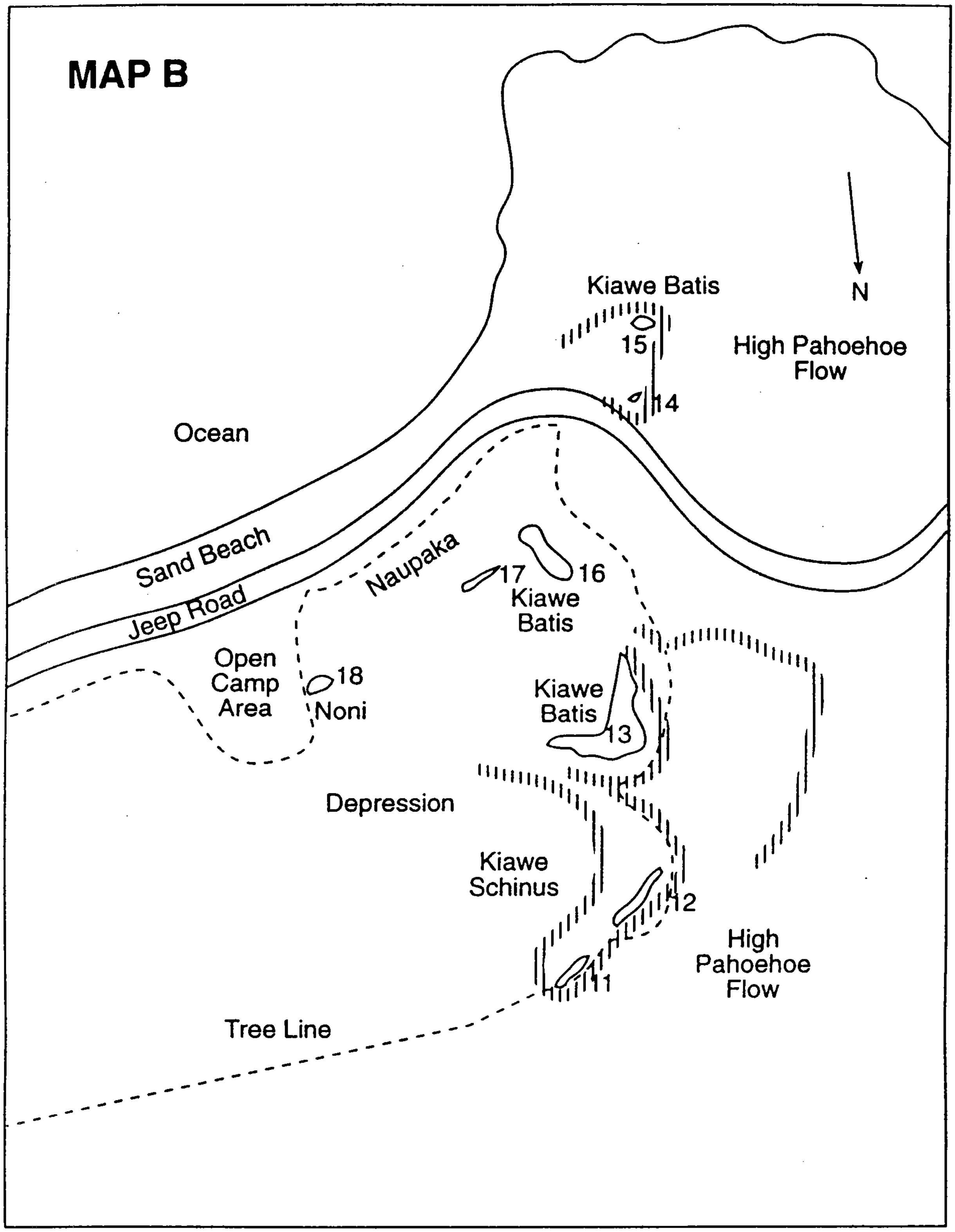


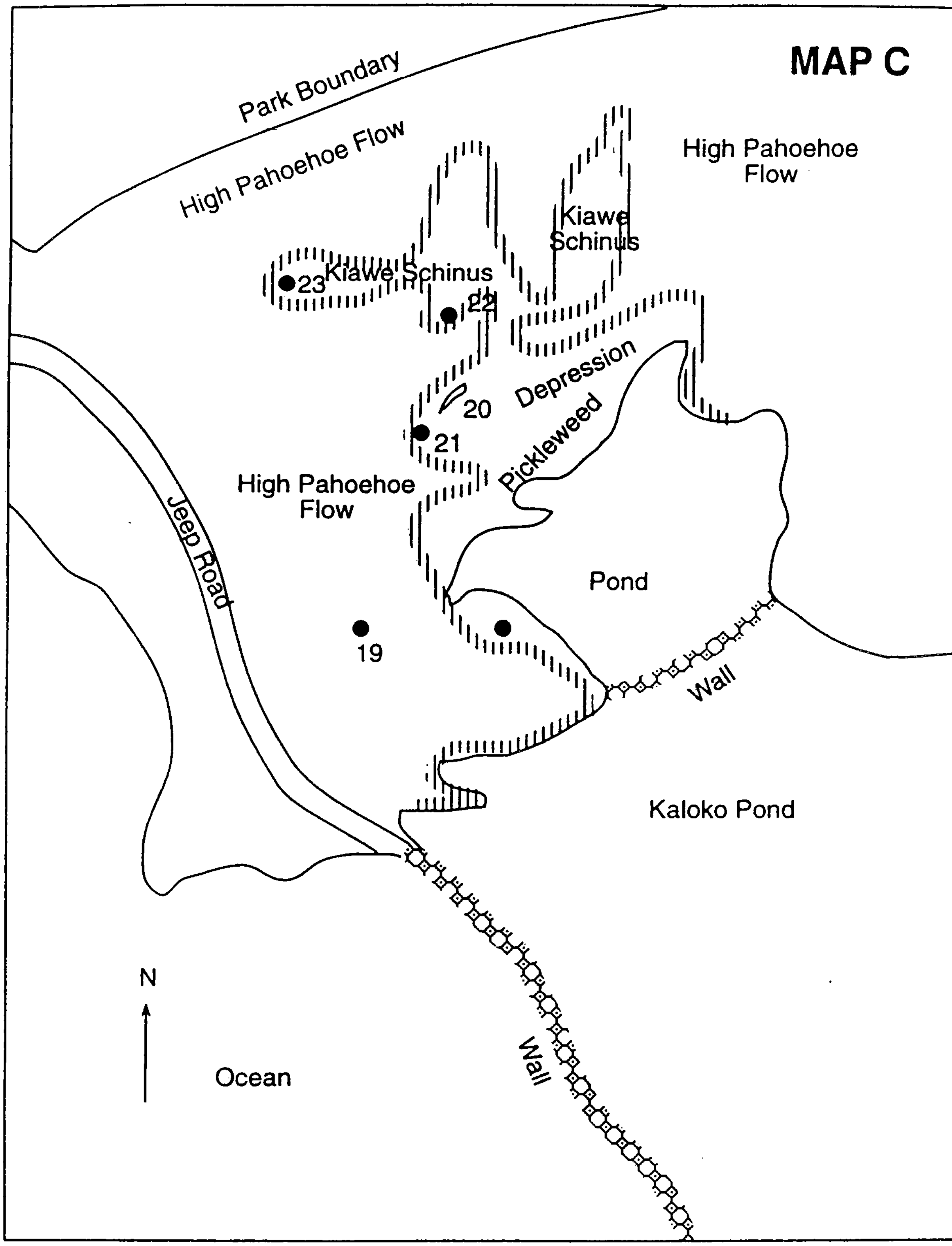
APPENDIX 1. Overview map showing locations of nine larger scale sectional maps along with these sectional maps, which indicate the approximate locations of sample, sites, anchialine ponds and other important features as mentioned in this study. Some of the anchialine pools that are located outside of the boundaries of the nine larger scale maps (A through I) are given on the first overview map and are shown with their assigned pond numbers. Note that none of the nine larger scale maps are drawn to scale.

