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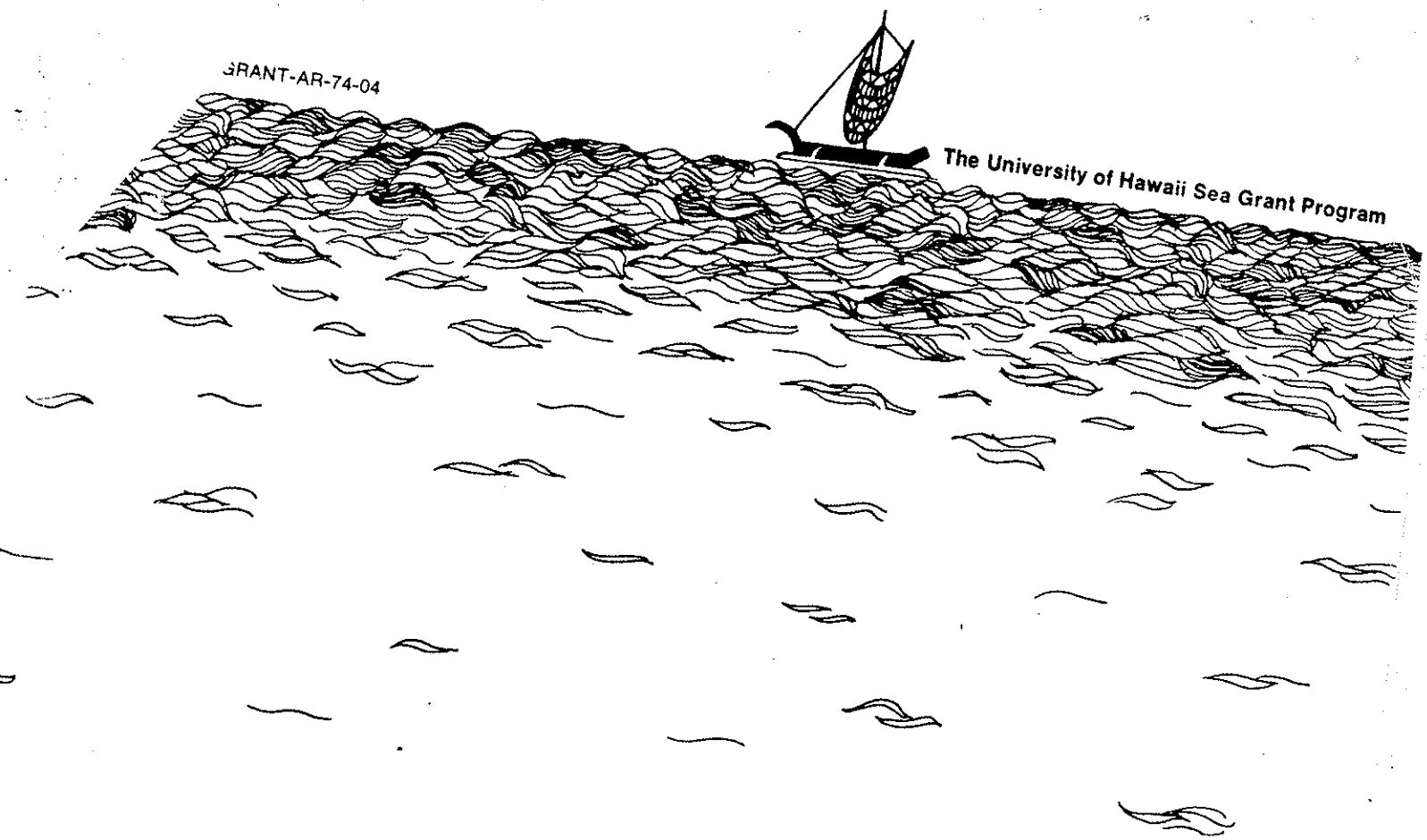

The University of Hawaii Sea Grant Program

Aquatic Survey of the Kona Coast Ponds, Hawaii Island

John A. Maciolek and Richard E. Brock

April 1974

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by

John A. Maciolek
and
Richard E. Brock

Sea Grant Advisory Report
UNIHI-SEAGRANT-AR-74-04

April 1974

This report is published under Grant No. 04-3-158-29, NOAA Office of Sea Grant, Department of Commerce in conjunction with the Hawaii Cooperative Fishery Unit, U.S. Bureau of Sport Fisheries and Wildlife (Contract No. 14-16-001-4896) administered under the direction of Dr. John Maciolek and the Planning Department of the County of Hawaii. The U.S. Government is authorized to produce and distribute reprints for governmental purposes notwithstanding any copyright notations that may appear hereon.

Team inventories an unvegetated pond located in black, sun-heated lava in the Awakee-Makalawena section of North Kona District.

ABSTRACT

During a 17-month period beginning July 1972, 318 shoreline ponds were located and surveyed in the five land districts of Hawaii Island's leeward coast. The survey concerned an inventory of environmental and biological characteristics for the purpose of assessing their scientific and natural resource values. This inventory includes all coastal waters--from excavated wells and small fissures to large Hawaiian fishponds--that are not part of the marine ecosystem. Relevant information on geology and terrestrial vegetation is presented.

Collectively, the ponds have distinctive environmental features: rocky (lava) basins, usually with biogenic sediments; mostly small (less than 100 sq m in surface area) and shallow (less than 1 m deep); mixohaline water (average salinity 7°/₀₀) representing an inland extension of the oceanic water table diluted by subsurface freshwater runoff; and tidal fluctuation of surface level.

Characteristic aquatic vegetation consists of the vascular aquatic pondweed, Ruppia maritima, *and two types of encrusting algal communities. Pond animal communities are divided into two main groups depending upon their connections to the sea. The 13 ponds with surface connections to the sea have diverse species that are mainly of marine origin. The remaining 305 ponds with only subterranean water connections contain fewer but more distinctive animals. In these "closed" ponds, crustaceans and mollusks are the most abundant and characteristic animals among the 55 taxons recognized. Nine of the most common native species are designated as being representative of this distinctive "anchialine" ecosystem class; representatives included four shrimps, three mollusks, and two fishes. Small red shrimps or opaeula* (Halocaridina rubra) *are probably the most characteristic species. In addition, several new species of crustaceans and other invertebrates were found during the survey.*

In final analysis, eight locations were selected as having ponds of exceptional natural geological and biological qualities that deserve protection as a unique and valuable resource. Most are in remote areas between Waiulua Bay (South Kohala District) in the north and Ka Lae (Ka'u District) in the south. Detailed maps and biota catalogs are provided.

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INTRODUCTION

More than a hundred sinuous miles of shoreline from Upolu Point southward to Ka Lae constitute Hawaii Island's leeward coastline. This western shore in its entirety is considered here as the Kona coast. Compared with windward areas, it has a definite arid appearance. Perennial streams are lacking and there are few intermittent streams of consequence. Two striking features of the Kona coast are the expanses of barren to sparsely vegetated lavas (a consequence of recent volcanism and a dry climate) and the occurrence of ponds, singly and in groups, at discrete locations very near the shoreline.

Although these coastal ponds figured prominently in early Hawaiian culture and a few are known to provide important waterbird habitats today, they had not been considered or evaluated as distinctive natural features. Similar ponds on Maui's Kalua o Lapa lava flow that forms Cape Kinau had been studied beginning in 1971. There, several new species of native crustaceans and other unusual forms of aquatic life were discovered. Certain characteristic features of the Kinau ponds, such as waters of intermediate salinity (brackish) and tidal surface level fluctuations, represent the inland extension of the oceanic water table. Recently, Holthuis (1973) proposed the class term "anchialine" (from Greek *anchialos* meaning near the sea) for such waters, i.e., shoreline pools without surface connection to the sea, having waters of measurable salinity and showing tidal rhythms. Such waters are known to occur variously around the world in lavas and elevated fossil reefs. In the Hawaiian Archipelago, these anchialine ponds exist almost exclusively along the shorelines of Hawaii and southwest Maui Islands.

Collectively, the Kona coast anchialine ponds have been an unrecognized natural attribute of the state and county. They have been decimated increasingly in recent years by coastal development associated with the growth of population and economy. This investigation was initiated to inventory Kona coast ponds extensively with regard to their numbers, locations, environmental characteristics, and particularly, their biota. The survey data, complementing other resource evaluations of the Kona coast, are intended to provide guidelines for the planning of both conservation and prudent development.

This investigation was accomplished mainly by funds and resources of the Bureau of Sport Fisheries and Wildlife, US Department of the Interior (University of Hawaii Contract No. 14-16-001-4896) with supplementary assistance from the University of Hawaii Sea Grant Program. Especially valuable was the field work done by students of the Marine Option Program, Hilo campus.

SCOPE OF SURVEY

Preliminary inventory of ponds was accomplished by small field crews of two to six persons working southward along the coast from the general area of Kawaihae. Pond locations were marked on standard quadrangle maps (USGS, 1:24,000). Information recorded include: size, depth, basin character, bank

vegetation, aquatic flora, temperature, salinity, and turbidity. Aquatic fauna was given special attention; invertebrates from most locations were preserved in a reference collection. Several ponds and pond areas were revisited after preliminary inventory for further specimen collecting and observations. The data, too voluminous to include here in entirety, are summarized in the Appendices of this report. Most of the survey was done during the summer and fall of 1972 and supplementary field information was obtained through October 1973.

Some ponds appear at roadside but most are in areas of trackless lava. Except for a few areas where pond occurrence seemed unlikely, the coastline was explored on foot as thoroughly as possible in the time available. Only selected ponds were inventoried at locations of pond multiplicity; elsewhere, all ponds found were sampled. In all, data were obtained on 318 ponds.

Because this survey was intended to be comprehensive with regard to coastal ponds, all water exposures not definitely part of the littoral marine ecosystem were included. The term "pond" is used here in a broad sense to cover typical ponds as well as waters in open wells, excavations, fissures, and fractures and also waters in dimly lit recesses under lava rock overhangs. Ponds without surface connection to the sea, here termed "closed," make up 96 percent of the total number inventoried. "Open ponds" are waters with restricted or occasional surface connections to the sea.

GEOLOGICAL RELATIONSHIPS

Absence of anchialine ponds in older parts of the Hawaiian Archipelago indicates that lava age is important to their occurrence. Volcanic chronology as described by MacDonald (1953) shows that about four-fifths of the Kona coastline consists of recent or post-Pleistocene lavas. Older deposits form the shorelines of North Kohala and northern North Kohala Districts (cf., locality map, Appendix A), the Kamaoa Puueo plain of Ka Lae, and a small anomaly at Kealakekua Bay. They consist of mid-Pleistocene and earlier lavas overlain by late-Pleistocene Pahala ash. Only five ponds, less than 2 percent of the total, occurred in those lavas and none was a typical anchialine water.

Post-Pleistocene lavas of the Kona coast include several historic flows beginning with the Kaupulehu flow of 1800-01. These lavas make up about 10 percent of the shoreline and contain 19 ponds. Among dated flows, however, there appears to be no correlation between lava age and number of ponds because of the added influences of topography, slope, and lava structure.

Pond basins are related to structural and depositional features. Lavas are too porous to support ponded water above sea level. Anchialine ponds occur mainly in low-lying flows having depressions which are sufficiently deep to extend into the water table. Such depressions usually are simple depositional features in aa and fractures or collapsed "bubbles" in pahoehoe. In lavas whose mean surface elevations are more than a few meters above sea level, water is found only in deep fissures or uncommon voids in the lava

structure. Recent coastal subsidence (Apple and MacDonald, 1966) may be important in the formation of anchialine ponds. Lastly, some ponds have resulted from shoreline depositional processes. Kuualii, Luahinewai, and Aimakapa (Appendix A: D-28, F-5, K-11) are examples of large ponds retained by beach bars.

Because anchialine waters are rare on ancient lavas, they are obviously temporary features on a geological time scale. Natural immediate obliteration occurs when flowing lavas override and fill existing pond depressions. Dramatic examples described by Kelly (1973) concern "destruction" of the Great Fishponds of Pa'aiea and Kiholo by the flows of 1801 and 1859, respectively. Gradual disappearance of ponds is a senescence phenomenon which results from the accumulation of organic and mineral deposits originating from aquatic production and wind-blown materials. Some algae form extensive mineral-organic deposits. As sediments fill a pond basin, emergent plants such as sedges, rushes, and grasses take root, succulents and vines encroach from the edges, and a damp, well-vegetated depression evolves. Conditions promoting rapid senescence are good exposure to light, shallowness, and weak connection with the water table so that sedimenting particles are not flushed away with tidal exchanges or groundwater flow. At one extreme are ponds showing few signs of senescence in lavas that must be many hundreds of years old; at the other, ponds on historic flows already partly obliterated.

HISTORICAL INFLUENCES

A century and more ago, Hawaiian villages and settlements dotted the Kona coast. Invariably, they were associated with anchialine water exposures. Small pools supplied potable water and bathing facilities; some ponds were adapted to fish retention and culture; and naturally occurring shrimps and mollusks provided food and bait. "Hawaiian fishponds" are included here but represent only a small proportion of the total number of ponds surveyed. Anthropological associations of Kona coast ponds are described elsewhere (Kelly, 1973; Kikuchi and Belshe, 1971) and are not a consideration of this investigation except to note the influence of Hawaiian culture on pond occurrence and character.

Some ponds in this inventory were Hawaiian-built. These include marine embayments isolated by rock walls (e.g., Waipuhi, Lahuipuaa, Kaloko) and obscure wells excavated into clinkery aa. Many Hawaiian modifications to natural ponds are apparent. Some closed ponds were opened to the sea by makahas (effluent channels; e.g., Kahapapa-Kuualii, Aimakapa), others were enlarged by excavation, and still others were divided or changed in shape by walling. Modifications for fish culture including makahas and stocking with fishes caused the greatest biological changes and in some ponds probably hastened senescence.

All of the larger ponds show signs of cultural modifications. Because minor and early historic changes in pond morphology are obscure, it is not possible to tally accurately the number of "changed" ponds. Modern culture has also modified many ponds. A reasonable estimate is that about half of the ponds surveyed show no significant cultural changes and thus represent

natural anchialine ecosystems. Many others have reverted to natural conditions through lack of use in recent decades.

POND DISTRIBUTION

The coastwise distribution of the ponds surveyed is shown on the index map, Appendix A. Rectangles represent large scale maps that appear on subsequent pages of Appendix A. These "quads," traced from US Geological Survey quadrangle maps, are coded by letters and ponds located on them by numbers from north to south. Data sheets accompanying each quad give pond latitudes which suffice to position most of them closely because of the north-south orientation of the coastline.

Three ponds not located on quads have their approximate positions shown on the index map and are described further below:

A-1. A well to the north of Kawaihae and the only anchialine water found in a cursory survey of North Kohala.

B-1. An intermittent stream (Makeahua) mouth impounded by a beach bar adjoining the south side of Kawaihae dredge spoils pile.

C-1. An unusual vertical shaft in older elevated pahoehoe just beyond the southern boundary of the City of Refuge National Historical Park.

Approximate locations of the remaining 315 ponds are shown by size-distinguishing symbols on the 20 quad maps. Most of them are very close to the shoreline; farthest inland is K-2, approximately a half kilometer (one-third mile) from the ocean.

Ponds are distributed irregularly along the coast, singly and in groups of few to many, as can be seen by the array on Quad D. The few localities of pond multiplicity are discussed in the final section of this report. A disproportionate distribution of ponds among the five land districts is evident:

District	Number of ponds	Percentage of total
North Kohala	1	<< 1
South Kohala	39	12
North Kona	235	75
South Kona	13	4
Ka'u	30	9

North Kona, which contains three-fourths of the ponds inventoried, occupies only about one-third of the coastline. The paucity of ponds in South Kona relates mainly to steep coastal topography. North Kohala essentially lacks ponds because of slope and lava age.

POND BASIN MORPHOLOGY

Primary features of pond basins such as shape, size, and depth vary to some degree with tidal stage. Least variable in this respect is shape; most ponds are irregular because of the character of the lava. Generally, ponds in pahoehoe tend toward roundness except in fractures and those in fresher aa show the greatest irregularity. Fissure waters have the most extreme shapes.