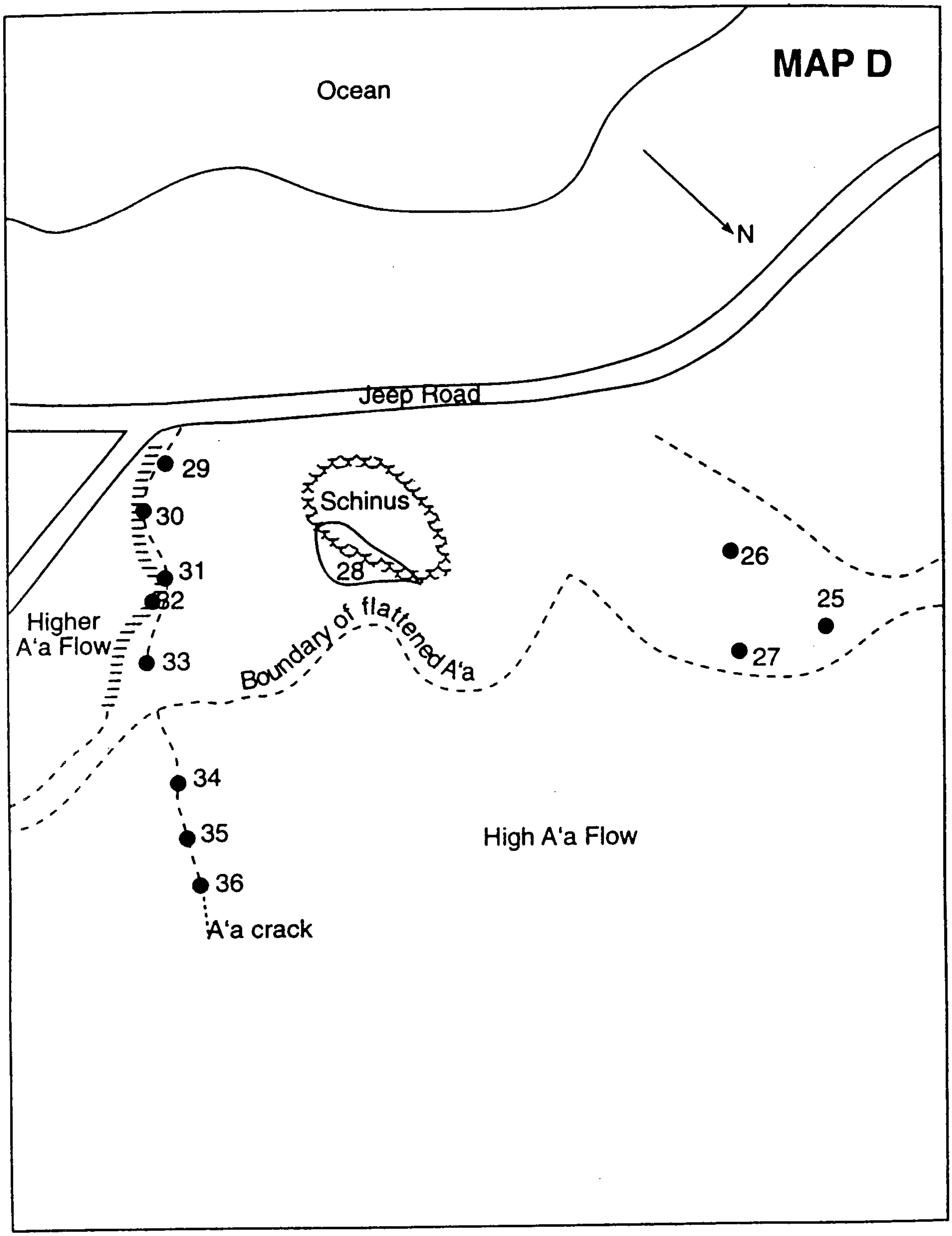
MAP A

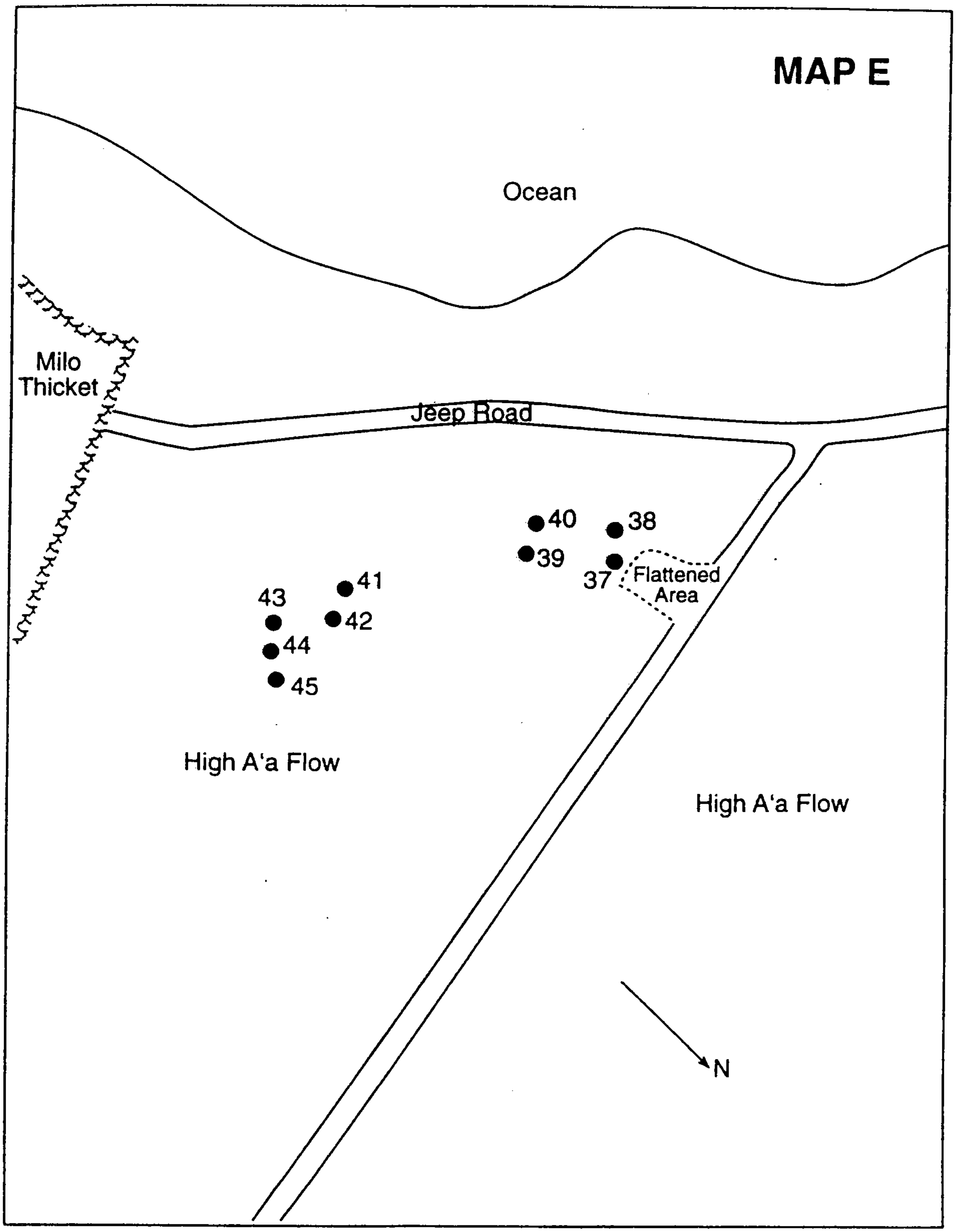

Shoreline
N
High pahoehoe flow
10
9
5
6
4
7
8
Depression
3
2
High pahoehoe flow

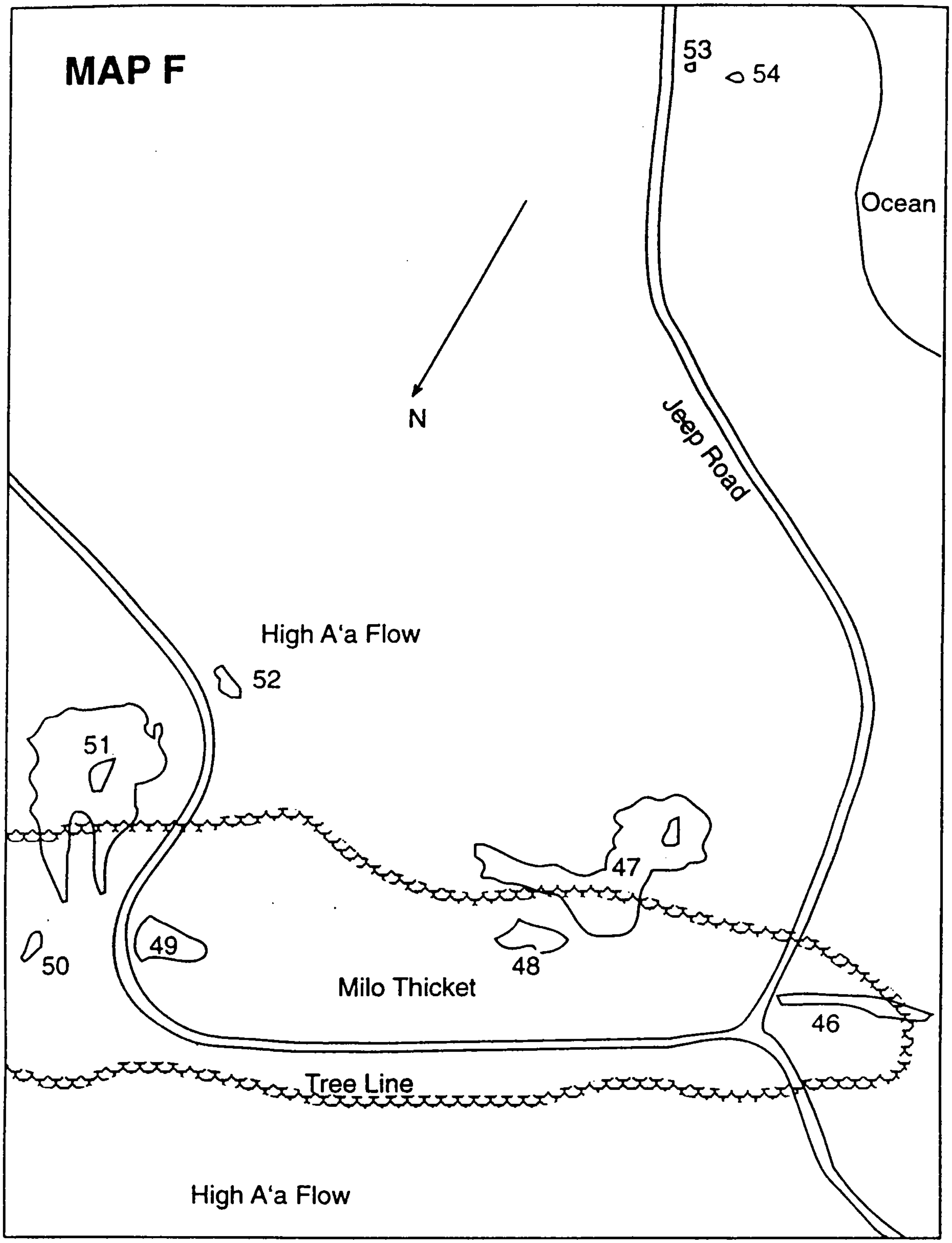
MAP B


Kiawe Batis
N
15
High Pahoehoe Flow
14
Ocean
Sand Beach
Jeep Road
Naupaka
17
16
Kiawe Batis
Open Camp Area
18
Noni
Kiawe Batis
13
Depression
Kiawe Schinus
12
High Pahoehoe Flow
11
Tree Line


MAP C
Park Boundary
High Pahoehoe Flow
High Pahoehoe Flow
Kiawe
Schinus
Kiawe Schinus
23
22
20
21
Depression
Pickleweed
High Pahoehoe Flow
Jeep Road
Pond
19
Wall
Kaloko Pond
N
Ocean
Wall

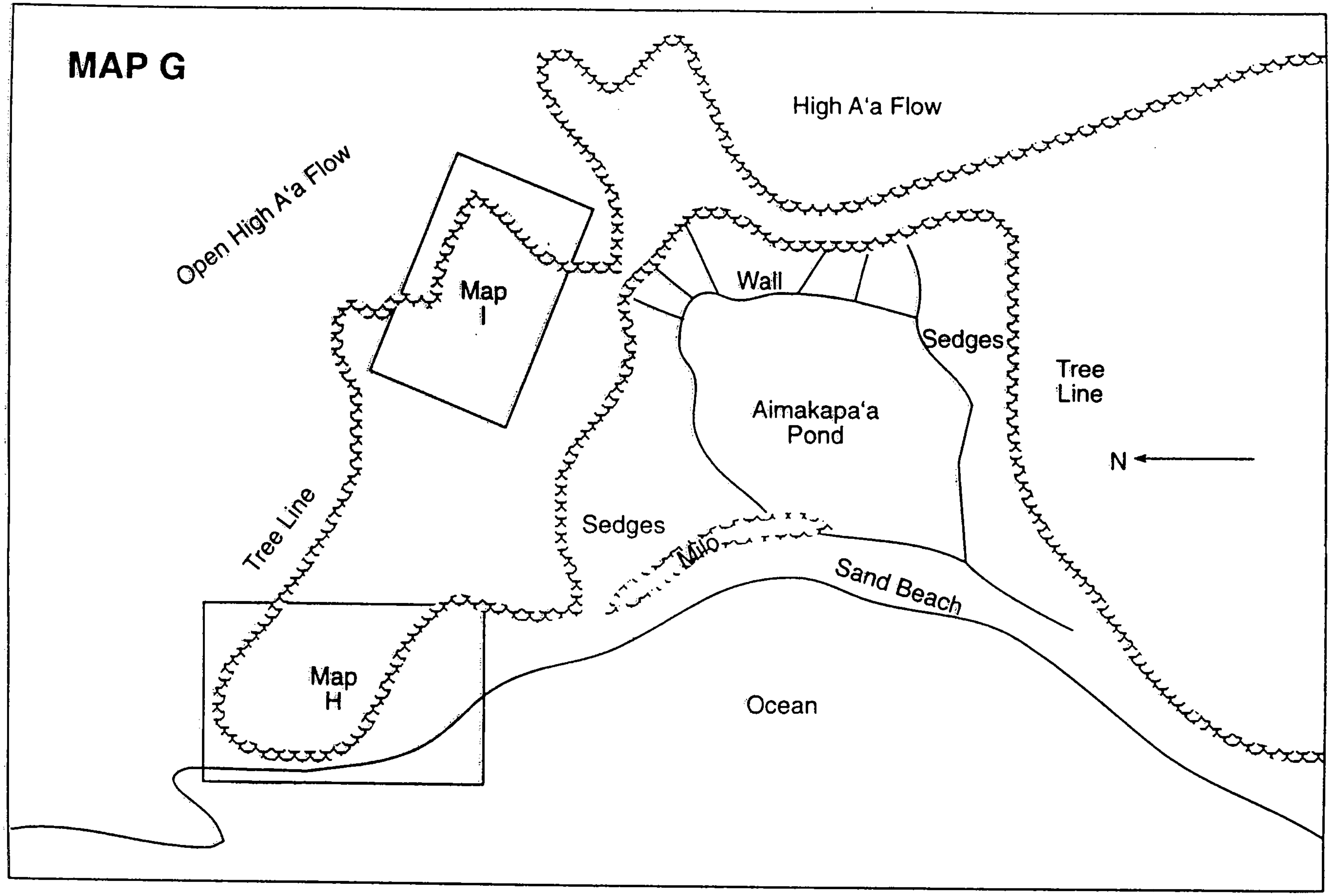

MAP D
Ocean
N
Jeep Road
Schinus
28
29
30
31
32
33
26
25
27
Higher A'a Flow
Boundary of flattened A'a
34
35
36
High A'a Flow
A'a crack


MAP E
Ocean
Milo
Thicket
Jeep Road
40
38
39
37
Flattened
Area
41
43
42
44
45
High A'a Flow
High A'a Flow
N

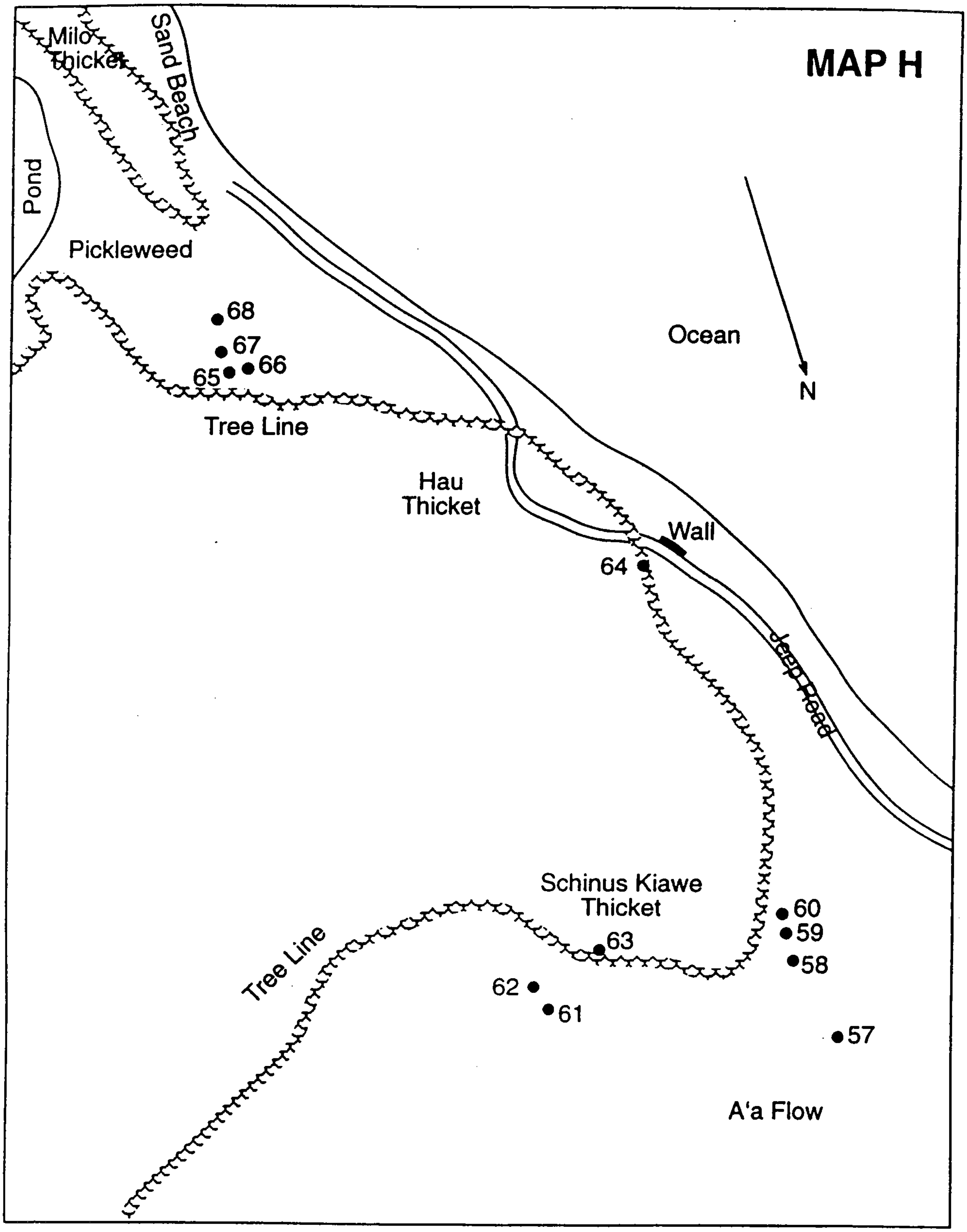


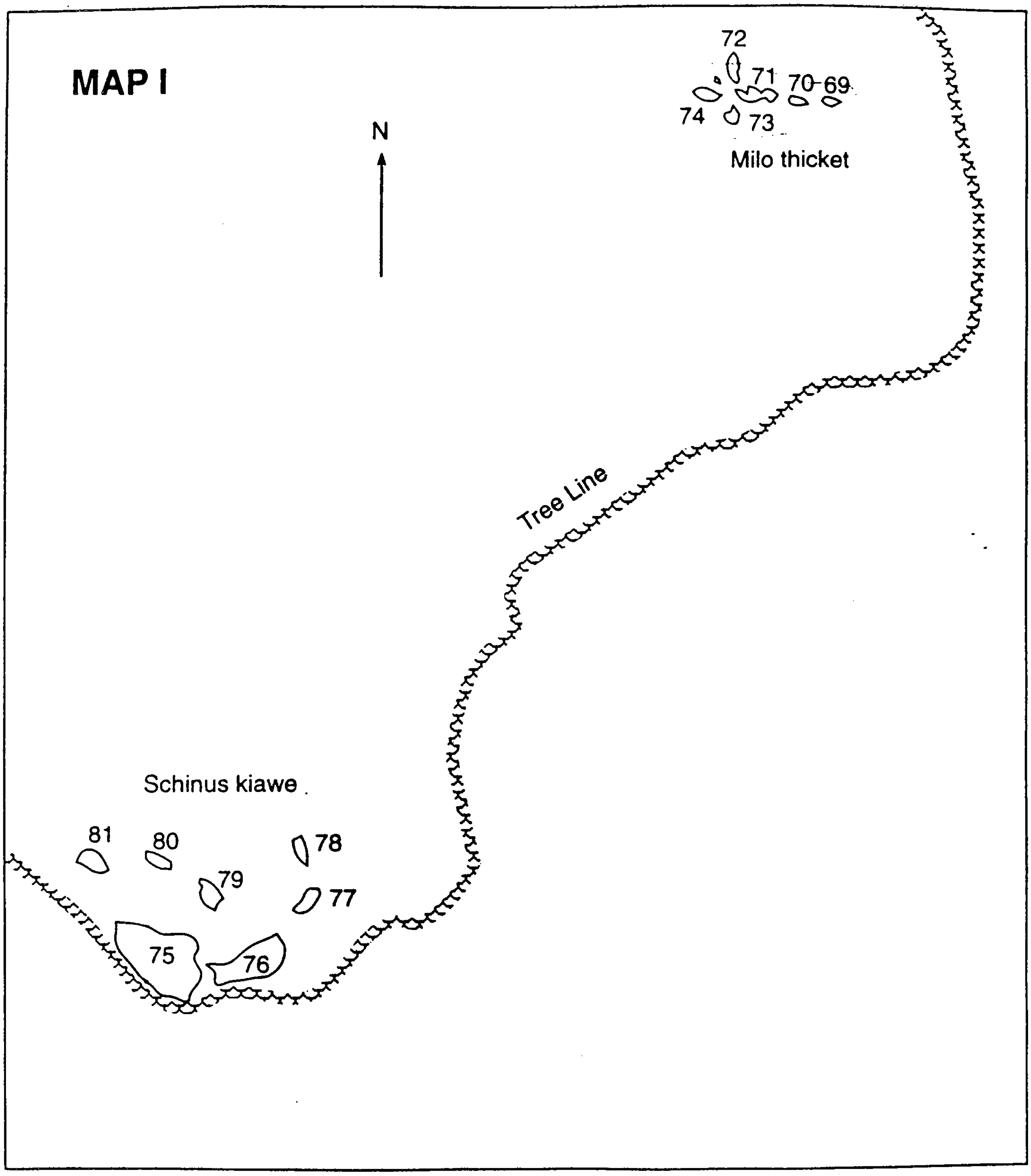
MAP F
N
Ocean
53
54
Jeep Road
High A'a Flow
52
51
47
49
50
48
Milo Thicket
46
Tree Line
High A'a Flow

MAP G



Open High A'a Flow
High A'a Flow
Map
I
Wall
Sedges
Tree
Line
Aimakapa'a
Pond
N
Tree Line
Sedges
Milo
Sand Beach
Map
H
Ocean


MAP H
Milo Thicket
Sand Beach
Pond
Pickleweed
Ocean
N
68
67
66
65
Tree Line
Hau Thicket
Wall
64
Jeep Road
Schinus Kiawe Thicket
60
59
58
63
Tree Line
62
61
57
A'a Flow


MAP I
N
72
71
70
69
74
73
Milo thicket
Tree Line
Schinus kiawe
81
80
78
79
77
75
76

APPENDIX 2. Summary of information on anchialine pools examined in this study. It should be noted that not all of the Park numbers could be completely matched with our numbering system. In the field it was often difficult to locate the Park's tags used to identify individual pools and the field notes taken by Park personnel did not always match our information.