Ponds with shallow, flat basins show the greatest variations in relative depth and area with tidal fluctuations. At the extreme are depressions that have water only at high tide stages. However, these intermittent ponds have ecological significance because they lack water only for short periods. Desiccation-resistant algae and animals such as snails occur in them as do shrimps and other crustaceans that appear with the influent water.

Relative surface areas and depths are given in Appendix A. Wherever possible, these dimensions were measured at or estimated for the water level of high tide, which is usually indicated by discoloration on shoreline rocks. The following is a summary of those observations:

Basin measurement	Number of ponds	Percentage of total
Surface area (data on 313 ponds)		
Small = < 10 m^2	131	42
Medium = 10-100 m^2	153	49
Large = > 100 m^2	29	9
Depth (data on 244 ponds)		
Shallow = < 0.5 m	130	53
Moderate = 0.5-1.5 m	92	38
Deep = > 1.5 m	22	9

Extremes in area ranged from pools much less than a square meter to a few very large ponds covering several hectares such as Kaloko and Aimakapa Ponds. In a strict sense most anchialine ponds are "bottomless" because they connect to the sea water table through fractures and other interstices in the lavas. Water depths to the "apparent" bottoms varied from a centimeter or so in intermittent ponds to more than 14 meters as in the case of Lua o Palahemo, X-5. Size and depth are not always correlated directly; for instance, some of the deeper waters were observed in fissures. Thus, most of the Kona coast ponds are very small and shallow.

Observations were made on the composition of pond bottoms. As would be expected in a lava-related system, rock (e.g., rubble, bedrock) was present in significant amounts in two-thirds of the ponds and predominated as bottom material in more than half of them. Noticeable fine sediment occurred in 51 percent of the ponds and formed essentially the entire basin in about one-fourth of them. Ponds with high proportion of bottom sediments generally showed damped tidal fluctuations, presumably because their basins were less porous.

WATER CHARACTER

Because salinity is a characteristic of anchialine waters and has an important influence on the distribution of many aquatic species, considerable attention was given to this factor. Salinities were measured with a field refractometer on 298 ponds; multiple measurements at different depths, surface locations, and dates were made on many of them. Temperatures and turbidities were noted for most ponds. Determinations of other characteristics of water quality, such as dissolved oxygen and specific ions, generally were beyond the scope of this survey. However, a few initial measurements of oxygen levels showed them to be at or near saturation even in deep fissure waters.

Salinities are given in Appendix A in parts per thousand ($^{\circ}/_{oo}$) where freshwater = 0 and seawater = 35. Ranges shown for some ponds represent either vertical stratification (deeper ponds) or horizontal variations. The latter are most common in large nearshore ponds having definite influx of fresher groundwater on the mauka or landward side. Waters in all ponds were mixohaline (a more formal and definitive term than "brackish" meaning a dilution of seawater with fresh water). Salinities ranged from 0.5 to $30^{\circ}/_{oo}$. All measurements considered, only a single freshwater value was noted from a seepage at pond E-14, Kiholo.

Below is the salinity distribution of 298 ponds summarized from data in Appendix A using the higher values where a range is given:

Salinity, $^{\circ}/_{oo}$	Number of ponds	Percentage of total
< 5	112	37
5-10	115	39
10-15	52	17
15-20	14	5
> 20	5	2

Obviously, most of the pond waters lie at the fresher end of mixohalinity, three-fourths having salinities less than $10^{\circ}/_{oo}$. The average salinity of all ponds was $7^{\circ}/_{oo}$; open ponds averaged $17^{\circ}/_{oo}$. Mixohalinity is caused by the dilution of seawater penetrating inland with outward-percolating groundwater. Because mixohalinity was characteristic of all the ponds surveyed, mixing of the watermasses apparently occurs at a considerable distance inland.

Although there appear to be coastal zones of higher and lower salinity pond waters, no single water exposure can be characterized by one salinity value or fixed range because of temporal fluctuations. Short-term variations occur with tidal changes and direct rainfall. In one pond, for example, bottom salinity was $6^{\circ}/_{oo}$ at low tide and $25^{\circ}/_{oo}$ at the following high tide. Long-term fluctuations evidently relate to seasonal climatic changes. During extended dry periods, evaporation increases surface salinities in ponds having a small water exchange. More common are salinity variations apparently caused by seasonal changes in groundwater outflow attributable to annual

rainfall patterns. Generally, such variations are no more than a few parts per thousand.

Literature occasionally mentions freshwater springs, outflows, or pools along the Kona coast. However, Campbell (1973) noted that "by present standards there are no ponds that contain potable water"--a statement confirmed by data obtained during this survey. Potable water, by public health standards, has an upper limit of 0.5°/$_{oo}$ dissolved solids. Low salinities of 1 to 4°/$_{oo}$ are difficult to detect by taste. Waters of such salinity, which are potable in a practical sense and also usable for irrigation, were satisfactory for domestic use in Hawaiian culture as they are for isolated inhabitants today.

Surface water temperatures in 210 ponds ranged from 19° to 35°C and were distributed as follows:

Temperature, °C	Number of ponds	Percentage of total
< 20	1	< 1
20-22	3	1
22-24	25	12
24-26	88	42
26-28	61	29
28-30	17	8
> 30	15	7

Characteristic temperatures of 83 percent of the observations lie between 22° and 28°C. The lowest temperature recorded (19°C) was in a narrow fissure (J-44) oriented perpendicular to the shoreline and with a noticeable outflowing current of groundwater. High values seemed to be caused by solar heating abetted by shallowness and a low rate of water exchange. The highest temperature (35°C) was observed twice--at low tide in a pond at Kiholo (F-2) and on a hot, sunny day in a sediment-lined pool (K-3) completely ringed by a mangrove thicket. The salinity of the pool was anomalously high for the area, suggesting strong heating and evaporative processes at work. Most high temperatures were noted at low tide in very shallow water, often overlying black lava. Those extremes probably do not influence the motile fauna (e.g., shrimps) which retreat into the cooler interstitial waters of the lava during low tide and emerge again with the incoming tide.

Pond waters were typically clear, although a few were permanently turbid to varying degrees, and the transparency of others was reduced temporarily on what appeared to be a seasonal basis. Turbidity was noticeable in 18 ponds and could be attributed mainly to phytoplankton. In three ponds (D-27, D-28, J-40) which were being dredged, a portion of the turbidity probably was due to suspended silt and organic detritus. Three types of planktonic turbidity were noted: a uniform green or yellow-green mass; greenish-yellow "streaks"; and a striking, dark red-brown stratified layer. Examination of a few samples indicated that the organisms responsible were unicellular flagellates of different algal taxons, perhaps complemented by diatoms.

Turbid waters occurred mostly in large ponds, especially those with meager growths of aquatic plants, suggesting that small water exchange per unit volume is a relevant factor. Planktonic turbidity apparently is a natural phenomenon in some ponds. Evidences are the occurrence of temporary streaks and plumes in some remote ponds and Hawaiian lore related by Kelly (1973) that attributes periodic turbidity to the menstruation of female mo'o (pond spirits). This explanation would seem especially apropos to the red-brown turbidity noted above.

The principal factors promoting aquatic primary productivity, dissolved nutrients and light energy, seem to have the most time for interaction in large, open ponds. Apparently that is why such ponds have luxuriant growths of aquatic plants. If dissolved nutrients are not absorbed by benthic flora such as filamentous algae and pondweeds, phytoplankton may develop to cause turbidity as it did after the "cleaning" of ponds D-28 and J-40. Before the ponds were dredged, both had well-developed benthic flora and fairly clear water; after removal of aquatic plants and sediments, significant turbidity developed in each. Sediment disturbance also liberates nutrients bound in the substratum and may increase the intensity and duration of phytoplankton blooms.

RIPARIAN AND AQUATIC FLORA

Information from notes on types and abundance of plants bordering the ponds is given in the tables of Appendix A. Ponds in newer lavas, about 20 percent of the total, usually had no riparian vegetation. The kinds and abundance of riparian plants elsewhere are coded in three simple morphological groups as qualified below: (Only the more common species in each group are noted.)

T = trees and shrubs: *Prosopis pallida* (kiawe), *Thespesia populnea* (milo), *Schinus terebrinthifolius* (wilelaiki), *Lantana camara* (lakana), *Pluchea odorata, Scaevola taccada* (naupaka).

V = vines and succulents: *Sesuvium portulacastrum* (akulikuli), *Batis maritima* (akulikulikai), *Ipomoea pes-caprae* (pohuehue).

G = grasses, sedges, etc.: *Pennisetum setaceum* (fountain grass), *Brachiaria mutica* (California grass), various Cyperaceae--e.g., *Carex laevigatus* (makaloa).

As a group, trees and shrubs were most obtrusive and ubiquitous, occurring around nearly two-thirds of the ponds. Vines and succulents were present at one-third of the ponds; grasses, etc. at one-fourth. Exotic plants predominated; the only native among the grasses, shrubs, and trees listed above is naupaka. Several native species were among the unlisted less-common plants. Montgomery (1973) described many coastal plants of northern Kona in their communities. Some uncommon coast-wide species may be dominant in limited areas. An example is the introduced mangrove (*Rhizophora mangle*) that forms dense thickets at ponds J-20 and K-3.

Aquatic plants are considered here to be those that normally are submerged but sometimes afloat. Nearly all species are algae (limu) with both fresh and saltwater affinities. Two exceptions are the vascular plants, *Potamogeton* sp., which was found only in pond K-11, and *Ruppia maritima* (Widgeongrass or tassel pondweed), which was widespread and classed as a representative plant species.

Algae are present in all ponds, although sometimes not obvious, and form the basic food source for aquatic fauna. Algal inventory and identifications are notably incomplete for lack of time and botanical expertise. Algae of open ponds were not surveyed. Attention was given to the more common and obvious forms in the 305 closed ponds. These are described below in very generalized communities:

Phytoplankton. This community of open-water microphytes was visually obvious in only a few ponds as described in the previous discussion on turbidity. It consists mainly of flagellated unicells maong which *Gyrodinium, Pyranomonas,* and *Chlorocentrum* have been identified tentatively as "bloom" dominants.

Epilithon. Included here are large and small algae that attach to solid submerged surfaces. It is the dominant community in young, unproductive ponds. Although most of these algae are unnoticeable, even the "cleanest" rock taken from the water will show isolated cells and minute colonies if viewed under sufficient magnification. Sometimes a slight green "fuzz" can be seen by eye. Somewhat more obvious is *Hildenbrandtia* sp., a rhodophyte appearing as a very thin dark-red coating that might be mistaken for a mineral deposit. Although *Hildenbrandtia* sometimes occurs on sunlit rocks, it is more often found in dark recesses where it thrives at an illumination level too dim for other algae. It is found in both fresh and marine waters and is probably common in anchialine ponds. Another rhodophyte, *Ahnfeldtia concccina,* is the largest of the pond epilithic species. It forms brist, open, olive-green to reddish-brown mats up to several centimeters thick. *Ahnfeldtia* was found in several ponds on rock surfaces below low tide level, being especially noticeable in the J-7 to J-37 pond series.

Filamentous. This community is defined as the more massive colonies of fine green filaments that sometimes attach but usually occur as floating, suspended, or settled clumps. It is characteristic of older ponds with eutrophic waters. Various species of Chlorophyta and Cyanophyta are included. One interesting growth form is the marble-size, green, felt-like balls found resting on the bottom of several ponds.

Sediment. Surfaces of all sediments contain a variety of algal species as single cells and small colonies. One distinct type consisting of a soft mass of gray-green amorphous particles often dominated by *Anacystis* was found in several ponds, particularly in ponds of older pahoehoe. Also associated with sediments in a few ponds is the erect, branched chlorophyte, *Chara* sp.

Crust. Crusts are distinguished here as compact algal communities that develop into a distinctive layer or deposit that becomes the "apparent" bottom material in advanced stages of development. A few peculiar

types of crusts were found; two were encountered frequently enough to be considered common and characteristic of Kona coast ponds (Appendix B, entries 1 and 2). Each consists of a dominant algal species that produces the distinctive growth form and several subsidiary species.

Schizothrix (S. vaginata?): mineralized, white-to-orange crusts that often build to massive deposits. Associated algae include *Chroococcus* and *Gloeocapsa*. They were recorded from 20 percent of the ponds surveyed and occurred mainly in young to intermediate-age ponds having good solar exposure.

Rhizoclonium sp.: non-mineralized, dark-green, crusty layer up to 1 cm thick. It carpets the bottom loosely with overlying rock and sediment and is found in 15 percent of the ponds; mostly in shaded areas in ponds of intermediate age. Associated algae include *Enteromorpha* and *Lyngbya*.

Sediments are necessary for the rooting of *Ruppia maritima* (Appendix B, entry 3), but this vascular plant may continue to grow for a considerable time after being dislodged. *Ruppia* which appears to occur only in brackish waters in Hawaii was recorded in 15 percent of the Kona coast inventory. It grows only to a few centimeters in height in shallow water, but extends vertically more than 2 meters in the deep water of Luahinewai Pond, F-5. Because *Ruppia* and the *Schizothrix-Rhizoclonium* crust communities seem to be restricted to anchialine waters, they are considered representative flora of the Kona coast closed ponds. All three occur in the salinity range of 2 to 18°/$_{oo}$ and therefore are moderately euryhaline within the lower end of the mixohaline salinity range.

AQUATIC FAUNA

Most of the effort of this investigation was devoted to observing, collecting, and identifying the macroscopic animals of the ponds. Early in the survey, a division was made between closed ponds and those with surface connection to the sea because of the lower species diversity but greater distinctiveness of the closed-pond faunas. A tally of species and larger taxons by pond code for closed systems is given in Appendices B and C. Faunal species noted in open ponds are grouped together in a single taxonomic list, Appendix D.

Open ponds, because of their direct sea connection and higher average salinity have greater species diversities because marine biota invade them. The 65 species recorded in Appendix D are mostly the larger, more common animals. Distribution of species numbers by major taxons for the open ponds is:

Major taxon	Number of species
Sponges	2
Coelenterates	1
Worms	11
Mollusks	15
Crustaceans	10
Fishes	23

In addition, there are a few open-pond species that also occur in closed ponds, particularly *Palaemon debilis* (shrimp), *Theodoxus cariosa* (mollusk), and *Eleotris sandwicensis* (fish). This list is not exhaustive because there are probably many more species of smaller invertebrates and a few rare large animals that were not detected.

Although most closed ponds were sampled intensively, it is probable that all species present in this habitat class were not collected and identified. Several new species were found; some of which remain unidentified. Probably many new species are yet to be discovered. The distributions of the organisms listed are also incomplete because most ponds were sampled only once and species that occur periodically or are very scarce could have escaped detection.

Fifty-five species and species groups of closed-pond animals are indexed in two lists: the common ones, or those occurring in more than 10 ponds, are in Appendix B; less common animals occurring in fewer ponds are listed in Appendix C. This division was made so that the complement of important species in each pond's faunal community could be readily seen in Appendix B and different pond communities easily compared. The number of species detected in individual ponds varied from zero to ten with five or six being most characteristic. Mollusks and crustaceans generally were the most obvious and abundant animals; together, they accounted for more than half of the 55 faunal taxons present. Nine of the more common animal species are considered to be representative of Kona coast anchialine ponds. These are noted by the prefix "R-" in the following summary of closed-pond fauna.

Species or groups of aquatic fauna	Number of ponds	Percentage of ponds
Worms (includes oligochaetes and polychaetes, 3 or 4 species in all)	41	13
R-*Assiminea* sp. (small snail, not exceeding 5 mm in length; also occurs along damp beaches)	72	24
R-*Melania* sp. (larger snail, widely distributed in streams and low-land ponds)	189	62
R-*Theodoxus cariosa* (black limpet-like neritid snail also found in estuaries and mixohaline bays)	56	18
Amphipoda, red sp. (small, un-described crustacean known only from Kona coast ponds)	31	10
Amphipoda, other spp. (includes several new species known only from anchialine waters)	97	32
R-*Metabetaeus lohena* (small red alpheid shrimp, larger than and predaceous upon *Halocaridina*; limited to anchialine waters)	94	31

Species or groups of aquatic fauna	Number of ponds	Percentage of ponds
R-*Halocaridina rubra* (minute, red, atyid shrimp, = opaeula; herbivorous and limited to anchialine waters)	187	61
R-*Palaemon debilis* (usually transparent, medium-size palaemonid shrimp, = opaehuna; common in estuaries and protected marine inshore waters)	64	21
R-*Macrobrachium grandimanus* (larger palaemonid shrimp, = opae oehaa; a native prawn better known from streams)	37	12
Macrobrachium lar (large exotic "freshwater" prawn recently invading anchialine waters)	16	5
Metopograpsus thukuhar (small blackish crab common along coasts and in some estuaries)	54	18
Insects (combined tally of Odonata, Hemiptera, and other orders from Appendix B; only *Trichocorixa reticulata* is typical of saline waters)	53	17
R-*Eleotris sandwicensis* (secretive predaceous gobioid fish, = oopu akupa; usually associated with estuaries and lower reaches of streams)	15	5
R-*Kuhlia sandvicensis* (silvery carnivorous fish, = aholehole; normally marine but juveniles sometimes enter streams)	22	7
Other native fishes (includes mullet from Appendix B and all fish species from Appendix C except *Cyprinus carpio*)	31	10
Exotic fishes (includes *Tilapia* and two or more species of topminnows)	33	11

There are obvious positive and negative relationships among the animal species distributions that seem to reflect either similarities in habitat requirements, dependence of one species upon another, or incompatibility. Similarity in habitat requirements is demonstrated by the distributions of the two snails, *Melania* and *Assiminea*. *Melania* was found in 189 ponds,

Assiminea in 72, and they co-occurred in 65 ponds. Both are presumed to be herbivores and seem to co-exist so frequently because of mutual habitat needs.

The distributions of the two small red shrimps, *Metabetaeus* and *Halocaridina*, are similar to that of the snails: *Metabetaeus* was found in 94 ponds, *Halocaridina* in 187, and both occurred in 89 ponds (94 percent co-occurrence for *Metabetaeus*). *Metabetaeus* is a carnivore and *Halocaridina* a herbivore. *Metabetaeus* is known to devour *Halocaridina* and therefore co-occurs in a predator-prey relationship, a dependency of one species upon another.

The native and exotic prawns (*Macrobrachium grandimanus* and *M. lar*, respectively) are closely related species. Both are omnivores with carnivorous tendencies and similar habitat requirements. *M. grandimanus* was noted in 37 ponds and *M. lar* in 16 with an overlap of only 8 (50 percent co-occurrence for *M. lar*). Although the total number of ponds are lower, it appears that the two species are poorly compatible and that *M. lar* outcompetes *M. grandimanus*. That conclusion seems likely especially if one considers that the exotic *M. lar* has invaded Hawaiian waters only within the past few years (Maciolek, 1972).and has not had time to attain a population stability or fully interact with the native prawn. Its discovery in Kona coast ponds was totally unexpected because its natural habitat is insular streams. If *M. lar* expands its range further in coastal ponds in the future, there may be a concomittant decrease in distribution of the native prawn.

Similar relationships are found between exotic and native fish groups and between fishes and the atyid shrimp, *Halocaridina rubra* (included here because it seems to be an ideal food for all large predators). The following distributional tally includes all fish species found in closed ponds (Appendices B and C):

73 ponds with fishes

33 ponds with exotic fishes

45 ponds with native fishes

5 ponds with native and exotic fishes

26 ponds with fishes and *H. rubra*

20 ponds with native fishes only and *H. rubra*

5 ponds with exotic fishes only and *H. rubra*

Several conclusions can be drawn from the above data. Because of the poor overlap between native and exotic fishes, it seems that the two groups are not compatible. Field observations suggest that this is true, even though most native fishes occur naturally whereas exotics generally are transferred by man. Next, fishes and the shrimp tend to be incompatible; only one third of the fish-inhabited ponds also had *H. rubra*. Exotic fishes were less compatible with *H. rubra* than were native fishes inasmuch as only about one-sixth of the 28 ponds with only exotic fishes also had the shrimp. Again field observations support fish-shrimp incompatibility. Where *H. rubra* occurred in fish-inhabited ponds, either it was rare or the number

of fishes were low and usually the fishes were native species. Exotic fishes generally exist in large numbers because they breed entirely within the ponds; all native species, insofar as is known, require marine waters for part of their life cycle and some seek mixohaline waters as juveniles.

Certain of the less common species (Appendix C) deserve special mention because of their uniqueness, scientific importance, and eventual educational value. Three of the shrimps *(Antecaridina lauensis, Procaris hawaiana,* and *Calliasmata pholidota)* are rare and known only from one other Hawaiian locality (Cape Kinau, Maui), as noted by Holthuis (1973). Two of these species are blind and all three require a subterranean saline-water environment. Among other taxons, the hydroid *Ostromouvia horii* and the snail *Neritilia* sp. are known only in Kona coast anchialine pools. (The snail may be a new species and probably endemic to Hawaii.) Other new animal species will most likely be discovered in Kona coast ponds. Nine of the fishes listed are primarily marine species; it is remarkable to find most of them in pond waters that are nearly fresh. A rare endemic moray eel, *Gymnothorax hilonis*, was discovered in an open pond and its habitat may well extend into closed ponds also. The green sea turtle was seen in three ponds, but probably was placed there by man.

Another phenomenon of the anchialine habitat is the occurrence of ecotypes or morphological variants within a species apparently caused by environmental differences. Chace (1972), for example, described anatomical variation in the shrimp *Palaemon debilis*, that can be observed in nearby ponds such as at Awakee-Makalawena (H-2 to H-23 series). Ecotypes also seem to occur in other crustaceans (*M. grandimanus;* Holthuis, 1973) and mollusks (e.g., *T. cariosa*).

Nine of the more common native species, including three mollusks, two fishes, and four decapod crustaceans, were selected as "representatives" of a characteristic faunal community for Kona coast anchialine ponds. Two of the crustaceans, *Metabetaeus lohena* and *Halocaridina rubra*, are limited to Hawaiian anchialine waters. The endemic prawn *(Macrobrachium grandimanus)* and fish *(Eleotris sandwicensis)* are distributed widely in Hawaiian streams and estuaries, but along the Kona coast they were found only in ponds. The other fish *(Kuhlia sandvicensis)* is also endemic. Although the distribution of these two fishes was limited, they are probably more common in Kona ponds than this inventory indicates. Photographs of these representative species and maps of their coastal distributions appear in Appendix E.

SUMMARY AND CONCLUSIONS

Among the 318 ponds inventoried, ecological distinctions can be made between closed and open ponds and between natural and culturally modified ponds. As a class, the unmodified, closed ponds alone possess both physical features and biota sufficiently distinct to be considered a unique type of aquatic ecosystem. They deserve recognition on that basis as important natural assets of Hawaii. Below is a summary of the features that distinguish this closed-pond ecosystem:

Physical features

Located in geologically recent low-elevation lavas within a few hundred meters of the coastline.

Water surface at sea level showing tidal fluctuations resulting from subsurface movement of water through interstices in lava or shoreline deposits.

Generally small (< 100 m^2 surface area) and shallow (< 1 m deep) ponds with irregular rocky basins; biogenic sediments occur in the more eutrophic ponds.

Normally clear mixohaline water of low salinity (2 to 12°/$_{oo}$) represents a dilution of subterranean seawater with seaward-percolating groundwater; temperatures are usually between 22° and 28°C.

Biota

Aquatic vegetation is dominated by benthic algae including *Rhizoclonium* and mineral-encrusting *Schizothrix* communities.

Ruppia maritima, a vascular plant, characterizes ponds with soft sediments.

Distinctive fauna with relatively few species (Appendix E) is represented mainly by four decapid crustaceans, two mollusks and two fishes.

Two crustaceans, the small red shrimps *Halocaridina rubra* and *Metabetaeus lohena*, both endemic to Hawaiian anchialine waters, are especially characteristic of the ecosystem.

The faunal community of closed ponds is clearly crustacean-mollusk dominated. New and uncommon species in these taxons were found; further investigation is certain to uncover other distinctive species, especially among the lower crustaceans (amphipods, isopods). Two common native snails, *Malania* sp. and *Assiminea* sp., are distributed ubiquitously. Fish occur naturally in only a small proportion of the ponds but the representative species, *Kuhlia sandvicensis* and *Eleotris sandwicensis*, are Hawaiian endemics. Because these and other fishes prey heavily on small crustaceans, the two groups tend to co-occur in an inverse relationship.

Open ponds are few in number and represent environmental intermediaries between closed ponds and inshore marine waters. The biota in open ponds is more diverse than that of closed ponds. Open ponds, as well as most of the larger closed ponds, show various degrees of cultural modification. Many of the smaller closed ponds have also been changed from a natural state, especially those in the vicinity of habitations. Cultural changes include physical modification of pond basins, direct and indirect contamination of the waters, and degradation of native aquatic communities by exotic species that would be difficult or impossible to eradicate.

The influence of Hawaiian culture on natural ponds was relatively slight and has significant historic value. The same cannot be said for recent

cultural modifications that tend to increase irreversible degradation or complete obliteration of pond ecosystems. Only about half of the closed ponds surveyed exist in an essentially natural state. Mounting developmental pressures along the Kona coast make it imperative to recognize and protect these unique natural resources from further attrition. For that reason a final evaluation of the survey information was made to locate ponds considered most important as natural anchialine ecosystems. Twelve sites identified in this analysis are located in Appendix F and described below in their respective land divisions. Four of them are sites of pond complexes that could not be mapped because of time and personnel limitations; the actual pond arrangements and relative sizes are estimated on tracings from aerial stereo photos included in Appendix F. (Some ponds are not shown on these tracing maps because the water exposures are too small to resolve visually or they are obscured by lava overhang.)

Class A. Pond sites of exceptional natural value based on physical structure, diversity, representative aquatic communities, and new or unusual endemic species. Locations are generally remote and in pristine condition. Preservation as a unique resource is recommended strongly.

Anaehoomalu: ponds D-7 to D-26 plus numerous unsampled ponds. The largest single concentration of anchialine ponds on the Kona coast and in the state is located in pahoehoe adjacent to Waiulua Bay and extending southward to the northern site of Anaehoomalu Bay. Principal biological features include representative anchialine communities (including mineral-encrusting algae, mollusks, and shrimps), the unusual occurrence of many marine fishes in low-salinity water, and the presence of the rare moray eel, *Gymnothorax hilonis*. This site is imminently threatened by resort development; recently bulldozed roads have obliterated a few ponds and modified others.

Puuwaawaa: pond F-5 = Luahinewai. This single pond at Kiholo Bay is an example of a basin retained by a sand beach bar and is notable for its depth and strong vertical salinity stratification. It has a diversity of crustaceans. The most luxuriant growth of *Ruppia maritima* was encountered here during this survey.

Kohanaiki: ponds J-7 to J-35. This site is made up of an array of physically diverse ponds in old pahoehoe in the vicinity of Wawahiwaa Point. Their biological features include a good representation of crustaceans and melaniid snails, an absence of fishes, and lush growths of *Ruppia*, *Ahnfeldtia*, and other characteristic algae. A complementary attribute is the habitat provided by large ponds for shorebirds (Hawaiian stilt, wandering tattler, etc.) and waterfowl. Natural pond environment is threatened by the spread of exotic mangrove trees from a mature stand near the center of the area and possibly by future commercial development.

Manuka: ponds S-1 to S-4. Three of these waters near Kauna Point are in massive deep fissures and the other is cavern-like. This is one of the remotest areas surveyed and the most pristine.

Notable here are the physical structure of the fissures and their deep, clear waters rather than aquatic biota (scarce). Natural value of the site is enhanced by pahoehoe seacliffs and the spectacular interaction with sea waves in forming surgepools, sprays, and perched tidepools.

Kahuku (north): ponds U-1 and U-2. This site consists of one large and one intermediate-size pond west of Pohue Bay and is an excellent example of pond retention by a natural bar of beach boulders with exceptionally clear water and remarkable growths of *Ruppia* and white mineral-encrusting *Schizothrix*. Migratory waterfowl were present at the time of survey.

Kahuku (south): ponds V-1 to V-12. This area contains a combination of open ponds and fissures of various sizes in the vicinity of Kahakahakea. The waters contain representative mollusks and crustaceans; an uncommon red shrimp, *Antecaridina lauensis* (known only from three localities in the state), was found in one of the larger fissures. Complementary natural values are the interesting pahoehoe formations and the biota diversity in tidepool and intertidal areas.

Pakini Nui: pond X-1. This is not an actual pond, but deep-lying cavern water in fractures in Puu Lohena, an old littoral cone surrounded by fresh aa to the northwest of Waiohukini. Made up of primarily curstacean fauna, it is the type locality of *Metabetaeus lohena* (Banner and Banner, 1960), a representative and endemic Hawaiian shrimp. Puu Lohena may be of geochronological value and appears to be an alii burial site (William Meinecke, personal communication).

Kamaoa Puueo: pond X-5 = Lua o Palahemo. This unusual pond in ancient lava immediately to the east of Ka Lae seems to be a collapsed point in a large lava tube. It is the deepest of the anchialine pools surveyed and exploration of it requires SCUBA gear. It has a variety of phytoplanktonic and marine-derived epilithic algae, but is most valuable for its shrimp fauna. Lua o Palahemo is only the second known habitat of the peculiar primitive shrimp (*Procaris hawaiana*) and also contains other new crustacean species (*Calliasmata pholidota, Antecaridina lauensis*). It has the greatest concentration of opaeula (*Halocaridina rubra*) observed during this or other surveys.

Class B. Pond sites of significant aquatic natural value whose importance is increased because of their anthropological or waterbird habitat values. They are threatened by development and generally found in accessible or culturally modified areas.

Lahuipuaa: ponds C-10 to D-5. A large number of diverse pond types is located between Pauoa and Iliilinaeheehe Bays. Large open ponds are best preserved examples of traditional Hawaiian fishponds. Accessory anchialine ponds have physical and biological diversity with good populations of representative species. Hotel-resort development is planned.

Awakee-Makalawena: ponds H-2 to H-28. An array of smaller anchialine ponds is found in the vicinity of Kapoikai (Opaeula)

pond. Diverse aquatic fauna consists of native and exotic fishes and ecotypes of shrimps and mollusks. The northernmost ponds have accretions of mineral-organic sediments; intermediate ponds in unvegetated aa are without sediments; and southernmost ponds in old, vegetated pahoehoe have well-developed sediments. Shallow, turbid Kapoikai is the premier stilt habitat of Hawaii Island. Makalawena village site which was destroyed by the 1946 tsunami is located here. Two resort development plans have been proposed for the area.

Honokohau: ponds K-1 to K-15. This is a complex of smaller pools and marshes surrounding and including Aimakapa, the largest pond of the Kona coast and the most important total waterbird habitat. Pond basins to the north of Aimakapa are in unusually low, flat pahoehoe. The system contains a complement of representative anchialine species and is the only locality (K-1) of the hydroid, *Ostromouvia horii*. The area is of great historical importance and is being threatened by resort development.

Kealakehe: ponds K-22 to K-30. This is a small group of ponds in higher pahoehoe to the south of Honokohau harbor which has representative anchialine fauna and pecularities in mollusk ecology. Its natural communities are partly destroyed by *Tilapia*. It makes up part of the general Honokohau historic area and is presently being threatened by harbor expansion and public recreational misuse.

ACKNOWLEDGMENTS

University of Hawaii staff members providing identification of biota were: algae, Drs. Maxwell Doty and Gerald Prowse; mollusks, Dr. E. Alison Kay; hydroid, William J. Cooke; and annelids and various marine invertebrates, Dr. Julie Brock. Dr. Brock also contributed considerable time in the field. Crustaceans were identified by Dr. L.B. Holthuis of the Rijksmuseum and Dr. J. Laurens Barnard of the Smithsonian Institution.