Pond 1: See Figure 1. Location 19°41'64"N, 156°02'60W. This pool was routinely sampled in this study. This pond is situated in an old pahoehoe flow south of Wawahia'a Point just inland of the proposed Park boundary. The pond is about 20m across and no more than 0.5m in depth. The bottom is mud and Ruppia covered much of the pond in our early surveys but by July 1996 *Cladophora* had grown to cover almost the entire surface of this pool. *Batis* has encroached into the pond. In 1972, this pond was clear of most plant growth because an individual who stocked it with mullet cared it for. Biota today is dominated by dragonfly nymphs, guppies (probably *Poecilia reticulata*), tilapia (probably *Tilapia mossambica*), *Melania*, *Paleomon debilis*, *Metapograpsus messor*, aholehole (*Kuhlia sandvicensis*) and ama'ama or mullet (*Mugil cephalus*). On the first (3 March 1994) survey one dead duck (collected) and one sick individual were seen. On 23 March 1995 we also say several juvenile hinalea lauwili (*Thalassoma duperrey*) which suggests that fishermen or campers are releasing marine fish into this pool. Unusually low dissolved oxygen concentrations are encountered in this pond.

Pond 2: See Appendix 1, Map A. Location adjacent to 19°41'60"N, 156°02'52"W. One of nine pools (numbers 2 through 10) located in one large depression surrounded by a high pahoehoe flow. The shoreline is about 100m away and this group of pools is outside of the proposed Park boundary. Pond 2 is about 4.5m long and 0.5m wide, depth 10cm, pahoehoe basin. Surrounding vegetation includes *Pluchea, Schinus,* kiawe and fountain grass. Aquatic species seen include *Schizothrix, Metabeteus lohena, Halocaridina rubra, Melania, Assiminea,* and red amphipods. All pools in this complex are relatively undisturbed; only Pond 6 is routinely sampled. No Park number.

Pond 3: See Appendix 1, Map A. Location adjacent to 19°41'60"N, 156°02'52"W. This pond is in the same complex as nos. 2-10. Size 1.2m by 0.5m, depth 20cm. Pahoehoe basin. Same species as above. No Park number.

Pond 4: See Appendix 1, Map A. Location adjacent to 19°41'60"N, 156°02'52"W. This pond is in the same complex as nos. 2-10. Size 2m by 3m, depth 25cm. Pahoehoe basin. Same species as above. No Park number.

Pond 5: See Appendix 1, Map A. Location adjacent to 19°41'60"N, 156°02'52"W. This pond is in the same complex as nos. 2-10. Size 1.5m by 0.8m, depth 25cm. Pahoehoe basin, some sediment present. Same species as above. No Park number.

APPENDIX 2. Continued.

Pond 6: See Appendix 1, Map A. Location 19°41'60"N, 156°02'52"W. This pond serves as the routine sample point for the group (nos. 2-10). Size 9m by 4m, depth 35cm. Pahoehoe basin with *Schixothrix*, sediment and *Ruppia* covers about half of the substrate. Same species as above; *H. rubra* range in numbers from 50 to 127 individuals/0.1m^2. However it should be noted that two aholehole were encountered in this pool on 4 June 1996. From this point forward, the native shrimp have been absent from this pool but remain in the other pools of this group. Furthermore, following the appearance of the aholehole, the *Schizothrix* mat is being overgrown by *Cladophora*. No Park number.

Pond 7: See Appendix 1, Map A. Location adjacent to 19°41'60"N, 156°02'52"W. This pond is in the same complex as nos. 2-10. Size 12m by 4m, depth 20cm. Pahoehoe, sediment and *Schizothrix* basin. Same species as above. No Park number.

Pond 8: See Appendix 1, Map A. Location adjacent to 19°41'60"N, 156°02'52"W. This pond is in the same complex as nos. 2-10. Size 1.4m by 0.4m, depth 25cm. Pahoehoe and sediment basin. Same species as above. No Park number.

Pond 9: See Appendix 1, Map A. Location adjacent to 19°41'60"N, 156°02'52"W. This pond is in the same complex as nos. 2-10. Size 1m by 0.3m, depth 10cm. Pahoehoe basin. Same species as above. No Park number.

Pond 10: See Appendix 1, Map A. Location adjacent to 19°41'60"N, 156°02'52"W. This pond is in the same complex as nos. 2-10. Size 8m by 2m, depth 20cm. Pahoehoe, sediment and *Schizothrix* basin. Same species as above. *H. rubra* very abundant in this pool. No Park number.

Pond 11: See Appendix 1, Map B. Location adjacent to 19°41'51"N, 156°02'22"W. This pond is located in a depression at the base of a high pahoehoe flow and nearly covered by *Schinus*. This pool is part of a group (nos. 11-18). The pool is about 1.5m by 0.4m, depth 15cm. Pahoehoe basin. Aquatic species present include *Halocaridina rubra* (up to 80/0.1m^2), red and white amphipods. No Park number.

Pond 12: See Appendix 1, Map B. Location adjacent to 19°41'51"N, 156°02'22"W. This pond is part of the group (nos. 11-18). Size 3.5m by 0.6m, depth 25cm. Again at the base of a high pahoehoe flow nearly covered by *Pluchea* and *Schinus*. Pahoehoe basin. Aquatic species present include *Halocaridina rubra* up to 50/0.1m^2, and red amphipods present. No Park number.

Pond 13: See Appendix 1, Map B. Location 19°41'51"N, 156°02'22"W. This pond serves as a routine sampling point and is in the group (nos. 11-18). Basin is "L" shaped and size is 40m by 35m, depth 20cm at the deepest point. Basin bottom is mud and pond is badly overgrown by *Batis* with kiawe overstory. Surrounded on the inland and north sides by a high pahoehoe flow.

APPENDIX 2. Continued.

Aquatic organisms include *Melania* and *Ligia*. No other aquatic species seen. No Park number.

Pond 14: See Appendix 1, Map B. Location north and makai of 19°41'51"N, 156°02'22"W. This pond is in the group (nos. 11-18). Size 0.8m by 0.6m, depth 2cm. This pool only contains water on the highest of high tides and has a bottom of sand and mud covered by *Batis*. Only aquatic species seen include grey amphipods and *Ligia*. This pool is under a canopy of kiawe trees and is surrounded by a high pahoehoe flow on the inland and northern sides. It is no more than 10m north of the coastal jeep road. No Park number.

Pond 15: See Appendix 1, Map B. Location north and makai of 19°41'51"N, 156°02'22"W. This pond is in the group (nos. 11-18) and is routinely sampled.. Size 1.5m by 1m, depth 80cm. This pool is in a partial cave at the base of a high pahoehoe flow. Bottom is comprised of pahoehoe and some sediment. Overstory of kiawe trees. This pond is about 8-10m north and makai of Pond 14. Aquatic species sometimes seen include *Macrobrachium grandimanus* and *Palaemon debilis*. No Park number.

Pond 16: See Appendix 1, Map B. Location seaward of 19°41'51"N, 156°02'22"W. This pond is in the group (nos. 11-18). Size 25m by 2.5m, depth 5cm. This pond is heavily covered by *Batis* with a kiawe overstory and has a sand/mud substratum. It is located about 30m makai of Pond 13. At low tide the pond has no water. Aquatic species present include *Halocaridina rubra* in low numbers and white amphipods. No Park number.

Pond 17: See Appendix 1, Map B. Location seaward of 19°41'51"N, 156°02'22"W. This pool served as a routine sample site for this study. This pond is in the group (nos. 11-18). Size 3m by 1m, depth 25cm. This small pond is located along a low pahoehoe edge and has a sand bottom with a thick kiawe overstory. Aquatic species present include *Halocaridina rubra* (ranging between 4-200 individuals/0.1m^2), *Metabeteus lohena* (average abundance 1 individual/0.1m^2) and red and white amphipods. No Park number.

Pond 18: See Appendix 1, Map B. Location south of 19°41'51"N, 156°02'22"W. This pond is in the group (nos. 11-18). Size 5m by 6m, depth to 40cm. Along the makai side of this pond is some pahoehoe but otherwise the pool is in a sandy basin surrounded by naupaka and noni. Toilet facilities were setup over part of this pond probably because of the proximity of a camping/parking area. The pond is located about 50m inland of the shoreline. Aquatic species present include *Halocaridina rubra* in densities ranging from 42 to 107 individuals/0.1m^2 and *Metabeteus lohena* is present at densities of 3-8 individuals/0.1m^2. This pond was sampled for water quality on three occasions. No Park number.

Pond 19: See Appendix 1, Map C. Location 11°41'36"N, 156°02'10"W. This pond served as a routine sample site for pond nos. 19-23 and it is located at the bottom of a 6.5m diameter sinkhole in the surrounding pahoehoe. The pool is about 2 to 3.5m in length (depending on the tide) and up to 0.9m wide, with a depth of 8cm. The substratum is a mix of mud and sand. This sinkhole has been used in the past for trash and there is an overstory of *Pluchea*. Aquatic species seen include *Melania* and one *H. rubra* on the first (3 March 1994) visit but guppies (probably *Poecilia reticulata*) have been present (and no *H. rubra*) on every subsequent visit. Park numbers P-003, 24.

Pond 20: See Appendix 1, Map C. Location mauka and north of 11°41'36"N, 156°02'10"W. This pond is located at the base of a high pahoehoe flow and is about 2.5m long, 0.5m wide and 10cm deep. The substratum is pahoehoe. This pool is close to a honeybee nest in a nearby pahoehoe crack. It is overrun by guppies (probably *Poecilia reticulata*). Other aquatic biota seen include *Ligia, Melania* and dragonfly nymphs. No Park number ?

Pond 21: See Appendix 1, Map C. Location mauka and north of 11°41'36"N, 156°02'10"W. This pond is located at the base of a high pahoehoe flow and is about 2.5m in diameter and partially forms a small cave. Pool depth is about 40cm with a pahoehoe and mud substratum. This pool is about 15m makai of Pond 20 and is both south and makai of the honeybee nest. A large *Schinus* tree covers most of the pool. It is overrun by guppies (probably *Poecilia reticulata*). Other aquatic biota seen include *Ligia, Melania* and dragonfly nymphs. Park numbers P-002, 19.

Pond 22: See Appendix 1, Map C. Location mauka and north of 11°41'36"N, 156°02'10"W. This pond is located at the base of a high pahoehoe flow that forms a partial overhang or cave. The pond is about 3.5m long, 2.5m wide and 60cm deep. The substratum is pahoehoe and mud in the deeper parts of the pool. This pool is overrun by guppies (probably *Poecilia reticulata*). Other aquatic biota seen include *Melania, Theodoxus cariosa* and dragonfly nymphs. Park numbers P-001, 18.

Pond 23: See Appendix 1, Map C. Location mauka and north of 11°41'36"N, 156°02'10"W. This pond is located at the base of a high pahoehoe flow and is completely covered by kiawe and *Schinus*. The size of the pool is about 1.2m long by 1m at the widest point. Maximum depth is about 50cm. The substratum is pahoehoe with some mud in the deeper parts of the pond. This pool is the only one in this group of ponds to have a complement of native aquatic species. *Halocaridina rubra* is very abundant occurring at a mean estimated density of 110 individuals/0.1m^2, *Metabeteus lohena* at a estimated density of 3 individuals/0.1m^2, and abundant red and white amphipods were also present. This pond is located about 50 mauka of the coastal jeep road and we believe that it had not been previously sampled in earlier studies. No Park number.

APPENDIX 2. Continued.

NOTE: There are numerous "ponds" present in the pickleweed and low-lying pahoehoe adjacent to the north end of Kaloko Fishpond. One of these was noted in the Park's numerical classification as pool P-004 or 23. These "pools" completely interconnect to the fishpond's waters at high tide (through the pickleweed) and the biota of all of them is dominated by nonnative fish that have driven native anchialine crustaceans from the system. We have ignored these "pools" in this study of anchialine resources because of their close association (surface water connection) with the fishpond and lack of anchialine biota.

Pond 24: See Figure 1, text. Location 19°41'07"N, 156°01'98"W. This pond is in a depression in the floor of an apparent cave living site that only contains water on the highest of high tides. Because of the lack of regular presence of water, we did not select this site for routine sampling. We did not find adequate water during our visits to this location to find any aquatic fauna except for white amphipods. If cleared of debris, this depression may be a suitable habitat for hypogeal shrimp. Not numbered by Park survey.

Pond 25: See Appendix 1, Map D. Location 19°40'97"N, 156°01'98"W. This pond is situated in a'a flow and is about 2m in diameter. The basin is primarily gravel and contains water only during high tides. The surrounding a'a lava has been leveled by a bulldozer during the early 1970's. There is no surrounding vegetation. During high tides this pool will contain *H. rubra* at densities up to $80/0.1m^2$; also present are *Metabeteus lohena* (to $1/0.1m^2$) as well as red amphipods. Not numbered by Park survey.

Pond 26: See Appendix 1, Map D. Location 19°40'98"N, 156°01'96"W. This pond is situated in a'a flow and is about 1.2m in diameter and has a maximum depth of about 25cm. This pond served as one of the routine monitoring sites for this study. The basin is primarily small a'a stones and contains water through all tide cycles. As with the previous pool, the surrounding a'a lava has been leveled by a bulldozer during the early 1970's. There is no surrounding vegetation. During high tides this pool will contain *H. rubra* at densities ranging from 6 to more than 120 individuals/$0.1m^2$; also present are *Metabeteus lohena* (up to 3 individuals /$0.1m^2$) as well as red amphipods. Park numbers P-017, 22.

Pond 27: See Appendix 1, Map D. Location 19°40'99"N, 156°01'97"W. This pond is situated in a'a flow and is about 0.8m in diameter and a depth of about 8cm. The basin is a'a and contains water through most tides. The surrounding a'a lava has been leveled by a bulldozer during the early 1970's. There is no surrounding vegetation. The aquatic fauna includes *H. rubra* at densities up to $20/0.1m^2$; also present are *Metabeteus lohena* (rare) as well as red amphipods. Park numbers P-005, 11.

Pond 28: See Appendix 1, Map D. Location about 60m south of 19°40'98"N, 156°01'96"W. This pond is situated in a'a flow and is about 8.5m in length and 5m in width and having a depth

APPENDIX 2. Continued.

of about 20cm. The basin is primarily a'a and gravel. The surrounding a'a lava has been leveled by a bulldozer during the early 1970's. A large *Schinus* tree has covered about one half of the pond's surface and sedges are growing over a large part of the remaining water surface. This pond is overrun by guppies (*Poecilia reticulata*). Other aquatic species seen include *Melania, Assiminea, Ligia* and *Schizothrix*. Chai's survey reported this pool to be one of the least disturbed in the Park. Park numbers P-006, Chai's pond "G".

Pond 29: See Appendix 1, Map D. Location about 85m south and makai of 19°40'98"N, 156°01'96"W. This pond is situated in mix of pahoehoe and a'a and is about 30cm long, 25cm wide and about 10cm deep. This pond is the most seaward (makai) of a series of pools (nos. 29-36) situated in a long mauka-makai crack. It is situated about 5m mauka of the jeep road. The surrounding a'a lava to the north of this pool has been leveled by a bulldozer during the early 1970's. There is no surrounding vegetation. A few *H. rubra* and red amphipods were seen in this pool. Not numbered by the Park.

Pond 30: See Appendix 1, Map D. Location about 80m south and makai of 19°40'98"N, 156°01'96"W. This pond is situated in a'a and is about 1m long, 25cm wide and up to 30cm deep. This pond is the second in the series (nos. 29-36) which is situated in a long mauka-makai crack. The surrounding a'a lava to the north has been leveled by a bulldozer during the early 1970's and probably filled in some of this pool. There is no surrounding vegetation. No aquatic fauna was seen in this pool although they probably occur there. Not numbered by the Park.

Pond 31: See Appendix 1, Map D. Location about 70m south of 19°40'98"N, 156°01'96"W. This pond is situated in a'a and located about 80cm makai of Pond 32. It is about 10cm long, 15cm wide and about 3cm deep. This pond is the third in the series (nos. 29-36) which is situated in a long mauka-makai crack. The surrounding a'a lava has been leveled by a bulldozer during the early 1970's and probably filled in some of this pool. There is no surrounding vegetation. No aquatic fauna was seen but probably occur in this pool. No Park number.