Sea Grant-Marine Option students from Hilo College who worked with the summer crew were R. Fujii, C. Guthier, and E. Katahira; general assistance was given by Robert Chase. Help in housing the field crew was extended by Edson Sheppard and Barry Machado. Superintendent Bryan Harry of Hawaii Volcanoes National Park made a field vehicle available to the survey group. Site information, field maps, and access to aerial photos were provided by Dr. T. Stell Newman of the Parks Division, Hawaii Department of Land and Natural Resources.

Finally, this survey would not have been accomplished without the cooperation of many landowners and managers in providing access to coastal areas: William Akau, D.W. Carlsmith, Norman Carlson, Fred Duerr, D.M. Fraser, Henry Greenwell, Dennis Haserot, Peggy Mae Hunter, George Schatthauer, Richard Schultz, and Mickey Waddoups. The Hawaii County Planning Department assisted with arrangements.

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APPENDICES

APPENDIX A. MAP LOCATIONS AND ENVIRONMENTAL DATA ON 318 KONA COAST PONDS, HAWAII ISLAND.

1. Index map (opposite page) shows leeward land districts and locations of 20 large-scale quad maps (rectangles) appearing on subsequent pages. Letters indicate individual quads; numerals refer to numbers of ponds inventoried on each. Quads with only one pond (A, B, P) are not included (see text description).

2. Data sheets facing each quad summarize the environmental features of the respective ponds and position them by latitude. Explanation of column headings:

   Riparian Plants--coded in groups (G = grasses, etc., T = trees and shrubs, V = vines and succulents, O = no bordering vegetation) in relative order of abundance;
   Bottom Type--distinguished as R = rock (rubble, bedrock, etc.) and S = sediment (silt, sand, organic detritus);
   Depth--coded in 3 ranges as S = shallow (< 0.5 m), M = moderate (0.5 - 1.5 m) and D = deep (> 1.5 m).
   Salinity--given in parts per thousand ($^{\circ}/_{oo}$) with ranges indicating vertical, horizontal or temporal variations.

3. Quads are traced from US Geological Survey quadrangle maps, scale 1:24,000. Names of original USGS maps are given in brackets (captilized). Unbracketed, capitalized names are land divisions. Geographical features (bays, points, major ponds, etc.) are noted in lower case type. Ponds are shown in their approximate locations by size symbols:

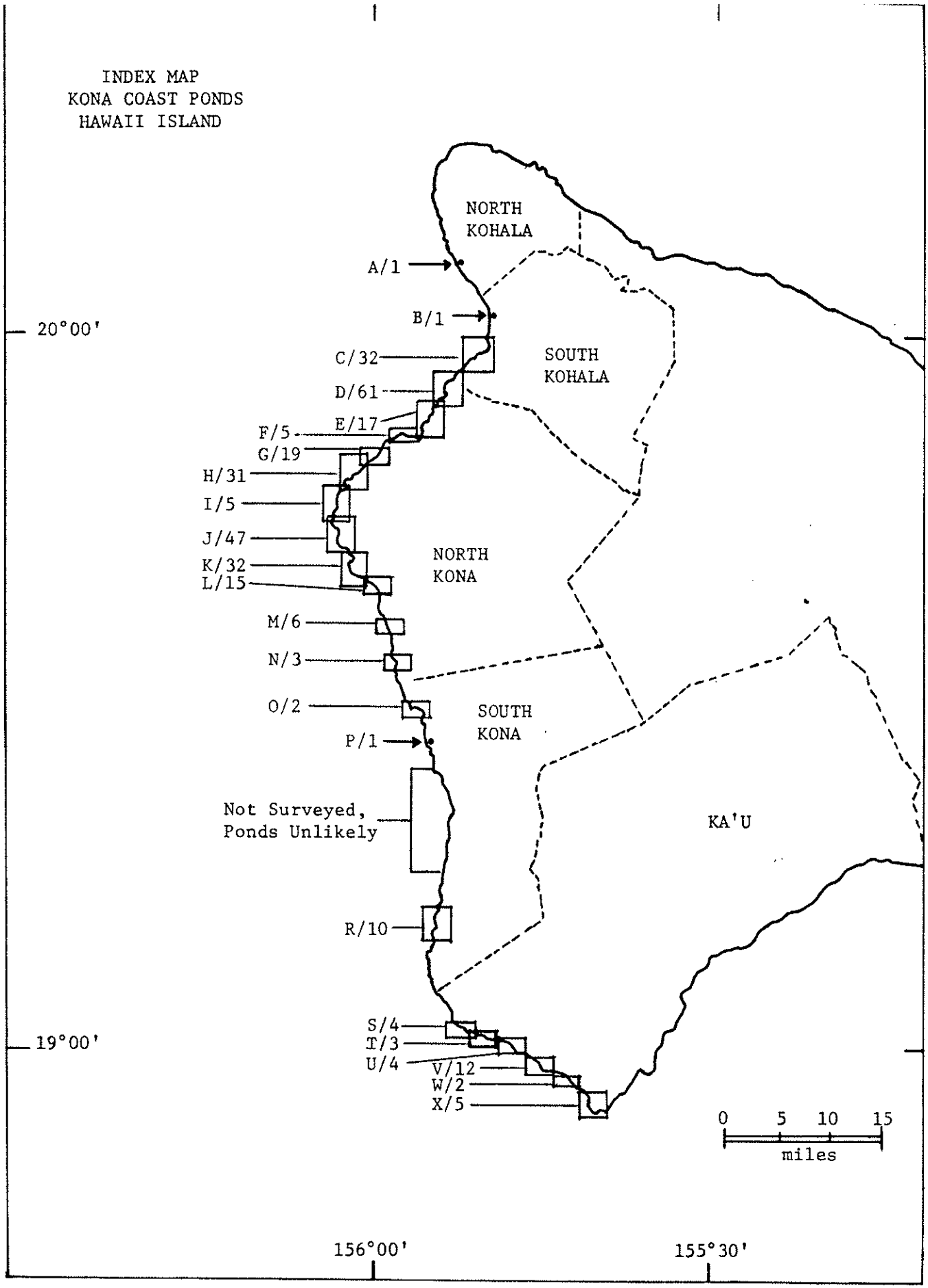
   ● = small, <10m^2 surface area

   ■ = intermediate, 10 - 100m^2 surface area

   ▲ = large, >100m^2 surface area

   Pond symbols are qualified by arrows (e.g., ◀▲) to indicate surface connection to the sea (open ponds) and by diagonal lines (e.g., ■) to show waters in caves or fissures.

Figure 1. Index map of Kona coast ponds, Hawaii Island.


INDEX MAP
KONA COAST PONDS
HAWAII ISLAND
NORTH KOHALA
SOUTH KOHALA
NORTH KONA
SOUTH KONA
KA'U
A/1
B/1
C/32
D/61
E/17
F/5
G/19
H/31
I/5
J/47
K/32
L/15
M/6
N/3
O/2
P/1
Not Surveyed, Ponds Unlikely
R/10
S/4
T/3
U/4
V/12
W/2
X/5
20°00'
19°00'
156°00'
155°30'
0 5 10 15
miles

APPENDIX A, continued. Pond environmental data.

Pond No.	Latitude	Riparian Plants	Bottom Type	Depth	Salinity °/oo
A 1	20° 6.1'	T	R,S	S	2
B 1	1.9'	G,T,V	S,R	M	8-15
C 1	19°58.3'	T	R,S	"	7
2	"	"	S	"	7
3	"	"	R	"	11
4	"	"	R,S	"	5
5	"	?	?	S	4
6	58.2'	T,G	S,R	M	9
7	58.1'	"	"	"	5
8	57.7'	"	R,S	"	27
9	"	"	R	?	?
10	57.3'	G,T	S	M	3
11-13	"	G,V,T	"	S	4
14	57.2'	T	R	"	4
15	"	O	S,R	"	4
16	"	T	"	M	3
17	"	O	R	S	4
18	"	T	"	"	4
19	57.1'	"	"	"	4
20	"	"	R,S	"	4
21	"	T,G,V	S	M	5
22	57.0'	T	R	S	4
23	"	T,G	S	"	4
24-25	"	T	R	"	4
26	"	O	"	"	4
27	"	T	S,R	"	5
28	56.9'	T,G,V	S	D	6-9
29	"	T	S,R	S	2
30	56.8'	"	"	D	5-27
31	"	"	R	M	5
32	56.6'	"	"	S	7

Figure 2, Quad C: (a) Air view of C 30, largest of the Lahuipuaa ponds and still managed for fish production. It is a marine embayment ponded by rock walls having two outlets to the sea. (b) Lahuipuaa pond, C 26, a water exposure recessed beneath overhanging lava.

QUAD C

19°59'

Puako Pt.

LALAMILO

1-5

Kapuniau Pt.

6-7

19°58'

WAIKOLOA

8-9

Pauoa Bay

10-32

Waipuhi

Lahuipuaa

Hopeaia

LAHUI-PUAA

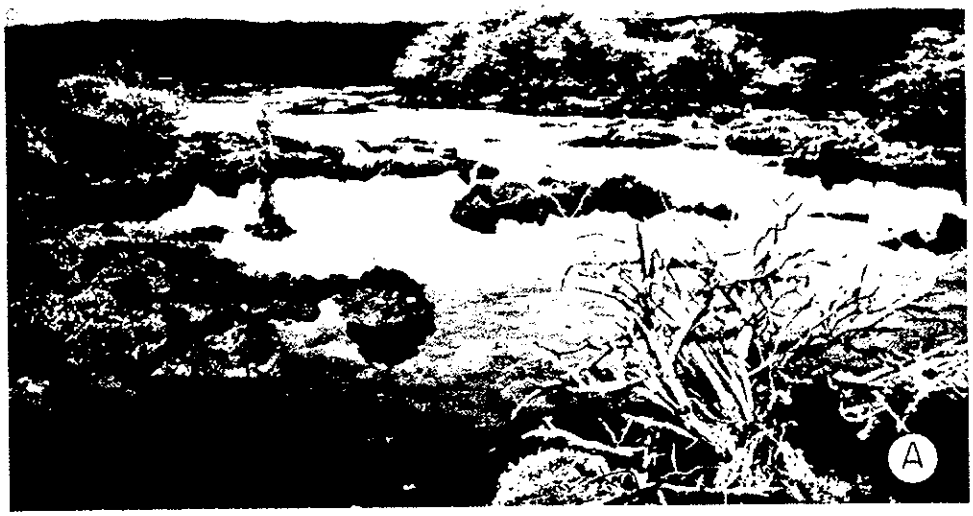
[PUU HINAI]

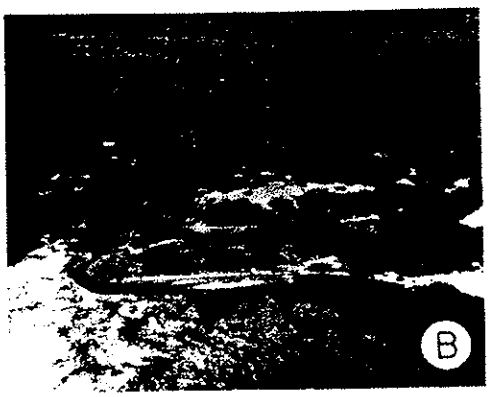
APPENDIX A, continued. Pond environmental data.

Pond No.	Latitude	Riparian Plants	Bottom Type	Depth	Salinity °/oo
D 1	19°56.7'	T	R	S	4
2	"	O	"	"	4
3	56.6'	G	"	D	4-5
4	56.5'	O	"	S	4
5	"	T	"	M	4
6	56.1'	O	"	"	2
7	55.8'	G	S	"	7-19
8	55.7'	T,G,V	R,S	D	4-5
9	"	T	R	S	5
10	"	O	S	M	6
11-12	"	"	R	S	5-6
13	"	"	"	M	3
14-16	55.5'	"	R,S	"	?
17-18	"	V	R	M/S	12-14
19-20	"	O	"	?	12
21	"	V	R,S	M	12
22-23	"	"	R	S/?	11-12
24	"	V,T	"	?	9-11
25	"	T,V	"	S	7-11
26	"	"	R,S	?	7
27	55.2'	G,V,T	S	S	17
28	55.1'	T,G,V	"	D	4-18
29	"	V	R,S	S	2
30	"	V,G,T	R	"	4-7
31	"	V,T	"	M	2-4
32	"	V	R,S	S	2
33-34	"	V,T	R	?	1-2
35	"	"	S	M	1
36-37	"	V,G,T	R	S	2-5
38	"	V,G	"	?	2
39	"	G,V,T	"	M	2
40	"	T,V,G	R,S	S	2
41	"	G,V	R	M	3
42	"	T,G,V	S	"	4-10
43-44	"	T,V	"	?	3-10
45-46	"	T,G,V	R,S	?	5
47	55.0'	"	S,R	S	2
48	"	O	R	D	1
49-50	54.8'	T	"	M	3-4
51-52	54.7'	"	"	"	5-6
53	"	T,G,V	S,R	"	12
54	"	"	R,S	"	4-6
55	"	V,T	R	"	5
56	"	T,G	R,S	"	5
57	"	T	R	S	2
58-59	"	V	R/?	?/S	4-5
60	54.4'	O	R	D	4
61	"	T	"	?	4

Figure 3, Quad D: (a) Pond D 8, largest of the many water exposures at Waiulua Bay (cf., Appendix F). Several marine fishes are present including the rare moray eel, *Gymnothorax hilonis*. (b) Air view of Anaehoomalu ponds (D 7-13 series) in vicinity of Waiulua Bay; largest one is pond D 8.

QUAD D





1-2

3-5

LAHUI-
PUAA

Honokaope
Bay

ANAEHOOMALU

6

19°56'

Waiulua Bay

7-13

14-26

PUUANAHULU

27-46

Anaehoomalu
Bay

19°55'

47-48

Kuualii

49-50

51-59

60-61

[ANAEHOOMALU]

APPENDIX A, continued. Pond environmental data.

Pond No.	Latitude	Riparian Plants	Bottom Type	Depth	Salinity °/oo
E 1	19°54.2'	T,V	S	S	4
2	"	"	R	?	4-5
3	54.1'	T	"	?	4
4	53.9'	"	"	M	2
5	"	T,V	"	?	2-3
6	"	T	"	S	2
7	53.6'	"	"	?	?
8	53.5'	V	"	D	2
9	"	T,V	S	?	2
10	"	T	S	S	2
11	52.7'	"	R	M	4
12	52.3'	O	"	S	4
13	51.6'	T	S,R	D	12
14	"	T,G	S	M	0-3
15	51.4'	T	R,S	S	2-4
16	51.5'	T,G	"	M	2
17	"	T	S	"	2

Figure 4, Quad E: (a) Puu Anahulu pond, E 1, in aa lava and bordered by hala and wilelaiki. White-appearing areas on pond bottom are orange crusts of mineral-depositing algae. (b) E 16, one of the larger ponds at Kiholo Bay. Emergent vegetation and extensive floating clumps of filamentous algae indicate advanced senescence; kiawe trees are the principal riparian plants.

QUAD E

1-2

3

19°54'

Pueo Bay

4-6

7

Keawaiki Bay

8-10

A

19°53'

PUUWAAWAA

PUUANAHULU

Ohiki Bay

11

[ANAEHOOMALU]

[KIHOLO]

12

Hou Pt.

B

13

Kiholo Bay

14

17

16

15

APPENDIX A, continued. Pond environmental data.