Pond 32: See Appendix 1, Map D. Location about 70m south of 19°40'98"N, 156°01'96"W. This pond is situated in a'a and located about 25m north of the jeep road. It is about 40cm long, 15cm wide and about 3cm deep. This pond is the fourth in the series (nos. 29-36) which is situated in a long mauka-makai crack. The surrounding a'a lava has been leveled by a bulldozer during the early 1970's and probably filled in some of this pool. There is no surrounding vegetation. One small *H. rubra* was seen. No Park number.

Pond 33: See Appendix 1, Map D. Location about 70m south and mauka of 19°40'98"N, 156°01'96"W. This pond is situated in a'a and located about 8m mauka of Pond 32. It is about 60cm long, 20cm wide and about 18cm deep. This pond is the fifth in the series (nos. 29-36) which is situated in a long mauka-makai crack. The surrounding a'a lava has been leveled by a bulldozer during the early 1970's and probably filled in some of this pool. There is no surrounding vegetation. No aquatic fauna was seen but probably occur in this pool. No Park number.

Pond 34: See Appendix 1, Map D. Location about 100m south and mauka of 19°40'98"N, 156°01'96"W. This pond is situated in higher surrounding a'a flow and located about 25m mauka of Pond 33 (which is in the middle of a bulldozed patch of a'a). It is about 80cm long, 25cm wide and about 30cm deep. This pond is the sixth in the series (nos. 29-36) which is situated in a long mauka-makai crack. There is no surrounding vegetation. Only a few *H. rubra* and red amphipods were seen in this pool. No park number.

Pond 35: See Appendix 1, Map D. Location more than 100m south and mauka of 19°40'98"N, 156°01'96"W. This pond is situated in higher surrounding a'a flow and located about 10m mauka of Pond 34. It is about 1.5m long, 35cm wide and about 60cm deep. This pond is the seventh in the series (nos. 29-36) which is situated in a long mauka-makai crack. There is no surrounding vegetation. Only a few *H. rubra* and red amphipods were seen in this pool. No park number.

Pond 36: See Appendix 1, Map D. Location more than 100m south and mauka of 19°40'98"N, 156°01'96"W. This pond is situated in higher surrounding a'a flow and located about 20m mauka of Pond 35. It is about 1m long, 20cm wide and about 30cm deep. This pond is the eighth in the series (nos. 29-36) which is situated in a long mauka-makai crack. There is no surrounding vegetation. Only a few *H. rubra* and red amphipods were seen in this pool. No park number.

Pond 37: See Appendix 1, Map E. Location not determined with GPS but this pool is about 40m south of the mauka-makai jeep road close to a bulldozed and flattened section of a'a. It is also about 35m mauka or inland of the coastal jeep road. Pool located in a'a flow and is under a overhang creating a "cave" pool. At low tides, this pool is dry; at higher tides the pool is about 1m x 80cm x 15cm deep. No aquatic fauna present during our site visit. Park numbers P-009, 17.

Pond 38: See Appendix 1, Map E. Location not determined by GPS but this pool is about 15m makai of Pond 37 and is located in a'a. The coastal jeep road is about 20m makai of this pool. The dimensions of this pool are about 1.2m by 1m and having a depth of 20cm at maximum. At the time of sampling this pool was only damp, indicating that it has water only during the higher portions of the tidal cycle. There was no aquatic fauna present during our visit to this pool. Park numbers P-007, 9.

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Pond 39: See Appendix 1, Map E. Location not determined by GPS but this pool is about 45m south of Pond 37. It is located in a fissure in the a'a and has a mauka-makai orientation. This pool is about45cm long, 20cm wide and about 5cm deep. Two small *H. rubra* were seen in this pool during our sampling efforts. Park numbers P-008, 16.

Pond 40: See Appendix 1, Map E. Location not determined by GPS but this pool is about 5m makai of Pond 39. It is located in the same fissure in the a'a and has a mauka-makai orientation. This pool is about5cm long, 4cm wide and about 4cm deep. No aquatic fauna was seen during our sampling of this small pool. No Park number.

Pond 41: See Appendix 1, Map E. Location not determined by GPS but this series of small pools (nos. 41-45) are located in a rough a'a flow about 30-40m north of the large milo thicket and about 40m inland of the coastal jeep road. This pond appears to have been dug out in loose a'a and has an approximate 60cm diameter. It may have been used as a well at one time. Only aquatic fauna seen was a single *Metopograpsus messor*. No Park number.

Pond 42: See Appendix 1, Map E. Location not determined by GPS but this series of small pools (nos. 41-45) are located in a rough a'a flow about 30-40m north of the large milo thicket and about 40m inland of the coastal jeep road. This pond appears to have been modified as a bathing pool with walling and smooth (waterworn) stones having been placed in and adjacent to it. This pond is about 15m south and mauka of Pond 41. This pool is about 1m in diameter and has a depth of 35cm. Several small *H. rubra* were seen. No Park number.

Pond 43: See Appendix 1, Map E. Location not determined by GPS but this series of small pools (nos. 41-45) are located in a rough a'a flow about 30-40m north of the large milo thicket and about 40m inland of the coastal jeep road. This pond is 80 x 80cm with a depth of 25cm, rough a'a basin. *H. rubra* occurs at a density of $1/0.1m^2$; red amphipods are also present. No Park number.

Pond 44: See Appendix 1, Map E. Location not determined by GPS but this series of small pools (nos. 41-45) are located in a rough a'a flow about 30-40m north of the large milo thicket and about 40m inland of the coastal jeep road. This pool is mauka of what appears to be some house platforms and there are some smooth waterworn stones that assist in walking near the pool. This pool is about 1.2m by 1m in dimensions and is about 35cm deep. *H. rubra* and red amphipods were seen in this pool at low densities during our sampling of this pool. No Park number.

Pond 45: See Appendix 1, Map E. Location not determined by GPS but this series of small pools (nos. 41-45) are located in a rough a'a flow about 30-40m north of the large milo thicket and about 40m inland of the coastal jeep road. This pool is about 10m inland of Pond 44 and is

APPENDIX 2. Continued.

located in a fissure in the a'a. Size is about 30cm long, 20cm wide and about 15cm deep. No aquatic fauna was seen during our survey of this pool. No Park number.

Pond 46: See Appendix 1, Map F. Location 19°40'84"N, 156°01'97W. This pool is part of a group of ponds located within and adjacent to the milo thicket (nos. 46-51). The milo thicket is located in a shallow gulch that opens up in a makai direction and is exposed to high storm waves. The periodic inundation of some of these pools is evident by the unusual number of marine species found in some of the ponds. The substratum of much of the gulch and makai of it is comprised of waterworn basalt rocks and boulders. Pond 46 is comprised of waterworn basalt stone, sand and some a'a and is situated under the milo trees. It is elongate and has an mauka-makai orientation. The mauka side of this pool is about 3m makai of the coastal jeep road. Aquatic species seen in this pool include *Palaemon debilis, Theodoxus neglectus,* juvenile aholehole (*Kuhlia sandvicensis*) and guppies (*Poecilia reticulata*); around the pool are *Ligia*. Pond size 20m long, up to 2m in width and a maximum 25cm deep. Park numbers P-010, 15.

Pond 47: See Appendix 1, Map F. Location about 50m north and makai of 19°40'87"N, 156°01'91W. This pond was routinely sampled during this study. This pool is part of a group of ponds located within and adjacent to the milo thicket (nos. 46-51). The milo thicket is located in a shallow gulch that opens up in a makai direction and is exposed to high storm waves. The periodic inundation of some of these pools is evident by the unusual number of marine species found in some of the ponds. This pond is situated in a'a and the irregular basin is comprised of sand, mud and a'a. Part of this pool is situated under the milo trees and part of it is extends into the a'a flow just south of the milo thicket. Dimensions on this pool are 25m in length, 20m in width and up to 60cm deep. Species seen in this pool include guppies (*Poecilia reticulata*), weke (*Mulloides flavolineatus*), aholehole *Kuhlia sandvicensis*), mamo (*Abudefduf abdominalis*), pua or juvenile mullet (*Mugil cephalus*) uouoa (*Neopmyxus chaptalii*), *Theodoxus neglectus* and *T. cariosa* (with abundances depending on the tide state ranging from 8 to 23 individuals/0.1m^2), *Palaemon debilis*, and *Metopograpsus messor*. Park numbers P-012, 3.

Pond 48: See Appendix 1, Map F. Location about 10m north of Pond 47 or 25m north of 19°40'87"N, 156°01'91W. This pool is part of a group of ponds located within and adjacent to the milo thicket (nos. 46-51). The milo thicket is located in a shallow gulch that opens up in a makai direction and is exposed to high storm waves. The periodic inundation of some of these pools is evident by the unusual number of marine species found in some of the ponds. Size 8m long, 4.5m wide and about 20cm deep. This pond is situated under the milo trees. Species present include *Ligia*, guppies (*Poecilia reticulata*), aholehole (*Kuhlia sandvicensis*), *Palaemon debilis* and *Theodoxus cariosa.* Park numbers P-014, 8.

Pond 49: See Appendix 1, Map F. Location directly adjacent to mauka jeep path; no GPS reading taken at this pool. This pool is part of a group of ponds located within and adjacent to the milo thicket (nos. 46-51). The milo thicket is located in a shallow gulch that opens up in a makai direction and is exposed to high storm waves. The periodic inundation of some of these pools is evident by the unusual number of marine species found in some of the ponds. This pond is situated under the milo trees and is 7m long, 5m wide and about 40cm deep. The bottom of this pool is covered by milo leaf litter. Species present include *Ligia*, guppies (*Poecilia reticulata*) and *Palaemon debilis*. Park numbers P-011, 2.

NOTE: Pond numbers 46, 48 and 49 appear to be especially subject to inundation by storm generated surf. As such, the basins of these pools are subject to change by the movement of sand, rocks and debris in or out of the basin. Over the course of this study we have seen Ponds 46 and 48 fluctuate dramatically in size.

Pond 50: See Appendix 1, Map F. Location about 20m mauka of the mauka jeep path and 10m north of Pond 51. No GPS reading taken at this pool. This pool is part of a group of ponds located within and adjacent to the milo thicket (nos. 46-51). The milo thicket is located in a shallow gulch that opens up in a makai direction and is exposed to high storm waves. The periodic inundation of some of these pools is evident by the unusual number of marine species found in some of the ponds. This pond is under a thick canopy of milo and the mud bottom is covered by milo leaves. This pool is dry at low tides. At high tide the size of this pool is about 60m in length, 1.5m in greatest width and probably about 15cm deep. At the time of sampling (low tide) this pool was damp and contained no aquatic fauna. We did see *Ligia* around the banks of this pool. No Park number.

Pond 51: See Appendix 1, Map F. Location about 10m mauka of the mauka jeep path. No GPS reading taken. This pond was a routine sample site for this study. This pool is part of a group of ponds located within and adjacent to the milo thicket (nos. 46-51). The milo thicket is located in a shallow gulch that opens up in a makai direction and is exposed to high storm waves. The periodic inundation of some of these pools is evident by the unusual number of marine species found in some of the ponds. This pond is situated partially under the milo trees and is a highly irregular basin in a'a lava. The bottom is a mix of mud, milo leaves, and a'a rock. Size 20m long, 13m wide and up to 45cm deep. Species present include *Theodoxus cariosa* (with a mean abundance estimated to be 17 individuals/0.1m^2 prior to 23 March 1995; subsequently, mean abundance was estimated to be 2 individuals/0.1m^2), *Kuhlia sandvicensis, Poecilia reticulata, Palaemon debilis, Metapograpsus messor, Neomyxus chaptalii.* The decrease in abundance of *Theodoxus* is probably due to harvesting for consumption. Park numbers P-015, 5.

Pond 52: See Appendix 1, Map F. Location about 25m south of Pond 51 situated in a depression in the high surround a'a flow. No GPS reading for this site. This pool is about 6m long, 2.5m wide and at the deepest 30cm. Much of the highly irregular basin is quite shallow and is dry at low tide. The bottom of this pool is a'a rock. Aquatic species seen include just a few *H. rubra* and red amphipods. Park numbers P-013, 1.

APPENDIX 2. Continued.

Pond 53: See Appendix 1, Map F. Location about 100m south of the milo thicket, about 3m makai of the coastal jeep road. No GPS reading taken. This pond is situated in an a'a flow and is approximately circular with a diameter of 1.2m and depth of 25cm. The bottom of this pond is comprised of smaller a'a pieces. Aquatic species include *Schizothrix*, *H. rubra* at a density of $1/0.1m^2$ and red amphipods. No Park number.

Pond 54: See Appendix 1, Map F. Location about 100m south of the milo thicket, about 5m makai of Pond 53. No GPS reading taken. This pool is about 20m from the sea inland of a natural mound of waterworn stones probably piled up by storm waves. This pond is situated in an a'a flow and is about 1.5m x 1m in dimensions; there are waterworn stones set into the a'a to allow one to easily get to this pond. Bottom comprised of a'a. This pool is about 45cm deep and aquatic species seen include *Schizothrix, Theodoxus cariosa, Metapograpsus messor, Halocaridina rubra* (5 individuals/0.1m2), red amphipods and a single kupipi (*Abudefduf sordidus*). No Park number.

Pond 55: See Figure 1, text. Location about 215m inland of the ocean, 195m south of the milo thicket in high a'a flow. This pool served as a routine sample site for this study. Three large ahus (or above ground graves) are just south and makai of this pool. This pool is commonly referred to as "the Queen's bath". It is located in an a'a flow and has an irregular basin with an a'a bottom. The pool is about 6m in length, 4.5m in width and about 1.2m in depth. There is a *Schinus* tree located along the mauka side of the pool. Aquatic species seen in this pool include *Schizothrix*, *Poecilia reticulata*, *Halocaridina rubra* (at about $2/0.1m^2$) and *Palaemon debilis.* On the 23 March 1995 survey there were two goldfish (*Cyprinus carpio*) present in the pool but subsequently disappeared. This pond is often used as a bathing pool. Park numbers P-016, 14.

Pond 56: See Figure 1, text. This pond is located in a fissure south and makai of Pond 55. It is just makai of the trail connecting Pond 55 with the coast to the south. No GPS reading taken. This pool is situated in a'a and has a highly irregular elongate basin the north end of which is broader. Over pond length is 15m half of which had a width of 25cm (as a sinuous crack in the a'a) and the other half opens up to a width of about 5m at high tide. Maximum depth about 80cm, bottom all a'a, no surrounding vegetation. Aquatic species seen include *H. rubra* (to about $5/0.1m^2$), red and white amphipods, dragonfly nymphs and a small amount of *Schizothrix*. Park numbers P-018, 13.

Pond 57: See Appendix 1, Maps G and H. Location about 20m north and inland of Pond 58. No GPS reading taken. This pond is situated in a depression in an old pahoehoe flow. There is a small *Schinus* tree on the makai side of the pool. The pond is approximately circular and is about 60cm in diameter with a rocky bottom. Aquatic species seen include red amphipods and *Halocaridina rubra* up to $8/0.1m^2$ at the time we surveyed the pool. Park numbers P-023, 4.

APPENDIX 2. Continued.

Pond 58: See Appendix 1, Maps G and H. Location about 50m northwest of 19°40'77"N, 156°01'81"W. This pool is situated in pahoehoe and is directly north of a large *Schinus* thicket. The bottom of the pool is a'a rocks and this pond is about 1.1m in diameter and 15cm deep. Aquatic species seen include *Schizothrix* and *Melania*. *Halocaridina rubra* occur in this pool very infrequently. The Park inventory tagged this pool with number P-019, yet their field notes for P-019 appear to be for Pond 64 below. Park number unknown.

Pond 59: See Appendix 1, Maps G and H. Location about 50m northwest of 19°40'77"N, 156°01'81"W. This pool is situated in pahoehoe and is directly north of a large *Schinus* thicket and is about 2m makai of Pond 58. Size 3m by 2.5m and is about 30cm deep. The bottom of the pool is a combination of a'a and pahoehoe. Aquatic species seen include *Schizothrix, Melania* and red amphipods. *Halocaridina rubra* occur in this pool very infrequently. Park numbers P-020, 6.