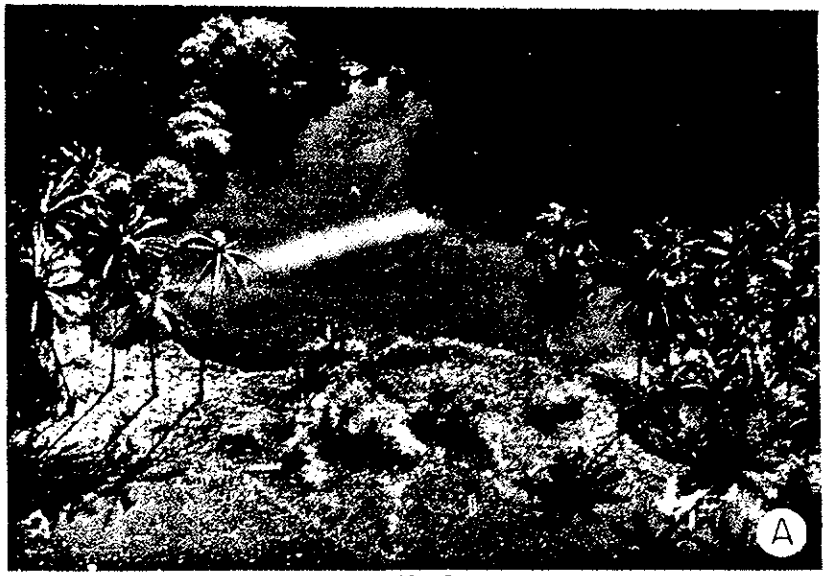
Pond No.	Latitude	Riparian Plants	Bottom Type	Depth	Salinity °/oo
F 1	19°51.3'	T	S	S	4
2	51.1'	"	S,R	"	1
3	"	"	S	"	2
4	51.2'	"	R	M	3-4
5	"	T,V,G	R,S	D	3-4
G 1	50.0'	V,T	S	S	2
2	"	T,V	"	?	?
3	"	"	S,R	S	4
4	"	V	R	"	3
5	"	"	S,R	"	3
6	"	V,T	S	"	4
7	"	T	R	"	2
8	"	T,V	S	M	4
9	"	T	"	"	4
10	"	"	"	S	4
11	49.8'	T,V	"	"	2
12	49.7'	"	R,S	M	3
13	49.5'	V,G,T	S	S	2
14	49.4'	T,V	R	"	4
15	"	V,T	S	"	3
16	"	"	S	?	2
17	"	T,V	S,R	"	2
18	49.3'	V,T	R	M	3-5
19	49.1'	V	"	?	4

Figure 5, Quads F and G: (a) Pond F 5, Luahinewai, is retained at the edge of a lava flow by a gray sand beach (foreground) partly covered by pohuehue. One of the deepest ponds surveyed, it has a pristine character and contains luxuriant growths of the submerged flowering plant, *Ruppia maritima*. (b) One of the mauka ponds in old pahoehoe at Kaupulehu (G 1-9 series). Water is obscured by encroaching succulents and emergent vegetation, a situation indicative of the final stages of senescence.

QUAD F

[KIHOLO]

19°52'



Mano Pt.

Kiholo Bay

1

Luahinewai

5

2-4

PUUWAAWAA

19°51'

155°57'

155°56'

QUAD G

Mahewalu Pt.

[MAKALA-WENA]

[KIHOLO]

19°50'

1-9

10

11

12

Kumukahu Pt.

Kukio Bay

13-17

18

19

19°49'

KUHIO-1

KAUPULEHU

156°00'

APPENDIX A, continued. Pond environmental data.

Pond No.	Latitude	Riparian Plants	Bottom Type	Depth	Salinity °/oo
H 1	19°48.9'	V,T,G	S	M	7
2	47.9'	V,T	S,R	"	6
3	"	O	S	"	6-7
4	"	T	"	"	6
5	"	O	R	"	6-8
6	"	T	"	"	6
7	"	"	S	"	6
8	47.8'	O	R	"	6
9	"	"	"	S	7
10-19	"	"	"	?	6
20	"	V,T	"	M	8
21	"	T	"	"	8-12
22	"	O	S	S	8
23	47.7'	T,V,G	"	M	6
24	"	T	S,R	S	4
25	"	V,T	"	M	4
26	"	T	R	"	4
27	"	T,V,G	S	S	3
28	"	T	R	M	4
29	47.5'	O	"	S	4
30	"	V	S	M	4
31	47.2'	T,G	R	S	3

Figure 6, Quad H: (a) Elongate pond in unvegetated aa to the north of Kapoikai (H 8-22 series; cf., Appendix F) is characterized by clear water and a rocky, sediment-free bottom. (b) Pond in moderately vegetated pahoehoe to the south of Kapoikai (H 24-28 series). Most of the bottom consists of fine sediments overlain by an algal crust.

QUAD H

[MAKALAWENA]

19°49'

19°48'

Kakapa Bay

Papiha Pt.

Kua Bay

1

Pulaloa Pt.

MANINIOWALI

AWAKEE

Awakee Bay

2-7

Puu Alii Bay

8-22

23

24-28

Kapoikai

29-30

31

MAKALAWENA

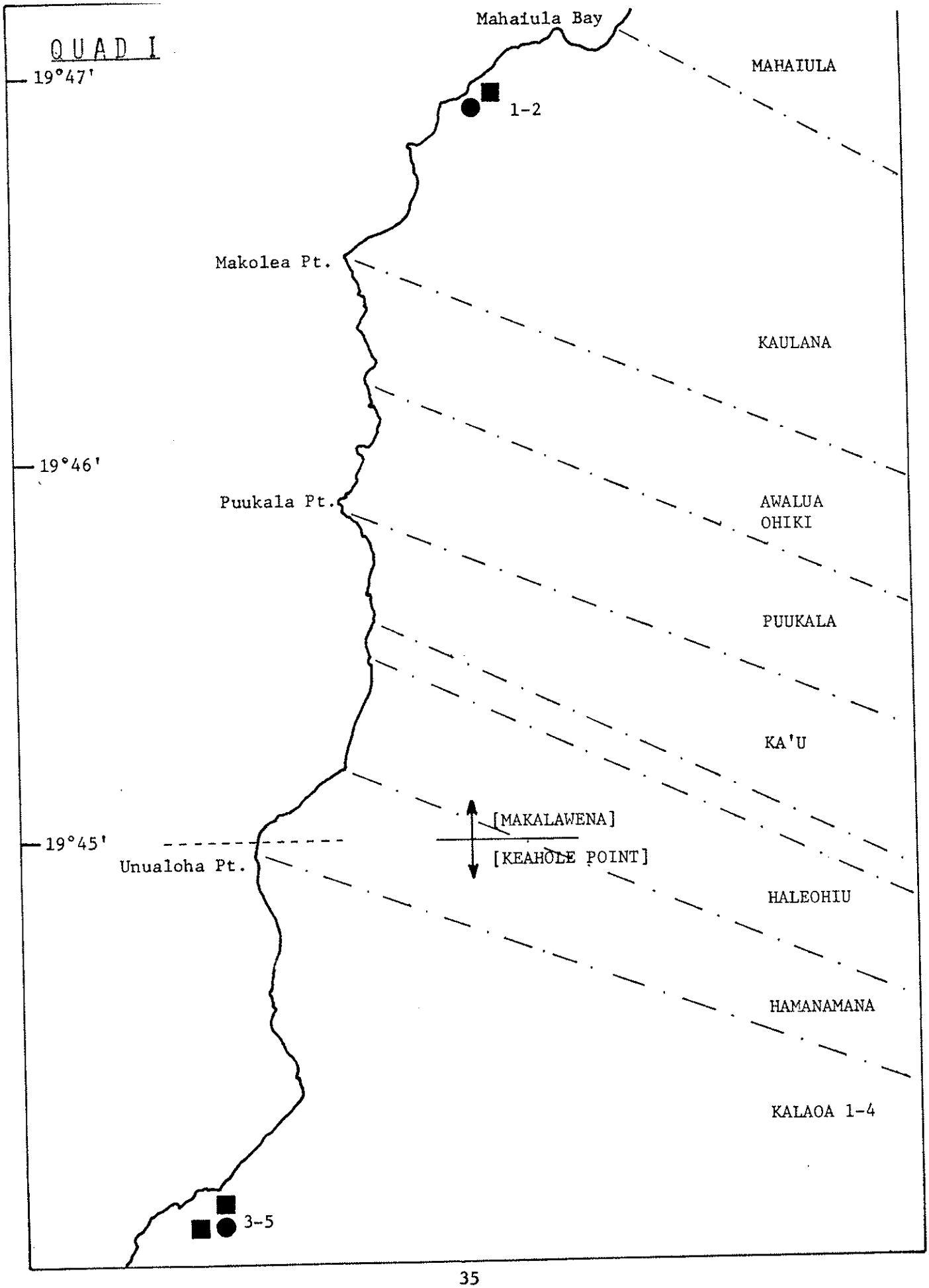
KAULANA

MAHAIULA

APPENDIX A, continued. Pond environmental data.

Pond No.	Latitude	Riparian Plants	Bottom Type	Depth	Salinity °/oo
I 1	19°47.0'	T,V	S	M	9
2	"	T,G	"	S	8
3	44.1'	O	R,S	"	8
4	"	"	"	"	7
5	"	T,V	S,R	"	8

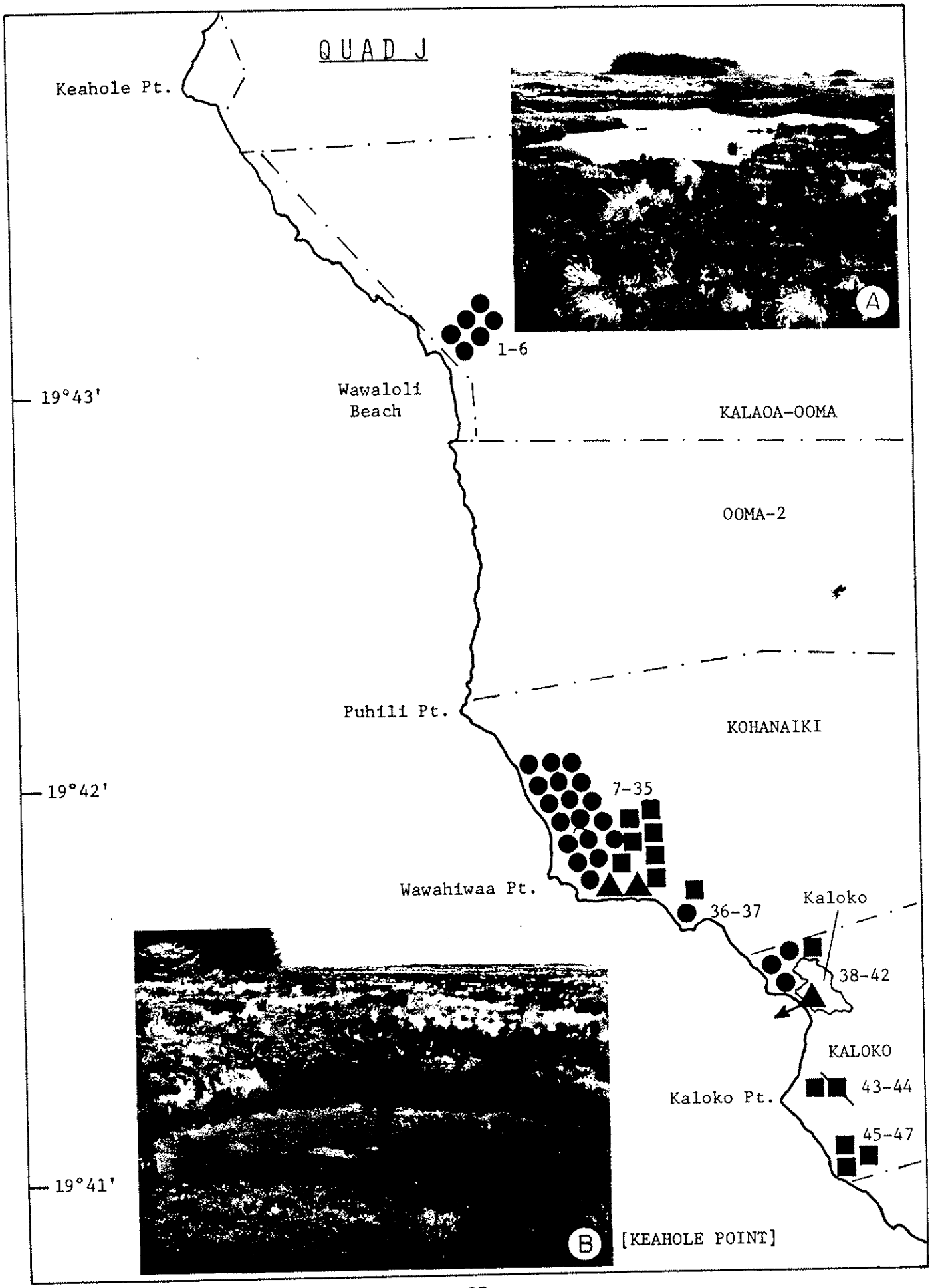
Figure 7, Quad I:


QUAD I
19°47'
19°46'
19°45'
Mahaiula Bay
Makolea Pt.
Puukala Pt.
Unualoha Pt.
1-2
3-5
MAHAIULA
KAULANA
AWALUA
OHIKI
PUUKALA
KA'U
[MAKALAWENA]
[KEAHOLE POINT]
HALEOHIU
HAMANAMANA
KALAOA 1-4

APPENDIX A, continued. Pond environmental data.

Pond No.	Latitude	Riparian Plants	Bottom Type	Depth	Salinity °/oo
J 1-2	19°43.2'	T,G	R	S	6
3-6	"	"	"	"	4-5
7	41.9'	G	R,S	M	13
8	"	"	"	?	14
9	"	"	"	?	12
10	"	T,G,V	S,R	"	13
11	"	G	R	"	12
12	41.8'	O	"	M	12-13
13	"	G	"	"	10-11
14-16	"	?	?	?	10-11
17	"	G	R	"	12
18	"	?	?	"	14
19	"	T	S	"	?
20	"	"	"	M	12
21	"	"	"	S	13
22-25	"	?	?	?	9-10
26	"	T,V	R,S	S	9
27	"	?	?	?	9
28-29	"	V,T,G	S	M	11-13
30	"	V,G	"	S	13
31	"	T,G	R	?	12
32	"	"	"	S	10
33	"	T	"	"	10
34	"	T,V	S	"	10
35	"	T,V,G	R	"	10
36	41.7'	T,V	S	M	9
37	"	T,G	R	S	9
38	41.5'	T,V,G	"	"	12-14
39	"	S	S	"	8
40	"	T,V,G	"	D	7-18
41	"	?	R	S	?
42	"	"	"	"	?
43	41.2'	V	"	?	?
44	"	T,G	R	D	8
45	41.0'	T	S	"	10
46	"	T,V	S,R	M	10
47	"	T,V,G	R	"	9-10

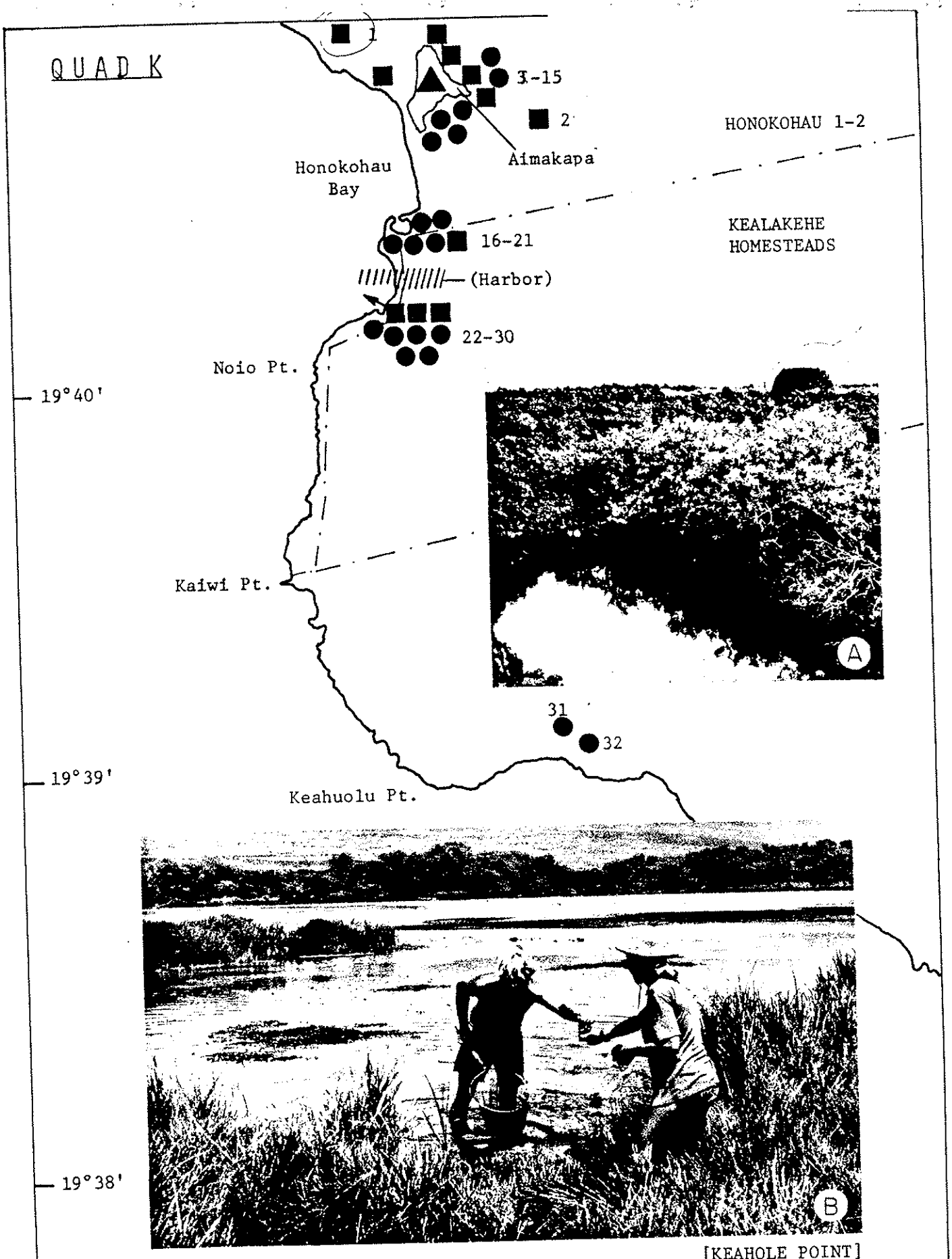
Figure 8, Quad J: (a) Kohanaiki, J 10, largest of the ponds on the north side of mangrove trees (center background; cf., Appendix F), is a habitat for several species of waterbirds. An interesting feature of ponds in this area is their algal diversity. Older pahoehoe is vegetated mostly with fountain grass but also has a scattering of native plants. (b) One of the many ponds on the Kaloko side of mangrove trees (J 20-35 series); bottom is carpeted by low-growing *Ruppia maritima*. Collectively, the Kohanaiki series is a prime example of pristine ponds in older pahoehoe.


QUAD J
Keahole Pt.
A
1-6
19°43'
Wawaloli Beach
KALAOA-OOMA
OOMA-2
Puhili Pt.
KOHANAIKI
19°42'
7-35
Wawahiwaa Pt.
36-37
Kaloko
38-42
KALOKO
Kaloko Pt.
43-44
45-47
19°41'
B
[KEAHOLE POINT]

APPENDIX A, continued. Pond environmental data.

Pond No.	Latitude	Riparian Plants	Bottom Type	Depth	Salinity °/₀₀
K 1	19°40.9'	T	R	M	5-6
2	"	T,G	"	D	4
3	40.8'	T,V	S	S	13
4	"	T	R	"	5
5	"	"	S	M	6
6-7	"	T,S	R	S	6
8	"	T	S	?	7
9	"	G,V	R	"	8
10	"	G,T,V	S	S	?
11	"	G,T,V	S	D	7-8
12-13	"	T	S,R	S	6
14-15	"	"	S	"	7
16-18	40.4'	T,V,G	?	"	15-17
19	"	V,G,T	S	M	13-17
20	"	T,G	?	S	14
21	"	T,V,G	?	"	11
22	40.2'	V,T	S	M	30
23	"	G,T,V	S	?	30
24-27	"	T	R	S/?	6-10
28-29	"	"	S,R	?	6-9
30	"	G	"	"	12
31	39.1'	T,G	S	S	7
32	"	O	R	"	7

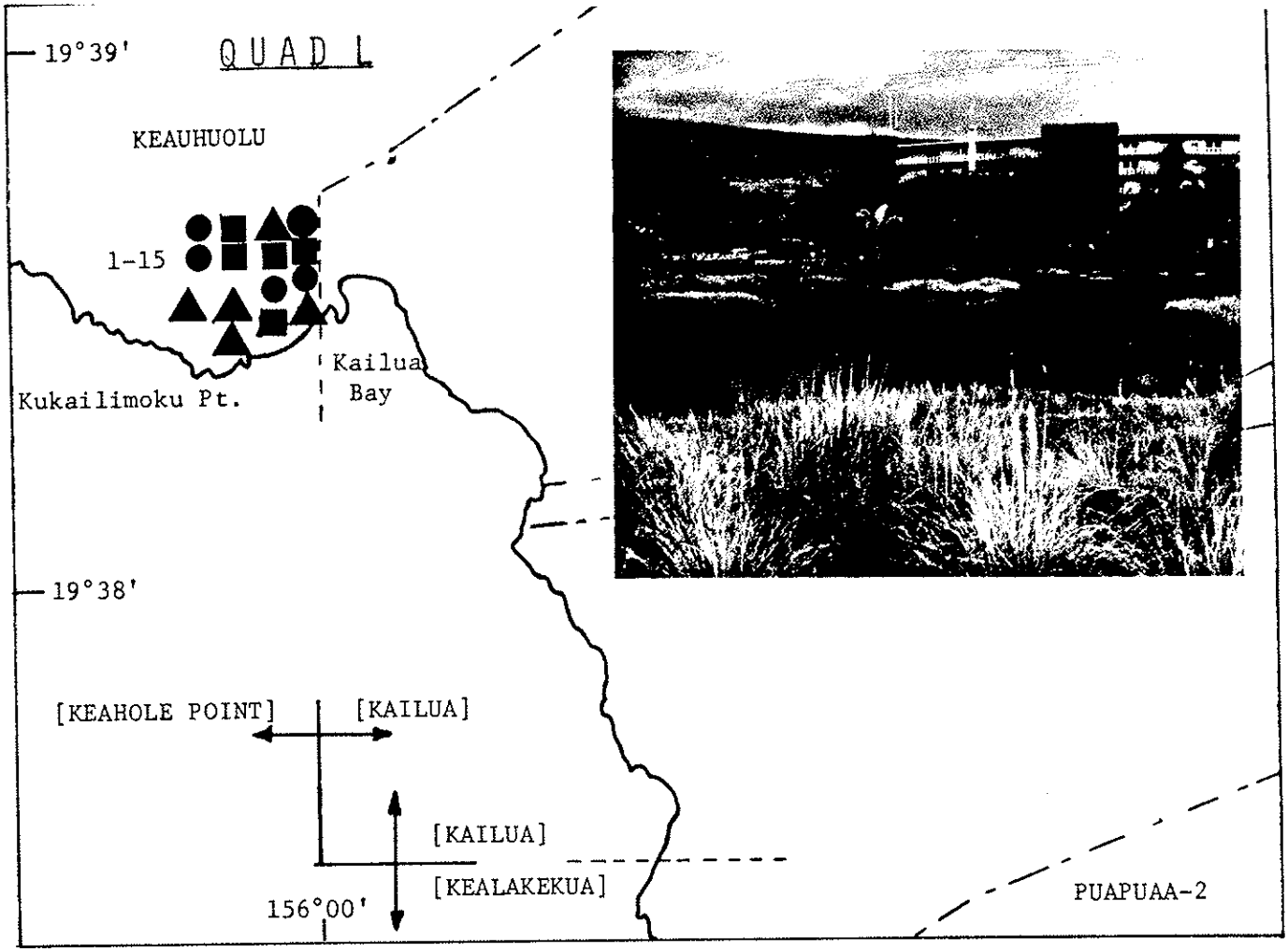
Figure 9, Quad K: (a) "Queen's Bath," Honokohau pond K 1, is of historical and biological interest. One of several large ahus near pond can be seen in upper right corner of photo; *Ostromouvia horii*, a solitary hydroid, is known only from this pond. (b) Biologists collect aquatic organisms from Aimakapa, K 11, largest pond surveyed and premier waterbird habitat of the Kona coast. The seaward shore is heavily grown with California grass.

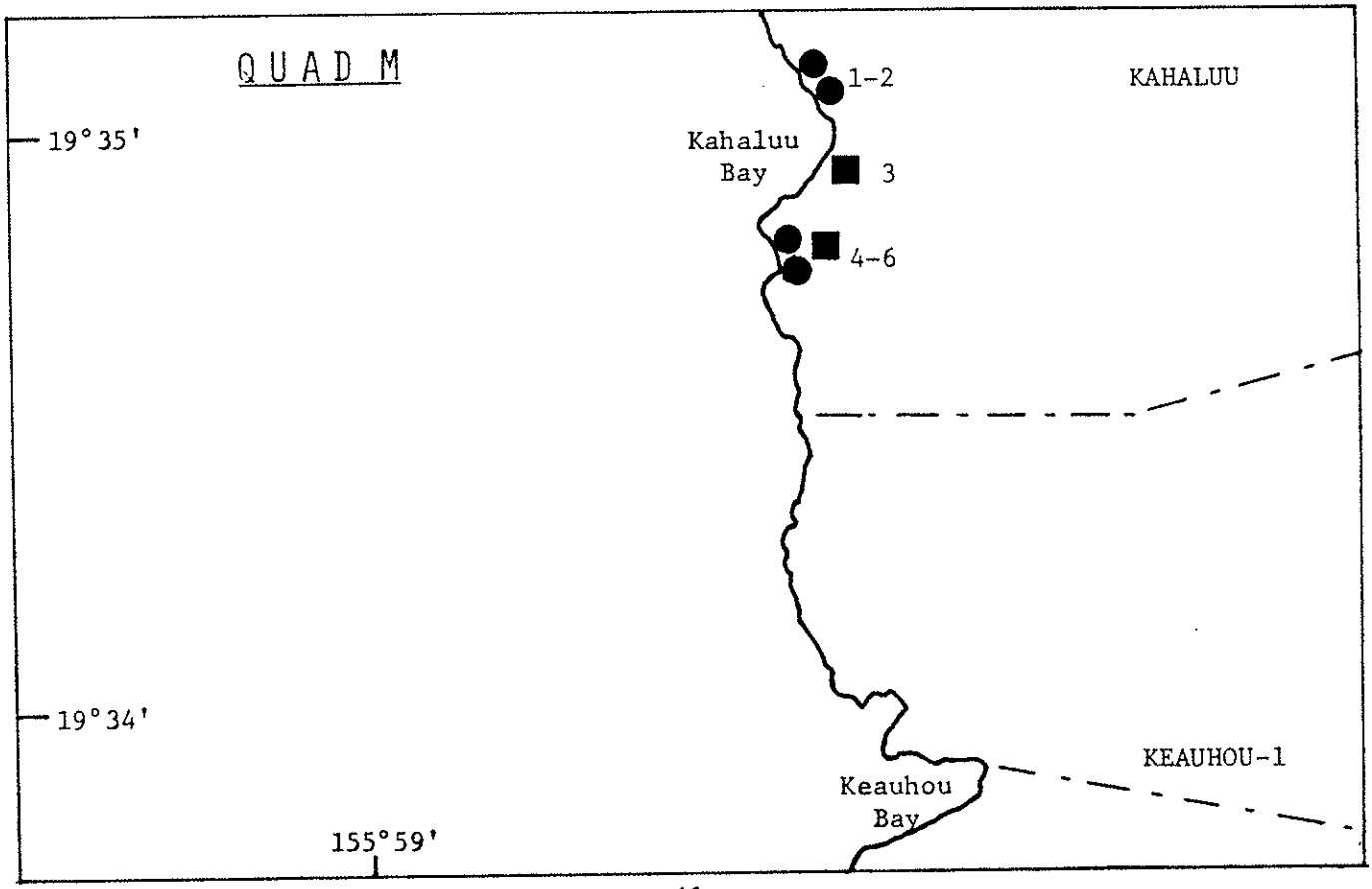

QUAD K
1
3-15
2
Aimakapa
HONOKOHAU 1-2
Honokohau Bay
KEALAKEHE HOMESTEADS
16-21
(Harbor)
22-30
Noio Pt.
19°40'
Kaiwi Pt.
A
31
32
19°39'
Keahuolu Pt.
19°38'
B
[KEAHOLE POINT]

APPENDIX A, continued. Pond environmental data.

Pond No.	Latitude	Riparian Plants	Bottom Type	Depth	Salinity °/oo
L 1	19°38.6'	V,G,T	S	S	15
2	"	"	"	M	17
3	"	V,G	S,R	S	12
4-5	"	V	S	"	?
6	"	O	R	"	14
7	"	V	S,R	"	13
8-9	"	T,G,V	"	M	?
10	"	V,G,T	"	S	?
11	"	V,T	R,S	M	10
12	"	V	S	"	11
13	"	V,G	S,R	S	8-9
14	"	V,T	"	M	7
15	"	V	R	S	7
M 1	35.0'	G,T	R	M	?
2	"	T,V	S	S	10
3	"	"	S,R	M	5
4	34.8'	O	S	?	4
5-6	"	?	?	"	3

Figure 10, Quads L and M: One of the ponds (L 1-15 series) behind the King Kamehameha Hotel in Kailua-Kona. As in other areas of human habitation, most of these ponds are degraded biologically, but native species thrive in a few of the small, obscure pools.

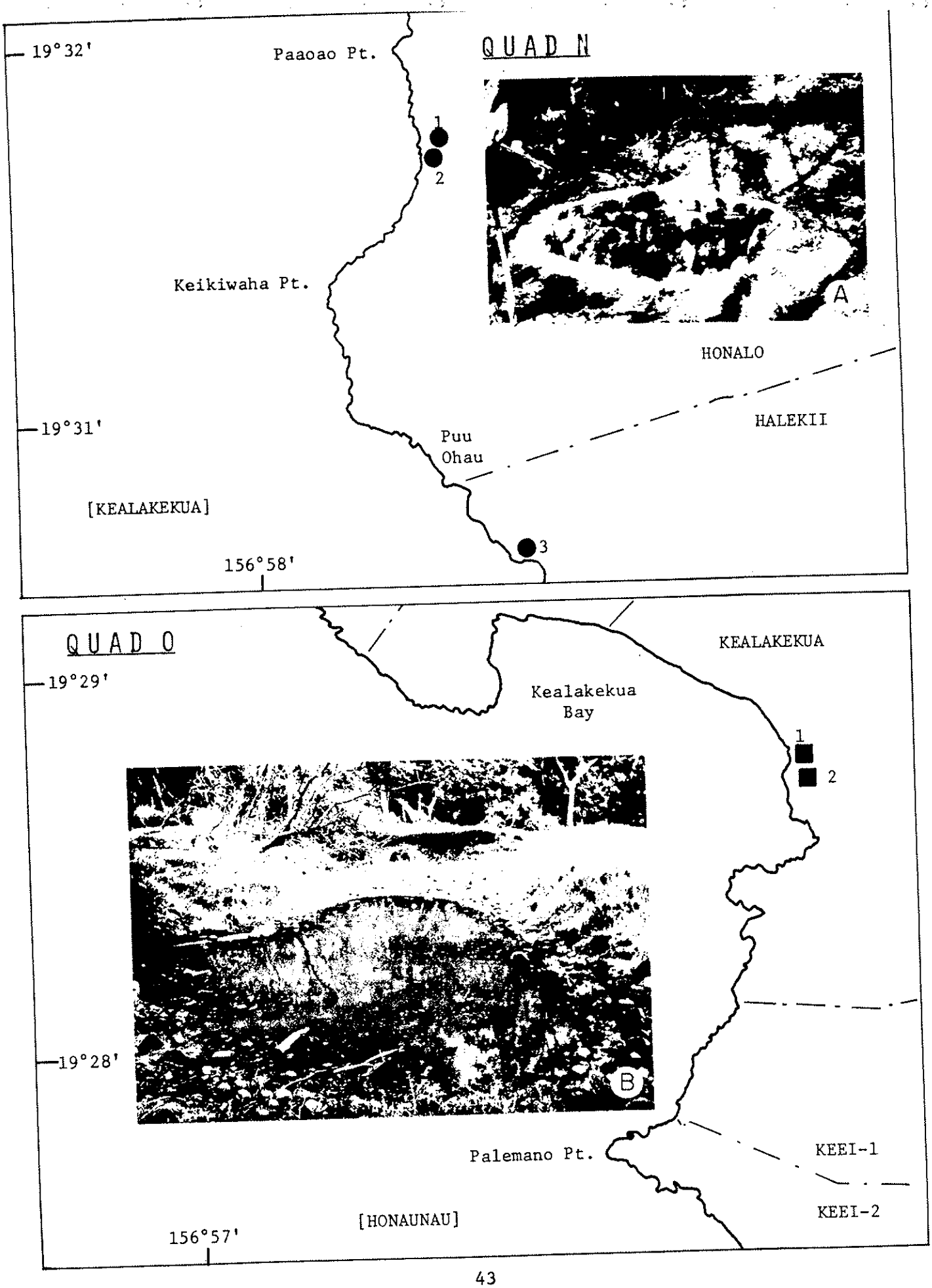

19°39'
QUAD L
KEAUHUOLU
1-15
Kukailimoku Pt.
Kailua Bay
19°38'
[KEAHOLE POINT]
[KAILUA]
[KAILUA]
[KEALAKEKUA]
156°00'
PUAPUAA-2


QUAD M
19°35'
1-2
KAHALUU
Kahaluu Bay
3
4-6
19°34'
KEAUHOU-1
Keauhou Bay
155°59'

APPENDIX A, continued. Pond environmental data.