Pond 60: See Appendix 1, Maps G and H. Location about 60m northwest of 19°40'77"N, 156°01'81"W. This pool is situated in pahoehoe and is directly north of a large *Schinus* thicket. The bottom of the pool is a'a rocks and this pond is about 2m by 2.5m in diameter and 15cm deep. Aquatic species seen include *Schizothrix* and red amphipods. *Halocaridina rubra* occur in this pool very infrequently. Park numbers P-022?, 21.

Pond 61: See Appendix 1, Maps G and H. Location about 15m mauka of 19°40'77"N, 156°01'81"W (Pond 62). This pool is situated in pahoehoe and has some fountain grass growing in the vicinity. The bottom of the pool is a'a rocks and this pond has no water at low tides. It is about 25cm in diameter and 2-5cm deep. No aquatic species have been seen in this pool. There is no Park number.

Pond 62: See Appendix 1, Maps G and H. Location 19°40'77"N, 156°01'81"W. This pool served as a routine sample point for this study. It is situated in a depression in the pahoehoe and has some fountain grass and small *Schinus* trees around it. This pond is mauka of a large *Schinus* thicket. The bottom of the pool is a combination of pahoehoe and a'a rocks. Size 2m long, 1.2m wide and having a very irregular basin shape. Water depth is about 35cm. Aquatic species seen include red amphipods, *Schizothrix* and *Metopograpsus messor*. *Halocaridina rubra* occasionally occurs in this pool at low densities. Park numbers P-021, 12.

Pond 63: See Appendix 1, Maps G and H. Location about 15m west of 19°40'77"N, 156°01'81"W (Pond 62) and is in a thicket of *Schinus*. This pool is situated in pahoehoe and the bottom of the pool is comprised of a'a. The dimensions of the pool are about 4m in length and 1m in width. This pond is dry except on high tide when 5-8cm of water may be seen. No aquatic species have been found in this pool. This pond was not inventoried by the Park.

APPENDIX 2. Continued.

Pond 64: See Appendix 1, Maps G and H. Location about 8m inland of stone wall along coastal jeep road. No GPS reading. Pond size is about 1m long, 0.5m wide and with a depth of 20cm. Pond is located under *Schinus* and is in a mix of pahoehoe and loose waterworn beach stones. Bottom of pond is covered with a'a and waterworn stones. Aquatic species encountered include red amphipods, white amphipods, *Theodoxus cariosa*, and the pulmonate snail, *Melampus parvulus*. As noted above, the Park inventory notes appear to have this pool numbered as P-019 but the P-019 tag is on our pool 58.

Pond 65: See Appendix 1, Maps G and H. Location: 19°40'73"N, 156°01'77W. This pool served as a routine sample site for this study. This pond is part of a series of small mud bottom pools (numbers 65-68) located in pickleweed or *Batis maritima*. Much of this area was under a canopy of mangroves and hau that have been cleared by Park personnel. The pools are heavily influenced by the sea because of their close proximity to the ocean. These pools are all interconnected into one complex at high tide. The pond was initially about 4m by 3m in surface area and about 10cm deep. Through the 2.5 years of this study, this pool has been partially filled in by floating debris and pickleweed. Aquatic fauna includes *Ligia* around the banks, *Metopograpsus messor, Poecilia reticulata,* and a few *Theodoxus cariosa*. No Park number.

Pond 66: See Appendix 1, Maps G and H. Location: 19°40'73"N, 156°01'77W. This pool is part of a series of small mud bottom pools (numbers 65-68) located in pickleweed or *Batis maritima*. Much of this area was under a canopy of mangroves and hau that have been cleared by Park personnel. The pools are heavily influenced by the sea because of their close proximity to the ocean. These pools are all interconnected into one complex at high tide. This pool is separated from Pond 65 by a 60cm wide a'a and mud wall and is about 6m in length, 2.5m wide and about 8cm deep with a mud bottom. It has also been largely filled in by debris. Aquatic fauna includes *Ligia* around the banks, *Metopograpsus messor, Poecilia reticulata,* and a few *Theodoxus cariosa*. No Park number.

Pond 67: See Appendix 1, Maps G and H. Location: about 8m south of 19°40'73"N, 156°01'77W. This pool is part of a series of small mud bottom pools (numbers 65-68) located in pickleweed or *Batis maritima*. Much of this area was under a canopy of mangroves and hau that have been cleared by Park personnel. The pools are heavily influenced by the sea because of their close proximity to the ocean. These pools are all interconnected into one complex at high tide. This pool is roughly circular with a diameter of 1.5m and is about 5cm deep. Aquatic fauna includes *Ligia* around the banks, *Metopograpsus messor,* and *Poecilia reticulata*. No Park number.

Pond 68: See Appendix 1, Maps G and H. Location about 25m south of 19°40'73"N, 156°01'77W. This pool is part of a series of small mud bottom pools (numbers 65-68) located in pickleweed or *Batis maritima*. Much of this area was under a canopy of mangroves and hau that have been cleared by Park personnel. The pools are heavily influenced by the sea because of

APPENDIX 2. Continued.

their close proximity to the ocean. These pools are all interconnected into one complex at high tide. This pond is about 80cm long by 40cm wide and about 5cm deep. The substratum is mud. Aquatic fauna includes *Ligia* around the banks, *Metopograpsus messor,* and *Poecilia reticulata.* No Park number.

Ponds 69 through 74: See Appendix 1, Maps G and I. Location in the middle of the milo and hau thicket along the north side of Aimaikapa Fishpond. No GPS reading taken. Six water-filled depressions (numbers 69-74) are located in an opening in the milo/hau thicket. At high tide these pools are all interconnected forming a complex of pools. The sizes of the individual pools varies considerably with the tides; in terms of depressions continuously containing water (despite the stage of the tide), the largest pool is no more than 4m in length and 2.5m wide and about 10cm deep; the smallest is less than 1m in diameter and about 5cm deep. The surrounding and emergent vegetation includes sedges, *Sesuvium* and grasses and some milo. Aquatic biota includes *Ruppia maritima, Schizothrix, Rhizoclonium, Melania, Assiminea, Theodoxus neglectus, Ligia,* red amphipods, white amphipods, *Palaemon debilis, Halocaridina rubra* (with estimated densities up to 150 individuals/0.1m^2. Also present were *Metabeteus lohena* occurring at densities up to 5 individual/0.1m^2. In July 1996 these ponds were colonized by guppies (*Poecilia reticulata*). Other than *Palaemon debilis* the shrimp and amphipods had disappeared (at least diurnally). The pools were almost completely choked with *Cladophora* sp. The source for the colonizing guppies was probably Aimakapa Fishpond. No Park numbers.

Pond 75: See Appendix 1, Maps G and I. Location 19°40'77"N, 156°01'60W. This pond served as a routine sample site for this study. Pond situated in a'a flow, partially under a canopy of kiawe and *Pluchea* trees. Size 10m long by 6m wide and about 30cm deep. Bottom comprised primarily of mud with some *Batis maritima* encroaching. A 1.3m high stone wall is present along the mauka side of this pond making up the edge of the pool. Aquatic species present include guppies (*Poecilia reticulata*), dragonfly nymphs, *Ruppia maritima, Melania, Cladophora, Rhizoclonium* and *Macrobrachium grandimanus*. Around the banks are *Ligia.* Park numbers P-025, 30.

Pond 76: See Appendix 1, Maps G and I. Location about 15m north of 19°40'77"N, 156°01'60W. Pond situated in a'a flow, under a canopy of kiawe and *Pluchea* trees with *Batis maritima* encroaching over much of the pond. Size 15m long by 2.5m wide and about 15cm deep. Bottom comprised primarily of mud with some emergent makaloa. A 1m wide stone wall separates this pool from Pond 75. Aquatic species present include guppies (*Poecilia reticulata*), dragonfly nymphs, *Melania, Cladophora,* and *Rhizoclonium*. Around the banks are *Ligia*. We cannot match the Park number with this pool because we do not have the Park field notes but the number is in the series from P-026 through P-031.

APPENDIX 2. Continued.

Pond 77: See Appendix 1, Maps G and I. Location about 30m north and makai of 19°40'77"N, 156°01'60W. Pond situated in a mixed pahoehoe and a'a flow, under a canopy of kiawe and *Schinus* trees with *Batis maritima* encroaching over much of the pond. Size 1.5m long by 0.7m wide and about 5cm deep. Bottom comprised primarily of mud. Aquatic species present include guppies (*Poecilia reticulata*), *Melania, Cladophora,* and makaloa. Around the banks are *Ligia.* We cannot match the Park number with this pool because we do not have the Park field notes but the number is in the series from P-026 through P-031.

Pond 78: See Appendix 1, Maps G and I. Location about 45m north and makai of 19°40'77"N, 156°01'60W. Pond situated in mixed pahoehoe and a'a flow, under a canopy of kiawe and *Schinus* trees with *Batis maritima* encroaching over most of the pond. Size 1m long by 0.4m wide and about 5cm deep. Bottom comprised primarily of mud. Aquatic species present include guppies (*Poecilia reticulata*), *Melania,* and makaloa. Around the banks are *Ligia.* We cannot match the Park number with this pool because we do not have the Park field notes but the number is in the series from P-026 through P-031.

Pond 79: See Appendix 1, Maps G and I. Location about 25m makai of 19°40'77"N, 156°01'60W, 5m seaward of Pond 75. Pond situated in a'a flow, under a canopy of kiawe trees with *Batis maritima* encroaching over much of the pond. Size 2.5m long by 2m wide and about 5cm deep. Bottom comprised primarily of mud with some a'a. Aquatic species present include guppies (*Poecilia reticulata*), *Melania,* and *Rhizoclonium.* Around the banks are *Ligia.* We cannot match the Park number with this pool because we do not have the Park field notes but the number is in the series from P-026 through P-031.

Pond 80: See Appendix 1, Maps G and I. Location about 15m north of 19°40'77"N, 156°01'60W, about 4m makai of Pond 75. Pond situated in a'a flow, under a canopy of kiawe and *Schinus* trees with *Batis maritima* encroaching over much of the pond. Size 3m long by 1.5m wide and about 6cm deep. Bottom comprised primarily of mud. Aquatic species present include guppies (*Poecilia reticulata*), and *Melania.* Around the banks are *Ligia.* We cannot match the Park number with this pool because we do not have the Park field notes but the number is in the series from P-026 through P-031.

Pond 81: See Appendix 1, Maps G and I. Location about 30m south and makai of 19°40'77"N, 156°01'60W, about 10m south and makai of Pond 75. Pond situated in a'a flow, under a canopy of kiawe and *Schinus* trees with *Batis maritima* encroaching over much of the pond. At low tides, this pool is dry. Size on high tide is 4m long by 3m wide and about 10cm deep. Bottom comprised primarily of mud. Aquatic species present include *Halocaridina rubra* at densities of up to 15 individuals/0.1m^2, red amphipods, *Ligia* (on banks), *Melania,* and *Rhizoclonium.* We cannot match the Park number with this pool because we do not have the Park field notes but the number is in the series from P-026 through P-031.

APPENDIX 2. Continued.

Pond 82: See Figure 1. Location 19°40'59"N, 156°01'23"W. This pool was a routine sample site for this study. Pond is located makai of the Park maintenance facility. This pool was dug in the early 1970's by the State as a water source (for dust control) while building the Queen Ka'ahamanu Highway. At present the pool is almost entirely covered by *Schinus* trees and is situated in a human dug depression about 7m below the surface. The pool is roughly circular and is approximately 7m in diameter with considerable mud and leaf litter on the bottom. Apparent depth is about 1m. Aquatic species present include guppies (*Poecilia reticulata*), *Melania*, dragonfly nymphs and there is a *Cladophora* mat across much of the pool bottom. When this pool was examined in 1972 aquatic species present included the introduced prawn (*Macrobrachium lar*), *Halocaridina rubra* and amphipods. No Park number.

APPENDIX 3. Summary of the water quality data by site for this study. Numbered sites are for 16 anchialine pools sampled, eight fishpond sites are denoted with an "F", ten marine sites with an "M" and the three coastal wells with the prefix "Well".

SITE	DATE	PO4 uM	NO3 uM	NH4 uM	SI uM	DOP uM	DON uM	TP uM	TN uM
1	03-Mar-94	0.33	4.71	2.26	371.47	0.37	16.86	0.70	23.83
1	10-Aug-94	0.13	2.21	0.10	502.27	0.37	15.07	0.50	17.38
1	23-Mar-95	0.18	4.91	0.59	469.90	0.55	19.20	0.73	24.70
1	04-Jun-96	0.75	8.84	4.83	320.72	0.25	13.43	1.00	27.10
1	31-Jul-96	0.60	5.83	3.89	473.96	0.31	14.00	0.91	23.72
1	18-Oct-96	0.85	13.43	2.62	499.62	0.25	7.45	1.10	23.50
6	03-Mar-94	2.05	31.28	7.11	495.85	0.39	7.56	2.44	45.95
6	10-Aug-94	1.80	43.67	1.16	557.42	0.26	5.14	2.06	49.97
6	23-Mar-95	1.83	34.37	2.40	574.50	0.41	10.36	2.24	47.13
6	04-Jun-96	2.25	42.55	1.08	658.51	0.16	11.00	2.41	54.63
6	31-Jul-96	2.00	35.16	2.05	557.68	0.21	10.03	2.21	47.24
6	18-Oct-96	2.00	42.86	1.86	537.27	0.30	4.44	2.30	49.16
13	03-Mar-94	1.93	26.95	1.75	499.84	0.30	10.45	2.23	39.15
13	10-Aug-94	3.05	43.19	1.54	561.43	0.29	6.60	3.34	51.33
13	23-Mar-95	3.41	49.57	1.24	586.60	0.59	10.07	4.00	60.88
13	04-Jun-96	2.77	49.06	2.50	625.87	0.22	11.94	2.99	63.50
13	31-Jul-96	2.43	26.58	5.92	521.05	0.28	14.31	2.71	46.81
13	18-Oct-96	2.97	49.23	3.74	530.76	0.47	7.10	3.44	60.07
15	10-Aug-94	2.42	57.64	0.12	570.04	0.54	3.04	2.96	60.80
15	23-Mar-95	3.18	64.16	0.45	596.90	0.11	3.78	3.29	68.39
15	04-Jun-96	2.99	66.64	0.13	651.68	0.05	7.22	3.04	73.99
15	31-Jul-96	3.04	62.27	0.18	560.75	0.05	8.55	3.09	71.00
15	18-Oct-96	2.85	60.80	0.50	545.16	0.11	4.20	2.96	65.50
17	03-Mar-94	2.93	55.89	0.44	521.89	0.13	3.15	3.06	59.48
17	10-Aug-94	2.43	53.32	1.14	569.28	0.64	3.78	3.07	58.24
17	23-Mar-95	3.15	57.43	0.51	594.30	0.19	5.44	3.34	63.38
17	04-Jun-96	3.24	36.03	1.19	639.67	0.16	11.42	3.40	48.64
17	18-Oct-96	3.22	56.30	2.00	540.49	0.17	7.27	3.39	65.57
18	10-Aug-94	2.72	46.83	2.53	551.63	0.38	5.86	3.10	55.22
18	23-Mar-95	3.23	59.02	0.19	594.80	0.05	2.87	3.28	62.08
18	18-Oct-96	2.79	55.80	0.63	536.80	0.15	2.51	2.94	58.94
19	03-Mar-94	1.42	8.46	1.62	329.17	0.50	19.13	1.92	29.21
19	10-Aug-94	2.54	40.06	0.58	499.90	0.16	5.70	2.70	46.34
19	23-Mar-95	2.78	46.03	0.88	531.30	0.22	5.13	3.00	52.04
19	04-Jun-96	2.66	45.83	1.63	578.29	0.17	10.95	2.83	58.41
19	31-Jul-96	2.31	30.22	2.13	474.76	0.16	9.16	2.47	41.51
19	18-Oct-96	2.45	43.55	0.96	484.95	0.15	5.85	2.60	50.36

APPENDIX 3. continued

SITE	DATE	PO4 uM	NO3 uM	NH4 uM	SI uM	DOP uM	DON uM	TP uM	TN uM
26	03-Mar-94	3.31	63.84	0.10	515.91	0.04	1.60	3.35	65.54
26	23-Mar-95	3.51	64.03	0.10	563.60	0.19	2.40	3.70	66.53
26	04-Jun-96	3.22	68.27	0.26	617.20	0.05	7.81	3.27	76.34
26	31-Jul-96	3.23	64.21	0.18	542.42	0.04	6.43	3.27	70.82
26	18-Oct-96	3.00	63.25	0.39	503.61	0.15	2.68	3.15	66.32
27	10-Aug-94	3.43	63.83	0.05	525.75	0.00	0.72	3.43	64.60
47	03-Mar-94	3.17	59.52	1.09	509.65	0.03	1.80	3.20	62.41
47	10-Aug-94	3.14	61.24	0.09	530.55	0.20	1.78	3.34	63.11
47	23-Mar-95	3.26	56.34	0.82	549.00	0.11	2.82	3.37	59.98
47	04-Jun-96	3.07	65.21	1.07	608.98	0.07	6.99	3.14	73.27
47	31-Jul-96	3.18	62.90	0.88	528.21	0.01	5.97	3.19	69.75
47	18-Oct-96	3.12	58.65	2.26	509.95	0.18	3.18	3.30	64.09
51	03-Mar-94	3.29	62.72	0.39	516.88	0.02	1.87	3.31	64.98
51	10-Aug-94	3.45	66.23	0.73	555.23	0.06	1.00	3.51	67.96
51	23-Mar-95	3.62	65.38	0.29	575.50	0.00	2.33	3.62	68.00
51	04-Jun-96	3.20	68.08	0.58	619.87	0.05	7.08	3.25	75.74
51	31-Jul-96	3.44	67.88	0.22	547.95	0.07	6.35	3.51	74.45
51	18-Oct-96	3.51	73.23	1.29	542.42	0.15	3.68	3.66	78.20
55	03-Mar-94	3.69	70.12	0.47	550.79	0.01	2.95	3.70	73.54
55	10-Aug-94	3.68	74.31	0.50	582.16	0.20	1.27	3.88	76.08
55	23-Mar-95	3.99	74.09	0.29	608.50	0.01	1.63	4.00	76.01
55	04-Jun-96	3.71	82.43	0.93	671.97	0.06	8.53	3.77	91.89
55	31-Jul-96	3.82	75.55	0.75	576.49	0.16	6.98	3.98	83.28
55	18-Oct-96	3.60	74.01	2.02	561.55	0.21	6.50	3.81	82.53
62	03-Mar-94	3.19	62.44	0.01	520.39	0.04	1.78	3.23	64.23
62	10-Aug-94	2.99	59.09	0.46	488.82	0.30	2.74	3.29	62.29
62	23-Mar-95	3.35	62.59	0.88	560.60	0.07	3.63	3.42	67.10
62	04-Jun-96	3.21	67.52	2.53	621.42	0.07	20.65	3.28	90.70
62	31-Jul-96	3.12	60.31	1.28	530.96	0.07	7.57	3.19	69.16
62	18-Oct-96	2.73	56.46	1.04	506.21	0.15	3.69	2.88	61.19
65	03-Mar-94	1.12	12.84	8.29	472.93	0.90	27.63	2.02	48.76
65	23-Mar-95	0.96	13.17	0.48	428.60	0.73	21.66	1.69	35.31
65	04-Jun-96	2.32	48.14	1.40	511.58	0.20	13.97	2.52	63.51
65	31-Jul-96	1.69	23.35	2.52	381.63	0.26	14.87	1.95	40.74
65	18-Oct-96	0.46	0.33	0.71	421.71	0.32	12.84	0.78	13.88

APPENDIX 3. continued

SITE	DATE	PO4 uM	NO3 uM	NH4 uM	SI uM	DOP uM	DON uM	TP uM	TN uM
75	03-Mar-94	2.02	23.34	2.20	529.85	0.44	12.54	2.46	38.08
75	10-Aug-94	1.26	16.00	0.63	557.72	0.90	15.49	2.16	32.12
75	23-Mar-95	1.99	34.55	2.37	585.40	0.36	10.22	2.35	47.14
75	04-Jun-96	1.80	34.84	3.59	675.97	0.42	23.28	2.22	61.71
75	31-Jul-96	1.64	9.66	6.78	564.09	0.47	19.53	2.11	35.97
75	18-Oct-96	2.33	43.35	0.97	546.07	0.44	10.33	2.77	54.65
82	03-Mar-94	4.86	45.19	9.33	568.92	0.38	6.45	5.24	61.69
82	10-Aug-94	2.86	51.06	0.69	581.77	0.44	6.49	3.30	58.24
82	23-Mar-95	2.58	41.20	0.94	594.30	0.22	6.47	2.80	48.61
82	04-Jun-96	2.78	33.59	9.20	688.00	0.37	12.21	3.15	55.00
82	31-Jul-96	1.10	1.25	1.88	621.36	0.63	19.68	1.73	22.81
82	18-Oct-96	3.22	39.29	5.68	547.46	0.38	2.19	3.60	47.16
F1	03-Mar-94	0.40	6.30	1.15	133.82	0.31	12.45	0.71	19.90
F1	10-Aug-94	2.83	44.80	1.16	515.75	0.28	4.73	3.11	50.69
F1	23-Mar-95	1.50	28.24	0.39	389.20	0.37	8.86	1.87	37.49
F1	04-Jun-96	0.17	1.19	1.01	35.88	0.33	14.91	0.50	17.11
F1	31-Jul-96	0.21	1.90	1.78	92.54	0.35	9.56	0.56	13.24
F1	18-Oct-96	2.84	46.22	2.64	519.69	0.21	6.11	3.05	54.97
F2	03-Mar-94	0.15	0.09	0.33	72.31	0.37	12.05	0.52	12.47
F2	10-Aug-94	0.27	1.12	0.12	103.17	0.45	12.32	0.72	13.56
F2	23-Mar-95	0.09	0.13	0.20	32.99	0.40	11.13	0.49	11.46
F2	04-Jun-96	0.12	0.46	0.21	41.13	0.41	12.14	0.53	12.81
F2	31-Jul-96	0.05	0.03	0.19	103.19	0.35	7.18	0.40	7.40
F2	18-Oct-96	0.26	0.61	0.51	160.62	0.36	8.43	0.62	9.55
F3	03-Mar-94	0.16	0.01	0.13	43.51	0.31	10.63	0.47	10.77
F3	10-Aug-94	0.10	0.02	0.10	39.20	0.36	7.80	0.46	7.92
F3	04-Jun-96	0.09	0.22	0.30	32.21	0.32	8.66	0.41	9.18
F3	31-Jul-96	0.15	0.05	0.51	43.14	0.38	7.51	0.53	8.07
F3	18-Oct-96	0.31	0.28	0.35	72.36	0.42	5.71	0.73	6.34
F4	03-Mar-94	0.15	0.15	0.68	52.14	0.25	11.39	0.40	12.22
F4	10-Aug-94	0.27	1.05	1.37	50.07	0.29	8.39	0.56	10.81
F4	23-Mar-95	0.07	0.04	0.23	30.97	0.38	10.24	0.45	10.51
F4	04-Jun-96	0.08	0.21	0.36	35.39	0.31	9.71	0.39	10.28
F4	31-Jul-96	0.08	0.07	0.17	68.89	0.33	6.89	0.41	7.13
F4	18-Oct-96	0.22	0.77	0.98	107.08	0.28	4.33	0.50	6.08

APPENDIX 3. continued

SITE	DATE	PO4 uM	NO3 uM	NH4 uM	SI uM	DOP uM	DON uM	TP uM	TN uM
F5	03-Mar-94	1.47	15.45	1.91	484.38	0.55	16.97	2.02	34.33
F5	10-Aug-94	1.61	25.83	0.63	492.46	0.57	11.22	2.18	37.68
F5	23-Mar-95	3.12	28.92	2.70	532.40	0.29	10.62	3.41	42.24
F5	04-Jun-96	2.31	33.04	7.44	577.15	0.49	28.29	2.80	68.77
F5	31-Jul-96	2.37	27.50	2.86	552.40	0.35	17.05	2.72	47.41
F5	18-Oct-96	2.93	45.46	4.68	539.58	0.26	4.52	3.19	54.66
F6	03-Mar-94	0.89	7.12	0.51	460.95	0.46	15.85	1.35	23.48
F6	23-Mar-95	0.76	10.50	0.43	491.80	0.92	13.18	1.68	24.11
F6	04-Jun-96	0.95	0.20	0.03	575.95	0.58	24.43	1.53	24.66
F6	31-Jul-96	1.00	0.26	0.03	545.42	0.56	19.41	1.56	19.70
F6	18-Oct-96	0.57	0.22	0.31	522.80	0.48	12.80	1.05	13.33
F7	03-Mar-94	0.63	4.03	0.35	459.58	0.54	18.27	1.17	22.65
F7	23-Mar-95	0.68	0.09	0.27	487.60	0.80	22.13	1.48	22.49
F7	04-Jun-96	0.89	0.09	0.00	577.12	0.65	25.85	1.54	25.94
F7	31-Jul-96	0.91	0.23	0.01	550.59	0.48	18.70	1.39	18.94
F7	18-Oct-96	0.49	0.09	0.23	524.04	0.57	12.82	1.06	13.14
F8	03-Mar-94	0.91	8.09	0.34	470.61	0.44	15.54	1.35	23.97
F8	10-Aug-94	0.68	0.33	0.40	469.92	1.00	21.98	1.68	22.71
F8	23-Mar-95	0.58	0.03	0.37	485.70	0.82	21.86	1.40	22.26
F8	04-Jun-96	0.79	0.02	0.00	572.24	0.64	24.34	1.43	24.36
F8	31-Jul-96	1.10	0.38	1.29	545.04	0.54	23.26	1.64	24.93
F8	18-Oct-96	0.34	0.04	0.39	519.24	0.66	17.05	1.00	17.48
M1	03-Mar-94	2.61	45.34	0.02	366.63	0.14	3.73	2.75	49.09
M1	10-Aug-94	2.43	37.94	0.09	415.35	0.06	3.24	2.49	41.27
M1	23-Mar-95	2.70	43.56	0.08	475.20	0.19	4.17	2.89	47.81
M1	04-Jun-96	2.62	45.52	0.09	529.84	0.05	4.87	2.67	50.48
M1	31-Jul-96	2.60	42.99	0.13	456.03	0.01	5.20	2.61	48.32
M2	03-Mar-94	0.22	1.37	0.21	25.55	0.26	6.74	0.48	8.32
M2	10-Aug-94	0.21	1.52	0.29	34.06	0.26	5.89	0.47	7.70
M2	23-Mar-95	0.30	1.67	0.30	31.50	0.28	6.82	0.58	8.79
M2	04-Jun-96	0.21	1.13	0.40	22.36	0.29	6.74	0.50	8.27
M2	31-Jul-96	0.33	3.61	0.46	56.11	0.27	4.80	0.60	8.87
M2	18-Oct-96	0.32	1.12	0.71	18.97	0.35	6.14	0.67	7.97
M3	03-Mar-94	0.23	1.42	0.21	26.16	0.21	5.93	0.44	7.56
M3	10-Aug-94	0.22	1.53	0.26	33.72	0.26	5.49	0.48	7.28
M3	23-Mar-95	0.30	1.70	0.32	32.18	0.32	7.76	0.62	9.78
M3	04-Jun-96	0.23	1.23	0.46	24.20	0.26	6.81	0.49	8.50
M3	31-Jul-96	0.29	2.74	0.49	44.63	0.29	6.15	0.58	9.38
M3	18-Oct-96	0.11	0.49	0.47	8.34	0.33	3.46	0.44	4.42

APPENDIX 3. continued

SITE	DATE	PO4 uM	NO3 uM	NH4 uM	SI uM	DOP uM	DON uM	TP uM	TN uM
M4	03-Mar-94	0.23	1.46	0.21	25.53	0.21	6.18	0.44	7.85
M4	10-Aug-94	0.24	1.82	0.26	34.53	0.28	6.01	0.52	8.09
M4	04-Jun-96	0.22	1.31	0.48	24.53	0.26	7.06	0.48	8.85
M4	31-Jul-96	0.32	3.45	0.43	55.14	0.28	5.34	0.60	9.22
M4	18-Oct-96	0.11	0.50	0.51	12.39	0.31	4.12	0.42	5.13
M5	03-Mar-94	0.17	0.42	0.12	8.62	0.20	6.37	0.37	6.91
M5	10-Aug-94	0.13	0.29	0.13	6.93	0.25	4.60	0.38	5.02
M5	23-Mar-95	0.20	0.44	0.23	7.93	0.27	6.29	0.47	6.96
M5	04-Jun-96	0.16	0.57	0.40	8.82	0.29	7.81	0.45	8.78
M5	31-Jul-96	0.16	0.84	0.25	14.24	0.31	5.35	0.47	6.44
M5	18-Oct-96	0.09	0.30	0.77	7.21	0.28	3.38	0.37	4.45
M6	03-Mar-94	0.40	3.24	0.32	78.95	0.18	5.64	0.58	9.20
M6	10-Aug-94	0.21	0.55	0.24	13.78	0.24	6.28	0.45	7.07
M6	23-Mar-95	0.48	1.51	0.48	60.46	0.26	7.61	0.74	9.60
M6	04-Jun-96	0.24	0.79	0.46	19.29	0.30	9.97	0.54	11.22
M6	31-Jul-96	0.41	2.89	0.69	86.78	0.33	7.92	0.74	11.50
M6	18-Oct-96	0.30	2.05	0.66	50.62	0.29	4.53	0.59	7.24
M7	03-Mar-94	0.27	1.27	0.17	55.79	0.19	6.85	0.46	8.29
M7	10-Aug-94	0.16	0.20	0.38	4.70	0.24	7.18	0.40	7.76
M7	23-Mar-95	0.29	0.98	0.56	31.52	0.26	5.82	0.55	7.36
M7	04-Jun-96	0.23	0.77	0.55	27.75	0.27	8.96	0.50	10.28
M7	31-Jul-96	0.31	1.74	1.08	72.37	0.36	10.69	0.67	13.51
M7	18-Oct-96	0.19	1.30	0.41	33.19	0.30	3.61	0.49	5.32
M8	03-Mar-94	0.26	1.24	0.15	55.85	0.25	6.05	0.51	7.44
M8	10-Aug-94	0.14	0.15	0.22	4.06	0.25	6.04	0.39	6.41
M8	23-Mar-95	0.28	0.66	0.62	23.19	0.24	5.76	0.52	7.04
M8	04-Jun-96	0.20	0.48	0.38	13.81	0.30	8.64	0.50	9.50
M8	31-Jul-96	0.20	0.66	0.42	37.94	0.34	6.81	0.54	7.89
M8	18-Oct-96	0.13	0.64	0.47	18.49	0.30	3.99	0.43	5.10
M9	03-Mar-94	0.15	0.18	0.12	10.10	0.21	6.08	0.36	6.38
M9	10-Aug-94	0.14	0.11	0.17	7.18	0.27	6.84	0.41	7.12
M9	23-Mar-95	0.25	0.44	0.44	28.52	0.47	6.01	0.72	6.89
M9	04-Jun-96	0.16	0.26	0.28	8.64	0.31	8.12	0.47	8.66
M9	31-Jul-96	0.20	0.86	0.70	45.03	0.33	7.47	0.53	9.03
M9	18-Oct-96	0.12	0.71	0.52	18.40	0.29	3.51	0.41	4.74