Pond No.	Latitude	Riparian Plants	Bottom Type	Depth	Salinity °/oo
N 1	19°31.7'	?	?	?	5
2	"	"	"	"	6
3	30.7'	"	"	"	2
O 1	28.8'	G,T	S	S	6
2	"	"	"	"	12
P 1	24.7'	T	S	S	3

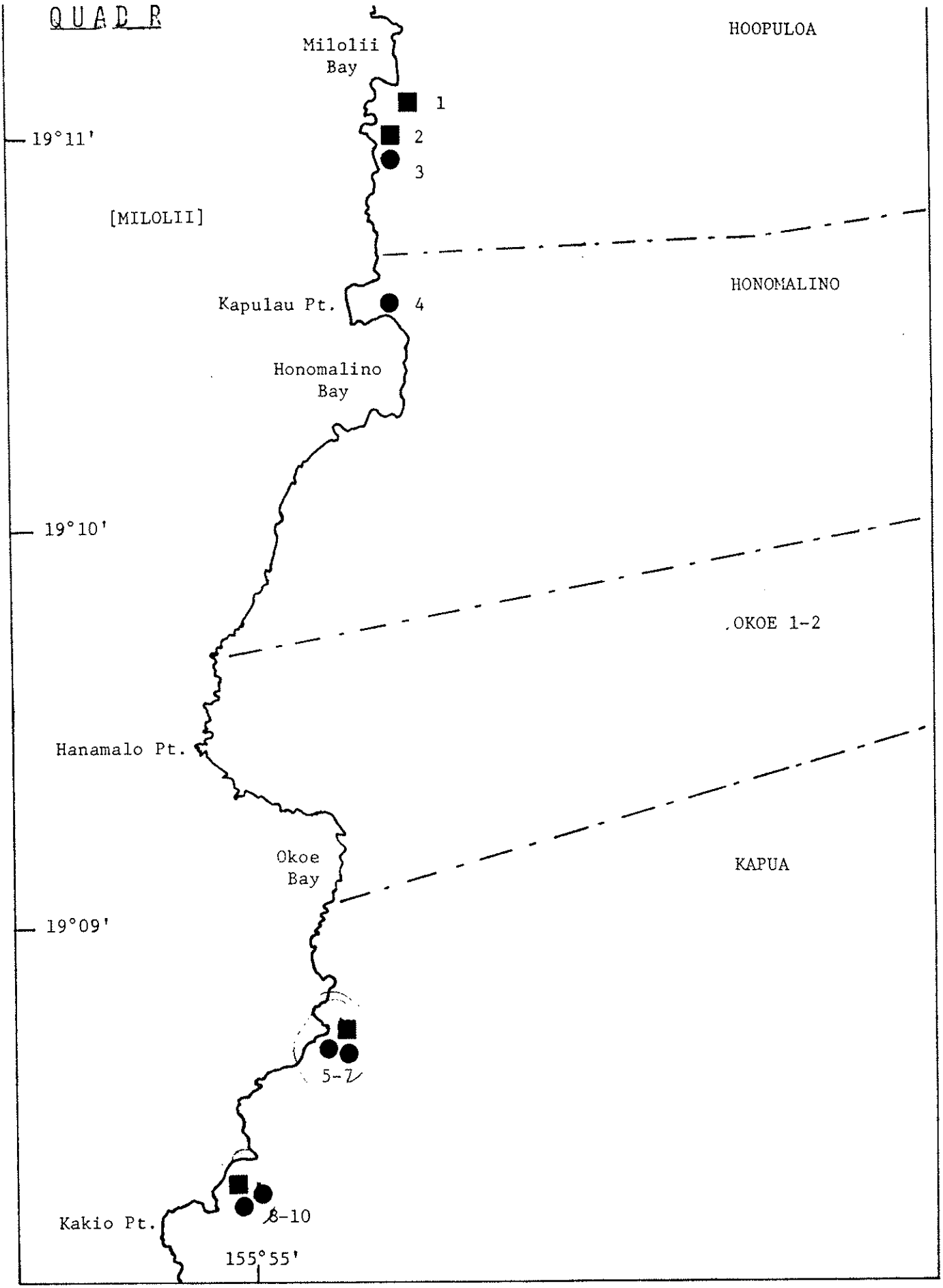
Figure 11, Quads N and O: (a) Honalo pond, N 2, is a recently walled well that contains small red shrimp (opaeula). (b) Pond O 2 at Kealakekua Bay shows effects of severe cultural degradation in the forms of litter and highly turbid water from nutrient enrichment.


19°32'
Paaoao Pt.
QUAD N
1
2
Keikiwaha Pt.
A
HONALO
19°31'
HALEKII
Puu
Ohau
[KEALAKEKUA]
3
156°58'
QUAD O
KEALAKEKUA
19°29'
Kealakekua
Bay
1
2
B
19°28'
Palemano Pt.
KEEI-1
KEEI-2
[HONAUNAU]
156°57'

APPENDIX A, continued. Pond environmental data.

Pond No.	Latitude	Riparian Plants	Bottom Type	Depth	Salinity °/oo
R 1	19°11,1'	T	S	S	5
2	11.0'	G,T	"	"	6
3	"	T	"	"	5
4	10.5'	"	S,R	M	5
5	8.7'	"	S	S	4
6	"	"	"	"	6
7	"	"	R	?	5
8	8.4'	"	S	S	5
9	8.3'	"	R	M	4
10	"	"	?	?	4

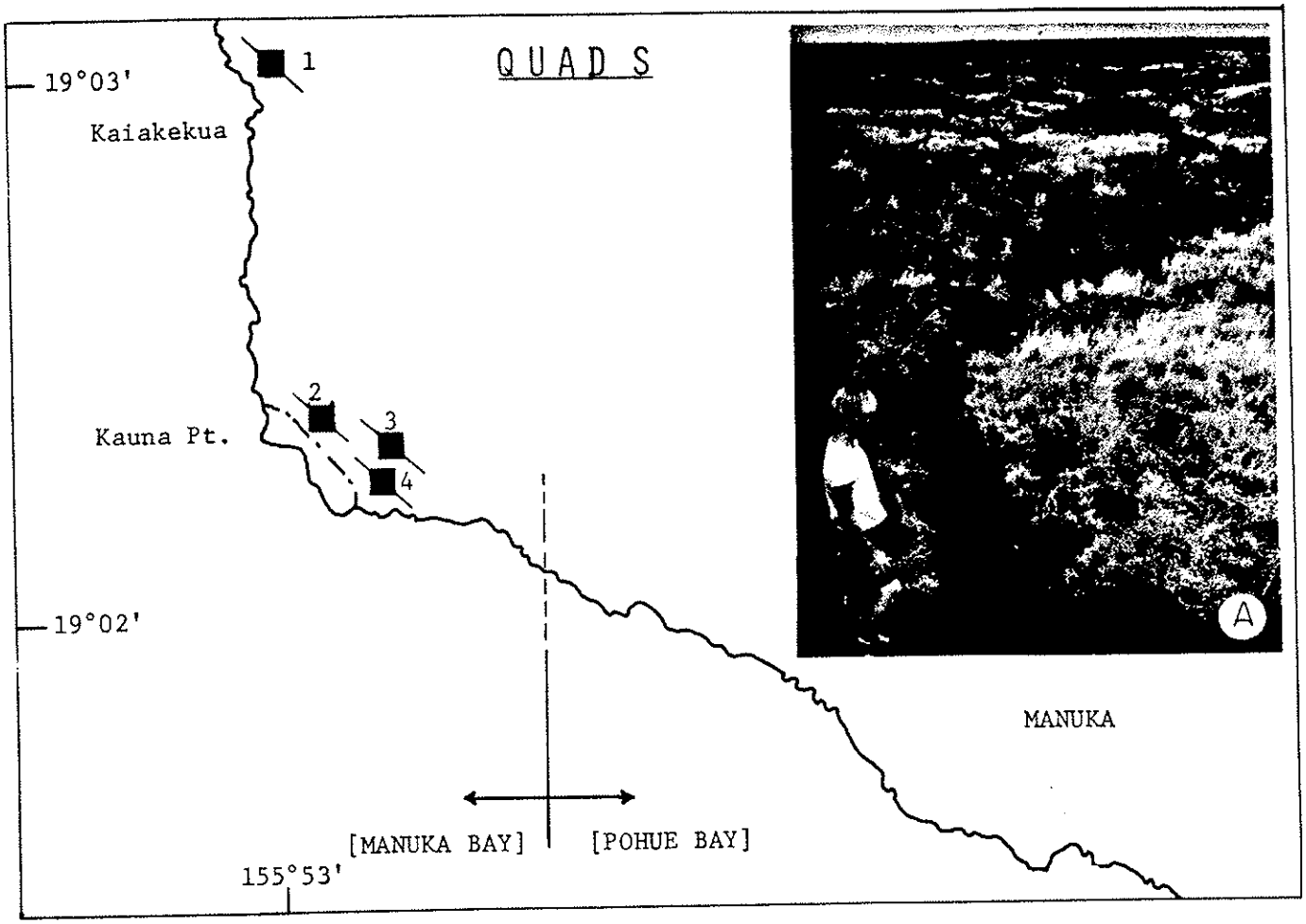
Figure 12, Quad R.

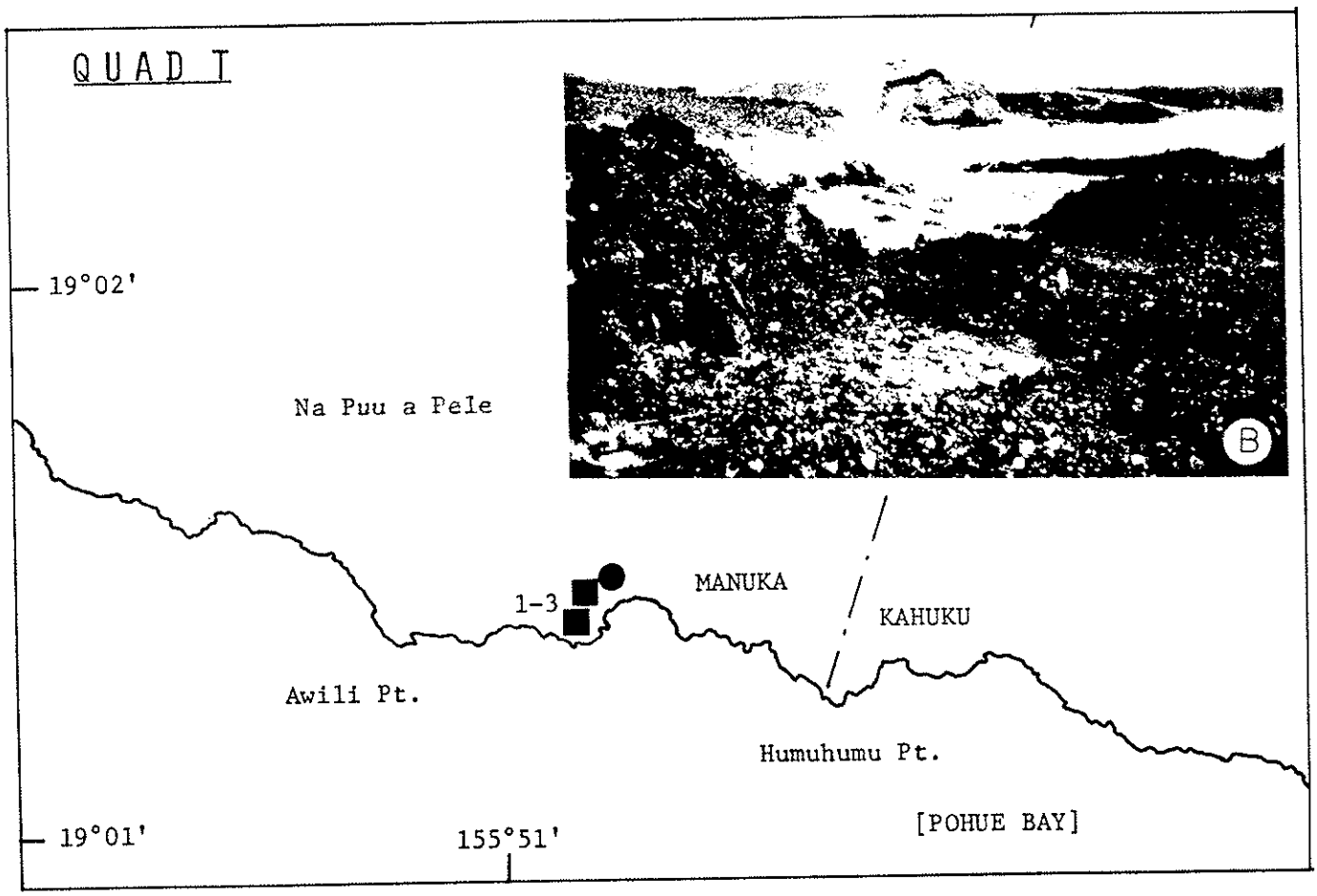

QUAD R
HOOPULOA
Milolii Bay
1
2
3
19°11'
[MILOLII]
HONOMALINO
Kapulau Pt.
4
Honomalino Bay
19°10'
OKOE 1-2
Hanamalo Pt.
Okoe Bay
KAPUA
19°09'
5-7
8-10
Kakio Pt.
155°55'

APPENDIX A, continued. Pond environmental data.

Pond No.	Latitude	Riparian Plants	Bottom Type	Depth	Salinity °/oo
S 1	19° 3.0'	0	R	S	6
2	2.3'	"	"	?	9
3	"	"	"	D	9
4	"	"	"	"	8
T 1	1.4'	0	R	M	16
2	"	"	"	"	15
3	"	"	S	"	15

Figure 13, Quads S and T: (a) A portion of S 3, one of the irregular fissures near Kauna Point. This is the longest (several hundred meters) and deepest (water surface at 15 meters below land surface in places) of the fissures inventoried. The water is exceptionally clear and poorly illuminated, but contains red shrimps. These waters are the most remote and pristine of the Kona coast. (b) Manuka pond, T 2, photographed at low tide. Areas of such pond with flat shorelines vary considerably during a tidal cycle.