APPENDIX 3. continued

SITE	DATE	PO4 uM	NO3 uM	NH4 uM	SI uM	DOP uM	DON uM	TP uM	TN uM
M10	03-Mar-94	0.16	0.19	0.11	11.05	0.19	5.97	0.35	6.27
M10	10-Aug-94	0.12	0.13	0.12	4.55	0.27	8.47	0.39	8.72
M10	23-Mar-95	0.28	0.45	0.53	20.03	0.25	3.49	0.53	4.47
M10	04-Jun-96	0.16	0.24	0.27	8.38	0.38	8.82	0.54	9.33
M10	31-Jul-96	0.17	0.60	0.66	34.01	0.34	7.02	0.51	8.28
M10	18-Oct-96	0.12	0.49	0.58	14.02	0.30	3.70	0.42	4.77
WELL1	17-May-96	0.96	17.23	6.36	332.53	0.18	16.72	1.14	40.31
WELL1	04-Jun-96	1.02	22.83	25.08	278.55	0.14	18.53	1.16	66.44
WELL1	31-Jul-96	1.34	25.84	22.39	318.70	0.26	12.95	1.60	61.18
WELL1	18-Oct-96	0.01	26.66	3.21	106.35	0.28	1.07	0.29	30.94
WELL2	17-May-96	4.30	81.38	0.37	742.10	0.02	8.46	4.32	90.21
WELL2	04-Jun-96	4.38	89.97	0.12	741.23	0.10	7.11	4.48	97.20
WELL2	31-Jul-96	4.41	84.05	0.00	636.11	0.08	6.21	4.49	90.26
WELL2	18-Oct-96	4.00	75.51	0.07	610.33	0.23	6.54	4.23	81.12
WELL3	17-May-96	4.59	80.76	0.76	746.91	0.54	13.39	5.13	94.91
WELL3	04-Jun-96	3.89	75.46	0.01	742.66	0.01	6.04	3.90	81.51
WELL3	31-Jul-96	3.96	72.94	0.07	635.89	0.07	5.44	4.03	78.45
WELL3	18-Oct-96	3.95	73.48	0.18	617.43	0.17	4.21	4.12	77.87

APPENDIX 3. continued

SITE	DATE	TOC mg/l	TURBIDITY ntu	SALINITY o/oo	CHL-a ug/l	TEMP 'C	pH	OXYGEN mg/l
1	03-Mar-94	0.39	0.21	14.606	0.767	26.1	7.98	2.80
1	10-Aug-94	0.92	0.20	16.169	14.534	28.4	7.53	2.56
1	23-Mar-95		0.45	15.882	3.493	25.3	8.14	5.60
1	04-Jun-96		0.21	17.545	0.260	32.4	7.58	3.91
1	31-Jul-96		1.36	17.662	21.893	26.8	7.27	0.93
1	18-Oct-96		0.40	15.139	3.098	26.1	7.22	2.52
6	03-Mar-94	0.60	0.33	11.720	0.695	22.9	7.30	3.12
6	10-Aug-94	0.51	0.17	12.419	0.504	25.1	7.36	4.18
6	23-Mar-95		0.43	12.401	0.480	21.7	7.21	2.53
6	04-Jun-96		0.15	12.859	0.056	25.6	7.20	2.99
6	31-Jul-96		0.50	12.819	0.216	24.2	7.33	3.33
6	18-Oct-96		0.30	11.896	0.386	24.0	7.43	3.66
13	03-Mar-94		0.24	11.811	0.349	26.1	8.24	12.93
13	10-Aug-94		0.09	11.145	0.318	22.1	7.14	5.24
13	23-Mar-95		0.20	11.278	0.531	20.3	7.15	4.89
13	04-Jun-96		0.22	11.964	1.073	22.6	7.08	5.25
13	31-Jul-96		1.44	12.062	1.296	21.6	7.17	2.98
13	18-Oct-96		0.22	11.468	0.209	22.3	7.30	3.94
15	10-Aug-94			10.781	0.059	20.7	7.63	6.81
15	23-Mar-95		0.14	10.914	0.352	19.8	7.72	7.40
15	04-Jun-96		0.12	11.756	0.038	18.6	7.54	7.04
15	31-Jul-96		0.32	11.431	0.052	20.2	7.71	7.22
15	18-Oct-96		0.10	11.078	0.055	20.8	7.80	5.37
17	03-Mar-94	0.02	0.10	11.925	0.088	21.4	7.45	6.44
17	10-Aug-94	0.52		10.765	0.148	22.8	7.26	6.69
17	23-Mar-95		0.28	11.020	1.457	19.7	7.43	4.94
17	04-Jun-96		0.28	12.751	0.331	24.1	7.12	6.50
17	18-Oct-96		0.22	11.778	0.437	23.0	7.20	4.51
18	10-Aug-94		0.17	11.870	0.341	22.0	7.18	4.76
18	23-Mar-95		0.20	10.955	0.063	21.7	7.31	5.10
18	18-Oct-96		0.12	11.831	0.096	21.4	7.50	4.92
19	03-Mar-94		2.80	15.113	4.729	29.5	8.29	12.84
19	10-Aug-94	0.63	0.11	14.521	0.302	25.0	7.25	6.75
19	23-Mar-95		0.23	14.209	0.585	22.1	7.40	5.05
19	04-Jun-96		0.17	15.629	0.179	24.4	7.43	4.07
19	31-Jul-96		1.07	16.586	3.064	24.6	7.43	3.59
19	18-Oct-96		0.11	14.357	0.084	23.8	7.25	7.05

APPENDIX 3. continued

SITE	DATE	TOC mg/l	TURBIDITY ntu	SALINITY o/oo	CHL-a ug/l	TEMP 'C	pH	OXYGEN mg/l
26	03-Mar-94		0.05	12.335	0.017	23.0	7.92	8.50
26	23-Mar-95		0.18	12.255	0.024	20.6	7.87	5.62
26	04-Jun-96		0.16	13.140	0.028	22.1	7.84	7.65
26	31-Jul-96		0.62	13.083	0.083	21.6	7.95	7.20
26	18-Oct-96		0.07	12.927	0.027	23.0	7.96	6.91
27	10-Aug-94		0.06	12.773	0.006	22.0	7.89	8.16
47	03-Mar-94		0.11	12.760	0.203	22.2	7.80	7.16
47	10-Aug-94		0.07	12.418	0.120	21.9	7.77	8.96
47	23-Mar-95		0.21	12.760	0.228	22.0	7.85	5.13
47	04-Jun-96		0.23	13.009	0.281	22.90	7.77	7.12
47	31-Jul-96		1.20	12.577	0.172	22.20	7.81	6.98
47	18-Oct-96		0.32	12.497	0.123	21.80	7.73	5.50
51	03-Mar-94	0.14	0.07	12.374	0.047	21.3	7.87	7.93
51	10-Aug-94	0.36	0.08	10.439	0.140	23.5	7.86	8.15
51	23-Mar-95		0.08	11.042	0.113	22.4	7.92	5.91
51	04-Jun-96		0.10	12.503	0.080	21.60	7.63	7.83
51	31-Jul-96		0.13	11.384	0.055	21.20	7.85	8.06
51	18-Oct-96		0.14	9.903	0.027	22.30	7.83	5.68
55	03-Mar-94	0.10	0.11	9.352	0.032	23.0	7.99	8.80
55	10-Aug-94	0.37	0.07	8.771	0.093	23.3	7.83	7.75
55	23-Mar-95		0.20	8.698	0.045	20.9	7.94	5.90
55	04-Jun-96		0.15	9.505	0.034	22.60	7.97	7.87
55	31-Jul-96		0.13	9.218	0.036	23.60	7.96	7.96
55	18-Oct-96		0.34	8.467	0.064	23.80	8.00	6.45
62	03-Mar-94	0.14	0.32	12.293	0.077	19.9	7.76	6.42
62	10-Aug-94	0.37	0.12	12.168	0.062	21.7	7.78	9.36
62	23-Mar-95		0.87	12.204	0.043	20.1	7.78	6.02
62	04-Jun-96		0.23	12.513	0.057	21.2	7.69	6.70
62	31-Jul-96		0.10	12.593	0.089	23.6	7.77	6.85
62	18-Oct-96		0.11	12.335	0.058	20.3	7.91	6.10
65	03-Mar-94	1.53	0.69	13.752	4.302	29.8	7.23	5.75
65	23-Mar-95		0.75	17.828	3.470	27.5	7.59	7.00
65	04-Jun-96		0.60	17.245	0.538	24.8	7.27	3.16
65	31-Jul-96		0.20	19.902	0.725	27.2	7.47	1.25
65	18-Oct-96		0.52	16.067	0.435	31.7	7.62	6.80

APPENDIX 3. continued

SITE	DATE	TOC mg/l	TURBIDITY ntu	SALINITY o/oo	CHL-a ug/l	TEMP 'C	pH	OXYGEN mg/l
75	03-Mar-94	0.78	0.32	8.459	3.121	29.6	8.80	15.69
75	10-Aug-94	1.26	0.13	8.895	0.403	27.7	8.55	13.40
75	23-Mar-95		0.43	8.366	1.122	27.3	8.28	10.74
75	04-Jun-96		0.40	9.178	0.235	28.6	8.21	6.77
75	31-Jul-96		0.50	9.599	0.406	27.5	8.02	7.35
75	18-Oct-96		0.38	8.487	0.480	26.8	7.44	4.84
82	03-Mar-94	0.58	0.25	8.086	0.433	20.2	6.92	4.35
82	10-Aug-94	0.79	0.09	8.211	0.222	22.9	7.94	11.68
82	23-Mar-95		0.22	8.283	0.813	21.4	7.20	6.73
82	04-Jun-96		0.35	8.367	1.052	22.6	6.93	3.97
82	31-Jul-96		2.90	8.641	4.362	24.2	6.94	4.92
82	18-Oct-96		0.35	8.201	1.237	24.1	6.98	3.34
F1	03-Mar-94	0.67	0.53	27.644	6.093	32.0	8.08	8.15
F1	10-Aug-94	0.49	0.17	11.964	1.628	32.5	7.95	7.35
F1	23-Mar-95		0.63	17.497	2.017	30.3	7.98	6.92
F1	04-Jun-96		0.26	33.791	0.429	31.6	8.16	7.41
F1	31-Jul-96		0.79	31.365	1.192	29.0	8.13	6.05
F1	18-Oct-96		0.60	11.380	0.958	27.3	7.34	6.15
F2	03-Mar-94		0.33	31.531	3.429	29.3	8.09	6.35
F2	10-Aug-94		0.28	30.739	2.046	29.7	8.04	7.50
F2	23-Mar-95		0.83	33.316	0.721	27.9	8.20	6.03
F2	04-Jun-96		0.42	33.640	1.705	28.80	8.23	7.03
F2	31-Jul-96		1.05	31.010	2.328	27.70	8.15	6.38
F2	18-Oct-96		0.60	27.573	2.028	29.00	7.95	5.80
F3	03-Mar-94		0.69	32.821	2.908	29.1	8.10	6.44
F3	10-Aug-94		0.76	33.407	3.581	30.1	8.07	6.92
F3	04-Jun-96		0.36	33.762	1.481	28.10	8.09	7.01
F3	31-Jul-96		2.60	33.106	2.733	28.00	8.16	5.89
F3	18-Oct-96		1.04	31.626	3.461	28.80	8.08	5.56
F4	03-Mar-94	0.59	0.18	32.402	0.812	29.9	8.09	7.14
F4	10-Aug-94	0.44	0.13	32.875	0.760	30.7	8.05	7.33
F4	23-Mar-95		0.89	33.377	1.060	27.8	8.19	6.40
F4	04-Jun-96		0.25	33.663	0.482	27.90	8.17	6.42
F4	31-Jul-96		0.81	31.883	1.777	28.00	8.17	5.94
F4	18-Oct-96		0.37	29.933	0.838	29.20	8.12	5.95

APPENDIX 3. continued

SITE	DATE	TOC mg/l	TURBIDITY ntu	SALINITY o/oo	CHL-a ug/l	TEMP 'C	pH	OXYGEN mg/l
F5	03-Mar-94	0.52	0.50	11.156	7.876	25.5	8.15	7.85
F5	10-Aug-94	0.80	0.10	12.106	0.318	29.4	7.53	5.36
F5	23-Mar-95		0.39	11.515	0.662	24.2	7.22	1.90
F5	04-Jun-96		0.58	13.005	0.307	30.2	7.72	2.30
F5	31-Jul-96		0.50	12.058	0.422	28.2	7.46	2.62
F5	18-Oct-96		0.26	10.799	0.229	28.1	7.42	3.82
F6	03-Mar-94		0.48	11.483	11.007	26.0	8.21	5.63
F6	23-Mar-95		1.27	11.814	3.384	27.5	8.35	8.30
F6	04-Jun-96		1.49	13.127	6.169	28.6	8.46	9.82
F6	31-Jul-96		3.20	12.124	10.300	28.0	8.38	9.33
F6	18-Oct-96		2.00	11.398	6.607	29.5	8.31	7.01
F7	03-Mar-94		0.67	11.547	11.976	25.9	8.20	5.47
F7	23-Mar-95		1.22	11.838	5.546	27.4	8.38	8.80
F7	04-Jun-96		1.53	13.129	8.422	28.9	8.43	9.27
F7	31-Jul-96		2.40	12.117	10.145	28.0	8.41	9.25
F7	18-Oct-96		1.90	11.418	5.976	29.5	8.25	7.41
F8	03-Mar-94	0.78	0.45	11.438	9.845	25.5	8.03	4.82
F8	10-Aug-94		0.24	12.395	8.953	31.5	8.33	8.02
F8	23-Mar-95		1.26	12.019	3.271	27.6	6.86	8.79
F8	04-Jun-96		1.57	13.259	3.047	29.3	8.40	9.39
F8	31-Jul-96		3.40	11.949	8.158	28.3	8.21	8.95
F8	18-Oct-96		1.90	11.734	4.578	30.4	7.81	5.90
M1	03-Mar-94	0.05	0.08	17.049	0.115	21.3	7.77	5.67
M1	10-Aug-94	0.44	0.10	18.393	0.203	23.2	7.64	7.93
M1	23-Mar-95		0.11	17.138	0.163	21.1	7.91	6.03
M1	04-Jun-96		0.13	17.624	0.050	22.6	7.50	5.84
M1	31-Jul-96		0.55	16.910	0.135	21.3	7.53	5.50
M2	03-Mar-94		0.08	33.445	0.133	25.4	8.15	6.82
M2	10-Aug-94	0.16	0.10	33.394	0.291	26.5	8.07	8.00
M2	23-Mar-95		0.18	33.263	0.115	24.4	8.23	7.51
M2	04-Jun-96		0.23	33.782	0.075	25.50	8.11	7.11
M2	31-Jul-96		0.23	32.638	0.154	23.70	8.05	6.38
M2	18-Oct-96		0.20	34.096	0.109	27.30	8.23	6.96
M3	03-Mar-94		0.05	33.413	0.184	25.2	8.18	6.96
M3	10-Aug-94		0.07	33.381	0.294	27.1	8.12	8.12
M3	23-Mar-95		0.20	33.278	0.127	24.8	8.20	7.86
M3	04-Jun-96		0.27	33.738	0.062	25.10	8.08	7.16
M3	31-Jul-96		0.15	33.096	0.172	23.80	8.12	6.40
M3	18-Oct-96		0.15	34.535	0.140	27.30	8.23	6.95

APPENDIX 3. continued

SITE	DATE	TOC mg/l	TURBIDITY ntu	SALINITY o/oo	CHL-a ug/l	TEMP 'C	pH	OXYGEN mg/l
M4	03-Mar-94	0.07	0.05	33.447	0.114	25.4	8.16	6.04
M4	10-Aug-94	0.21	0.10	33.268	0.225	27.2	8.11	8.07
M4	04-Jun-96		0.12	33.697	0.063	25.10	8.07	7.09
M4	31-Jul-96		0.32	32.710	0.164	23.80	8.14	6.28
M4	18-Oct-96		0.35	34.342	0.084	27.30	8.23	6.95
M5	03-Mar-94		0.06	34.024	0.111	25.5	8.05	6.39
M5	10-Aug-94		0.07	34.362	0.140	27.3	8.08	8.05
M5	23-Mar-95		0.10	34.103	0.107	24.6	8.12	7.58
M5	04-Jun-96		0.16	34.162	0.050	24.70	8.05	7.18
M5	31-Jul-96		0.12	34.216	0.123	23.80	8.13	6.03
M5	18-Oct-96		0.19	34.643	0.100	27.30	8.22	6.71
M6	03-Mar-94	0.30	0.27	30.743	0.403	24.7	7.99	6.70
M6	10-Aug-94	0.30	0.28	34.301	0.170	29.9	8.21	8.01
M6	23-Mar-95		0.65	32.118	0.645	27.4	8.20	8.04
M6	04-Jun-96		0.55	33.923	0.128	27.4	8.16	6.14
M6	31-Jul-96		1.50	31.278	0.882	27.3	8.24	6.87
M6	18-Oct-96		0.57	32.839	0.798	28.7	7.96	6.81
M7	03-Mar-94		0.11	31.883	0.296	25.2	8.09	7.28
M7	10-Aug-94		0.12	34.430	0.222	29.3	8.20	7.91
M7	23-Mar-95		0.27	33.318	0.117	26.8	8.24	7.54
M7	04-Jun-96		0.16	33.597	0.051	27.3	8.26	6.77
M7	31-Jul-96		1.00	31.824	0.243	27.2	8.26	8.00
M7	18-Oct-96		0.25	33.308	0.073	28.8	8.33	7.22
M8	03-Mar-94		0.10	31.874	0.581	24.9	8.13	7.20
M8	10-Aug-94		0.14	34.430	0.195	29.4	8.18	7.80
M8	23-Mar-95		0.16	33.601	0.141	26.8	8.24	7.76
M8	04-Jun-96		0.11	33.993	0.109	27.3	8.22	6.30
M8	31-Jul-96		0.70	33.142	0.247	27.2	8.25	7.74
M8	18-Oct-96		0.22	33.959	0.105	28.8	8.35	7.09
M9	03-Mar-94		0.07	33.948	0.123	25.5	8.18	7.50
M9	10-Aug-94		0.10	34.366	0.170	29.5	8.15	7.75
M9	23-Mar-95		0.19	33.708	0.211	26.8	8.21	7.50
M9	04-Jun-96		0.16	34.132	0.075	27.3	8.17	6.02
M9	31-Jul-96		0.20	32.833	0.228	27.2	8.24	7.25
M9	18-Oct-96		0.18	33.946	0.063	28.8	8.34	6.92

APPENDIX 3. continued

SITE	DATE	TOC mg/l	TURBIDITY ntu	SALINITY o/oo	CHL-a ug/l	TEMP 'C	pH	OXYGEN mg/l
M10	03-Mar-94		0.07	33.908	0.170	25.2	8.15	6.22
M10	10-Aug-94		0.09	34.383	0.122	29.5	8.18	7.63
M10	23-Mar-95		0.16	33.702	0.143	26.8	8.20	7.56
M10	04-Jun-96		0.13	34.142	0.074	27.3	8.16	5.82
M10	31-Jul-96		0.50	33.243	0.256	27.2	8.22	6.77
M10	18-Oct-96		0.15	34.176	0.078	28.8	8.33	7.09
WELL1	17-May-96		0.23	9.873			8.03	
WELL1	04-Jun-96		0.33	8.706		21.80	9.10	1.06
WELL1	31-Jul-96		1.63	9.451		20.9	9.3	1.21
WELL1	18-Oct-96		2.10	9.034		21.2	10.31	1.55
WELL2	17-May-96		0.20	4.921			6.32	
WELL2	04-Jun-96		0.11	4.866		18.21	7.20	8.42
WELL2	31-Jul-96		1.86	4.901		19.8	7.64	8.03
WELL2	18-Oct-96		0.21	4.676		19.8	7.37	7.43
WELL3	17-May-96		0.29	6.017			6.35	
WELL3	04-Jun-96		0.25	5.914		19.27	6.72	7.86
WELL3	31-Jul-96		0.72	5.944		20.8	6.9	7.53
WELL3	18-Oct-96		0.19	5.854		20.5	6.96	7.48

APPENDIX 4. Results of four pesticide screens on a single surface sediment sample from the middle of Aimakapa'a Fishpond and two tissue composite samples for mullet and milk-fish from this fishpond. All samples collected in March 1997.

ANALYTE	Sediment Sample	Mullet Sample	Chanos Sample	Detection Limits	Units
CHLORINATED PESTICIDES AND PCB's					
Aldrin	ND	ND	ND	0.002	mg/Kg
Alpha BHC	ND	ND	ND	0.002	mg/Kg
Beta BHC	ND	ND	ND	0.003	mg/Kg
Chlordane	ND	ND	ND	0.008	mg/Kg
DDD	ND	ND	ND	0.004	mg/Kg
DDE	ND	ND	ND	0.003	mg/Kg
DDT	ND	ND	ND	0.003	mg/Kg
Delta BHC	ND	ND	ND	0.005	mg/Kg
Dieldrin	ND	ND	ND	0.003	mg/Kg
Endosulfan I	ND	ND	ND	0.004	mg/Kg
Endosulfan II	ND	ND	ND	0.003	mg/Kg
Endosulfan sulfate	ND	ND	ND	0.003	mg/Kg
Endrin	ND	ND	ND	0.004	mg/Kg
Endrin aldehyde	ND	ND	ND	0.004	mg/Kg
Gamma BHC (Lindane)	ND	ND	ND	0.011	mg/Kg
Heptachlor	ND	ND	ND	0.002	mg/Kg
Heptachlor epoxide	ND	ND	ND	0.003	mg/Kg
Methoxychlor	ND	ND	ND	0.025	mg/Kg
PCB-1016	ND	ND	ND	0.033	mg/Kg
PCB-1221	ND	ND	ND		mg/Kg
PCB-1232	ND	ND	ND	0.040	mg/Kg
PCB-1242	ND	ND	ND	0.020	mg/Kg
PCB-1248	ND	ND	ND	0.080	mg/Kg
PCB-1254	ND	ND	ND	0.011	mg/Kg
PCB-1260	ND	ND	ND	0.025	mg/Kg
Toxaphene	ND	ND	ND	0.240	mg/Kg
ORGANOPHOSPHATE PESTICIDES					
Azinophos Methyl (Guthion)	ND	ND	ND	1.00	mg/Kg
Bolstar	ND	ND	ND	0.10	mg/Kg
Chlorpyrifos (Dusban)	ND	ND	ND	0.20	mg/Kg
Coumaphos	ND	ND	ND	1.00	mg/Kg
Demeton (Systox)-O	ND	ND	ND	0.17	mg/Kg
Demeton (Systox)-S	ND	ND	ND	0.17	mg/Kg
Diazinon	ND	ND	ND	0.40	mg/Kg
Dichlorvos	ND	ND	ND	0.07	mg/Kg

APPENDIX 4. continued

ANALYTE	Sediment Sample	Mullet Sample	Chanos Sample	Detection Limits	Units
Disulfoton (Disyston)	ND	ND	ND	0.13	mg/Kg
Ethoprop	ND	ND	ND	0.17	mg/Kg
Fensulfothion	ND	ND	ND	1.00	mg/Kg
Fenthion	ND	ND	ND	0.07	mg/Kg
Merphos	ND	ND	ND	0.17	mg/Kg
Mevinphos (Phosdrin)	ND	ND	ND	0.20	mg/Kg
Naled (Dibrom)	ND	ND	ND	0.07	mg/Kg
Parathion Methyl	ND	ND	ND	0.02	mg/Kg
Phorate (Thimet)	ND	ND	ND	0.10	mg/Kg
Ronnel	ND	ND	ND	0.20	mg/Kg
Stirophos (Tetrachlorvinphos)	ND	ND	ND	3.35	mg/Kg
Tokuthion (Prothiofos)	ND	ND	ND	0.33	mg/Kg
Trichloronate	ND	ND	ND	0.10	mg/Kg
VOLATILE ORGANIC COMPOUNDS					
1,1,1,2-Tetrachloroethane	ND	ND	ND	5	ug/Kg
1,1,1-Trichloroethane	ND	ND	ND	5	ug/Kg
1,1,2,2-Tetrachloroethane	ND	ND	ND	5	ug/Kg
1,1,2-Trichloroethane	ND	ND	ND	5	ug/Kg
1,1-Dichloroethane	ND	ND	ND	5	ug/Kg
1,1-Dichoroethene	ND	ND	ND	5	ug/Kg
1,2,3-Trichoropropane	ND	ND	ND	5	ug/Kg
1,2-Dibromo-3-chloropropane	ND	ND	ND	100	ug/Kg
1,2-Dibromoethane	ND	ND	ND	5	ug/Kg
1,2-Dichloroethane	ND	ND	ND	5	ug/Kg
1,2-Dichloropropane	ND	ND	ND	5	ug/Kg
1,4-Dichloro-2-butene	ND	ND	ND	100	ug/Kg
2-Butanone	ND	ND	ND	100	ug/Kg
2-Chloroethylvinyl ether	ND	ND	ND	50	ug/Kg
4-Methyl-2-pentanone	ND	ND	ND	50	ug/Kg
Acetone	ND	ND	ND	100	ug/Kg
Acetonitrile	ND	ND	ND	100	ug/Kg
Allyl chloride	ND	ND	ND	5	ug/Kg
Benzene	ND	ND	ND	5	ug/Kg
Benzyl chloride (-chlorotoluene)	ND	ND	ND	100	ug/Kg
Bromodichloromethane	ND	ND	ND	5	ug/Kg
Bromoform	ND	ND	ND	5	ug/Kg
Bromomethane	ND	ND	ND	10	ug/Kg
Carbon disulfide	ND	ND	ND	100	ug/Kg
Carbon tetrachloride	ND	ND	ND	5	ug/Kg

APPENDIX 4. continued

ANALYTE	Sediment Sample	Mullet Sample	Chanos Sample	Detection Limits	Units
Chlorobenzene	ND	ND	ND	5	ug/Kg
Chlorodibromomethane	ND	ND	ND	5	ug/Kg
Chloroethane	ND	ND	ND	10	ug/Kg
Chloroform	ND	ND	ND	5	ug/Kg
Chloromethane	ND	ND	ND	10	ug/Kg
Chloroprene	ND	ND	ND	5	ug/Kg
Dibromomethane	ND	ND	ND	5	ug/Kg
Dichlorodifluoromethane	ND	ND	ND	5	ug/Kg
Ethyl benzene	ND	ND	ND	5	ug/Kg
Ethyl methacrylate	ND	ND	ND	5	ug/Kg
Isobutyl alcohol	ND	ND	ND	100	ug/Kg
Methacrylonitrile	ND	ND	ND	100	ug/Kg
Methyl iodide	ND	ND	ND	5	ug/Kg
Methyl methacrylate	ND	ND	ND	50	ug/Kg
Methylene chloride	ND	ND	ND	5	ug/Kg
Pentachloroethane	ND	ND	ND	10	ug/Kg
Propionitrile	ND	ND	ND	100	ug/Kg
Styrene	ND	ND	ND	5	ug/Kg
Tetrachloroethene	ND	ND	ND	5	ug/Kg
Toluene	ND	ND	ND	5	ug/Kg
Trichloroethene	ND	ND	ND	5	ug/Kg
Vinyl acetate	ND	ND	ND	50	ug/Kg
Vinyl chloride	ND	ND	ND	10	ug/Kg
Xylene (total)	ND	ND	ND	5	ug/Kg
cis-1,3-Dichloropropene	ND	ND	ND	5	ug/Kg
trans-1,2-Dichloroethene	ND	ND	ND	5	ug/Kg
trans-1,3-Dichloropropene	ND	ND	ND	5	ug/Kg

APPENDIX 4. continued

ANALYTE	Sediment Sample	Mullet Sample	Chanos Sample	Detection Limits Sediments Mullet	Units	Detection Limits Milkfish	Units
ACID/BASE/NEUTRAL EXTRACTABLES							
1,2,4-Trichlorobenzene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
1,2-Dichlorobenzene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
2,4,5-Trichlorophenol	ND	ND	ND	1665	ug/Kg	49950	ug/Kg
2,4,6-Trichlorophenol	ND	ND	ND	1665	ug/Kg	49950	ug/Kg
2,4-Dichlorophenol	ND	ND	ND	333	ug/Kg	9990	ug/Kg
2,4-Dimethylphenol	ND	ND	ND	333	ug/Kg	9990	ug/Kg
2,4-Dinitrophenol	ND	ND	ND	1665	ug/Kg	49950	ug/Kg
2,4-Dinitrotoluene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
2-Chloronaphthalene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
2-Chlorophenol	ND	ND	ND	333	ug/Kg	9990	ug/Kg
2-Methylnapthalene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
2-Methylphenol	ND	ND	ND	333	ug/Kg	9990	ug/Kg
2-Nitroaniline	ND	ND	ND	1665	ug/Kg	49950	ug/Kg
3,3 Dichlorobenzidine	ND	ND	ND	333	ug/Kg	9990	ug/Kg
3 Nitroaniline	ND	ND	ND	1665	ug/Kg	49950	ug/Kg
4,6-Dinitro-2-methylphenol	ND	ND	ND	1665	ug/Kg	49950	ug/Kg
4-Bromophenyl-phenylether	ND	ND	ND	333	ug/Kg	9990	ug/Kg
4-Chloro-3-methylphenol	ND	ND	ND	333	ug/Kg	9990	ug/Kg
4-Chloroaniline	ND	ND	ND	333	ug/Kg	9990	ug/Kg
4-Chlorophenyl-phenylether	ND	ND	ND	333	ug/Kg	9990	ug/Kg
4-Methylphenol	ND	ND	ND	333	ug/Kg	9990	ug/Kg
4-Nitroaniline	ND	ND	ND	1665	ug/Kg	49950	ug/Kg
Acenapthene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Acenapthylene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Anthracene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Benzo(a)anthracene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Benzo(a)pyrene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Benzo(b)fluoranthene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Benzo(g,h,i)perylene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Benzo(k)fluoroanthene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Benzyl alcohol	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Butylbenzylphthalate	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Chrysene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Di-n-butylphthalate	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Di-n-octylphthalate	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Dibenz(a,h)anthracene	ND	ND	ND	333	ug/Kg	9990	ug/Kg

APPENDIX 4. continued

ANALYTE	Sediment Sample	Mullet Sample	Chanos Sample	Detection Limits Sediments Mullet	Units	Detection Limits Milkfish	Units
Dibenzofuran	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Diethylphthalate	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Dimenthylphthalate	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Fluoranthene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Fluorene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Hexachlorbenzene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Hexachlorobutadiene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Hexachlorocyclopentadiene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Hexachloroethane	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Indeno(1,2,3-c,d)pyrene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Isophorone	ND	ND	ND	333	ug/Kg	9990	ug/Kg
N-Nitroso-di-n-propylamine	ND	ND	ND	333	ug/Kg	9990	ug/Kg
N-Nitrosodiphenylamine	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Naphthalene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Nitrobenzene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Pentachlorophenol	ND	ND	ND	1665	ug/Kg	49950	ug/Kg
Phenanthrene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Phenol	ND	ND	ND	333	ug/Kg	9990	ug/Kg
Pyrene	ND	ND	ND	333	ug/Kg	9990	ug/Kg
bis(2-Chloroethoxy)methane	ND	ND	ND	333	ug/Kg	9990	ug/Kg
bis(2-Chloroethyl)ether	ND	ND	ND	333	ug/Kg	9990	ug/Kg
bis(2-Chloroisopropyl)ether	ND	ND	ND	333	ug/Kg	9990	ug/Kg
bis(2-Ethylhexyl)phthalate	ND	ND	ND	333	ug/Kg	9990	ug/Kg

APPENDIX 5. Glossary of some terms used in this study.

A'a - Hawaiian term referring to a very rough clinker lava. A'a lava is typically comprised of sharp, angular rocks usually with considerable space between the rocks thus is a setting in which anchialine pools are often found.

Allochthonous - origin elsewhere; formed elsewhere rather than *in situ*.

Anchialine - referring to a class of pools located close to the seashore having measurable salinities and whose water surface rises and falls with the tides yet having no surface connections to the sea. Anchialine pools are restricted to porous limestone or lava substrates in tropical and subtropical parts of the world.

Crevicular - here relating to or involving crevices or cracks in rocks; a shrimp with crevicular habits is one that lives in cracks or interstices in the substrate.

Ecotype - morphological or color variation in a species.

Epigeal - used here referring to species that live in the lighted portions of anchialine pools as opposed to hypogeal (see below).

Euryhaline - species with a wide tolerance to salinity; thus a euryhaline species is one that may survive in both low and high salinity habitats as opposed to a stenohaline species (i.e., one with narrow salinity tolerances).

Hypogeal - here species that have crevicular habits, living in the rock interstices below the apparent bottoms of anchialine pools.

Makai - Hawaiian term referring to the direction towards the sea; example: the trail lead in a makai direction.

Mauka - Hawaiian term referring to the direction towards the mountains as opposed to towards the sea.

Pahoehoe - A Hawaiian term referring to lava that has flowed forming a rather smooth, billowy or ropy surface.