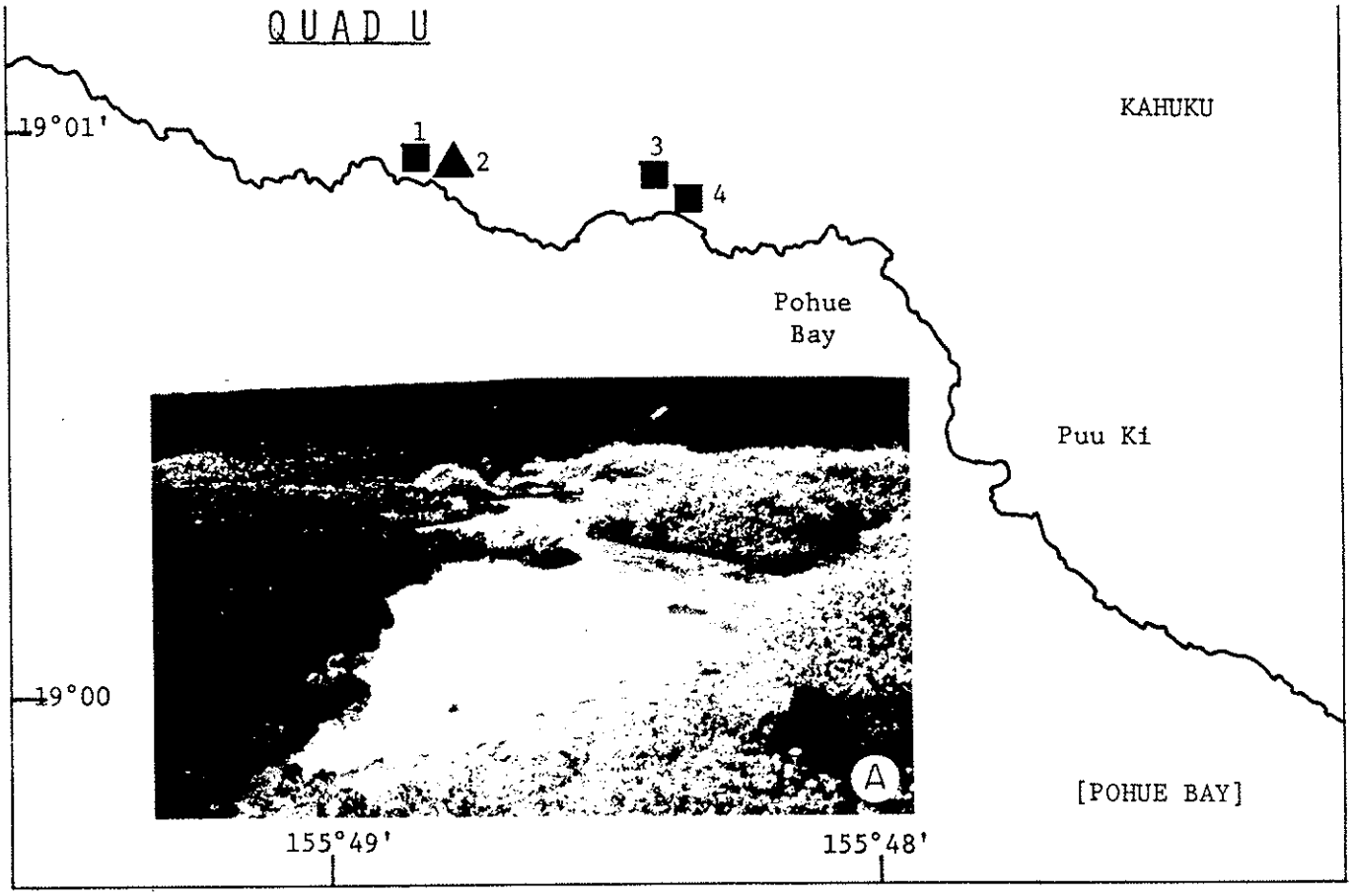

QUAD S
19°03'
Kaiakekua
1
2
3
4
Kauna Pt.
19°02'
MANUKA
[MANUKA BAY]
[POHUE BAY]
155°53'
A

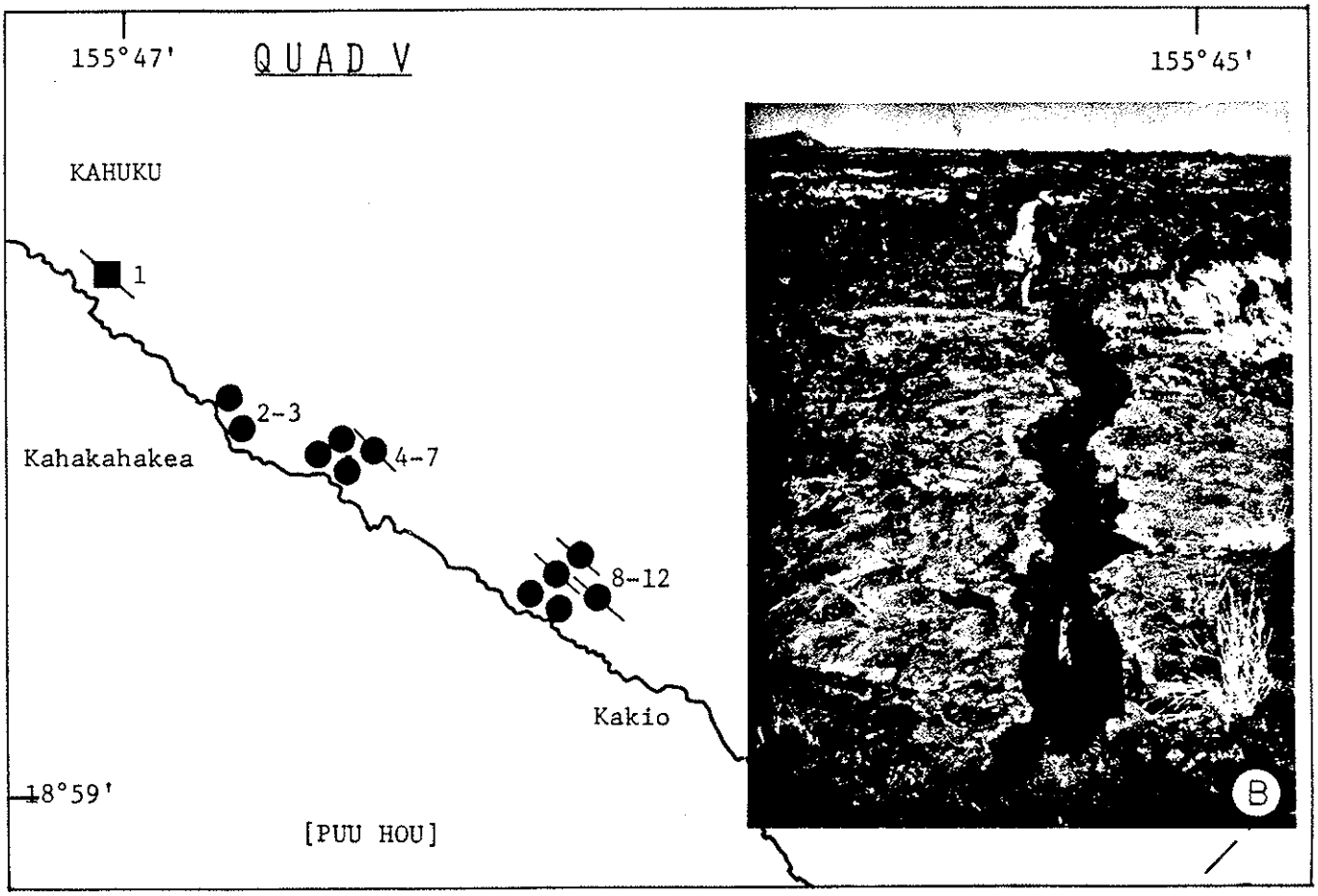

QUAD T
19°02'
Na Puu a Pele
1-3
MANUKA
KAHUKU
Awili Pt.
Humuhumu Pt.
[POHUE BAY]
19°01'
155°51'
B

APPENDIX A, continued. Pond environmental data.

Pond No.	Latitude	Riparian Plants	Bottom Type	Depth	Salinity °/oo
U 1	19° 0.9'	T,V	R	D	3
2	"	T	"	M	?
3	"	T,V	"	"	3
4	"	"	S,R	D	3-4
V 1	18°59.9'	O	R	D	3-4
2	59.7'	"	"	S	4
3	"	"	"	S	5
4	59.6'	V,G	"	"	4
5	"	O	?	?	?
6-7	"	"	R	S	5
8	59.4'	"	"	"	3
9	"	"	"	?	5
10	"	"	"	S	4
11	"	"	"	?	4
12	59.3'	"	"	M	3

Figure 14, Quads U and V: (a) Kahuku, U 2, is an impressive pond partly retained by a beach boulder bar (left background) and bordered mauka by shrubs (*Pluchea odorata*). The light-colored bottom, easily visible through clear water, consists of extensive mineral crusts formed by algal growth. Pond size can be estimated by comparing with seated figure in left foreground. (b) V 1, one of several fissures in the southern part of Kahuku land division, contains several native and unusual faunal species. Some of the other fissures were too narrow to enter for biota survey.

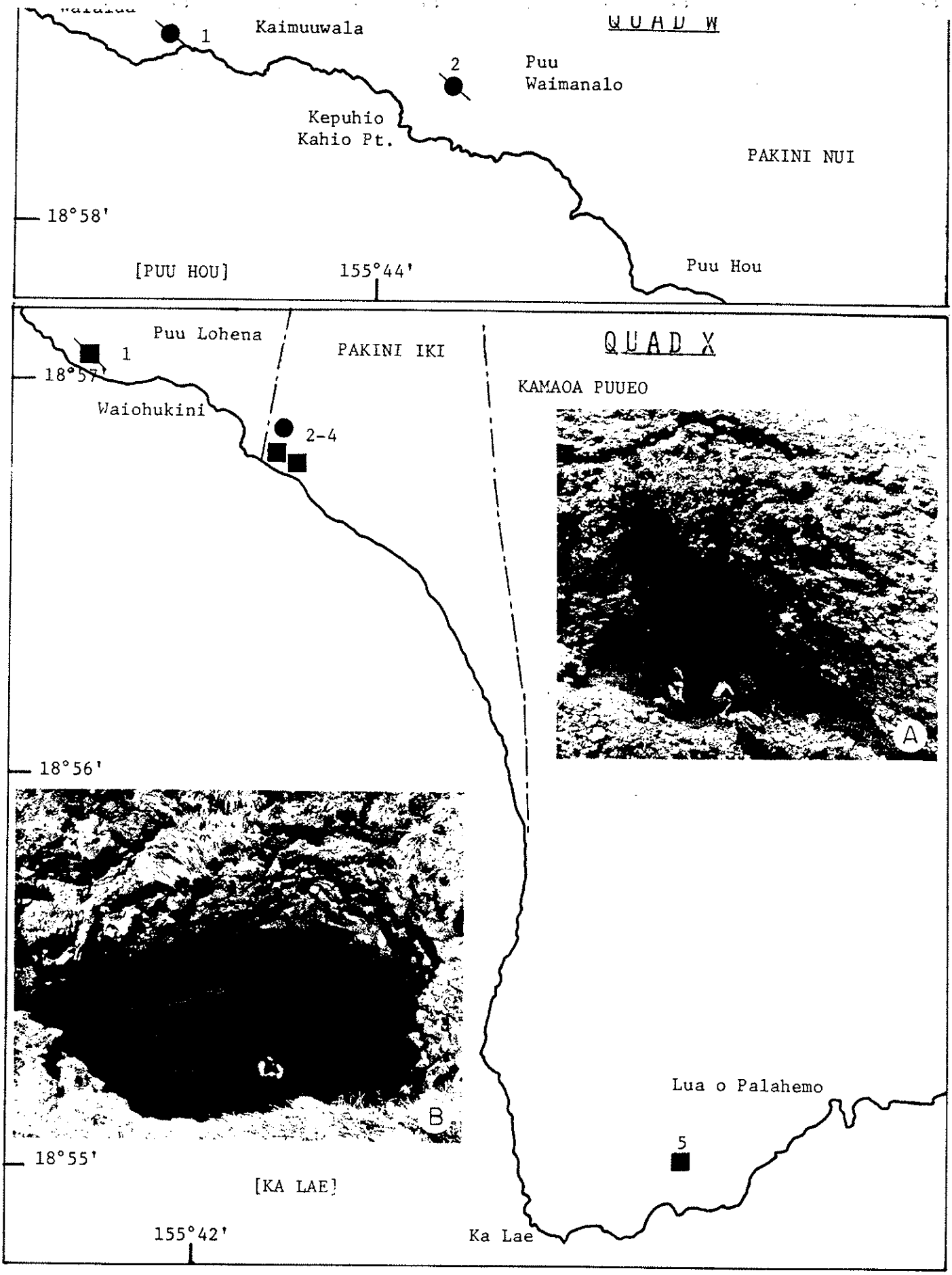

QUAD U
KAHUKU
19°01'
1
2
3
4
Pohue
Bay
Puu Ki
19°00
A
[POHUE BAY]
155°49'
155°48'


155°47'
QUAD V
155°45'
KAHUKU
1
2-3
Kahakahakea
4-7
8-12
Kakio
18°59'
[PUU HOU]
B

APPENDIX A, continued. Pond environmental data.

Pond No.	Latitude	Riparian Plants	Bottom Type	Depth	Salinity °/oo
W 1	18°58.5'	O	S,R	S	6
2	58.0'	"	?	?	4
X 1	57.1'	O	R	D	5
2	56.9'	V,T	S	M	9
3	"	T	S,R	S	7
4	56.8'	T,V	S	M	12
5	55.0'	G	S,R	D	18-22

Figure 15, Quads W and X: (a) One of the fractures in Puu Lohena (X 1), an old littoral cone surrounded by recent aa in southern Pakini Nui land division. It is notable as the location where the endemic alpheid shrimp, *Metabetaeus lohena*, first was found 15 years ago. (b) Lua o Palahemo, X 5, is the most peculiar pond with the most unusual biota found on this survey. It is very deep, apparently a part of an ancient flooded lava tube. It has a diversity of algae and invertebrates and is the only known habitat on Hawaii Island of the rare shrimps, *Procaris hawaiana* and *Calliasmata pholidota*.


QUAD W
1
Kaimuuwala
2
Puu
Waimanalo
Kepuhio
Kahio Pt.
PAKINI NUI
18°58'
[PUU HOU]
155°44'
Puu Hou
Puu Lohena
1
PAKINI IKI
QUAD X
18°57'
KAMAOA PUUEO
Waiohukini
2-4
A
18°56'
B
18°55'
Lua o Palahemo
5
[KA LAE]
155°42'
Ka Lae

APPENDIX B. DISTRIBUTION OF 27 MORE COMMON SPECIES AND SPECIES GROUPS OF AQUATIC PLANTS AND ANIMALS AMONG 305 CLOSED PONDS OF THE KONA COAST, HAWAII ISLAND. Explanatory notes: organisms listed occurred in at least 3 percent (10 or more) of the ponds; "x" preceding name refers to exotic species, all other being native; *Schizothrix* is the predominant alga in mineralized (white-to-orange) crusts; similarly, *Rhizoclonium* is the dominant alga in dark-green, non-mineralized benthic crusts and mats; unidentified organisms are listed by major taxons only; for pond locations and physical data refer "Pond No." to APPENDIX A.

	Flora		Worms	Mollusks		Crustaceans											Insects, etc.				Fishes				
Pond No.	*Schizothrix* sp.	*Rhizoclonium* sp.	*Ruppia maritima*	Oligochaeta, 1 sp.?	Polychaeta, >1 sp.?	*Assiminea* sp.	*Melania* sp.	*Theodoxus cariosa*	Isopoda *Ligia* sp.	Amphipoda, 1 reddish sp.	Amphipoda, other sp., >1	*Metabetaeus lohena*	*Halocaridina rubra*	*Palaemon debilis*	*Macrobrachium grandimanus*	x-*Macrobrachium lar*	*Metopograpsus thukuhar*	Collembola, 1 sp.?	x-Hemiptera/Veliidae, 1 sp.?	x-*Trichocorixa reticulata*	x-Odonata, >1 sp.	Acarina, 1 sp.	*Mugil cephalus*	*Kuhlia sandvicensis*	*Eleotris sandwicensis*	x-*Tilapia mossambica*	x-Poeciliidae, >1 sp.
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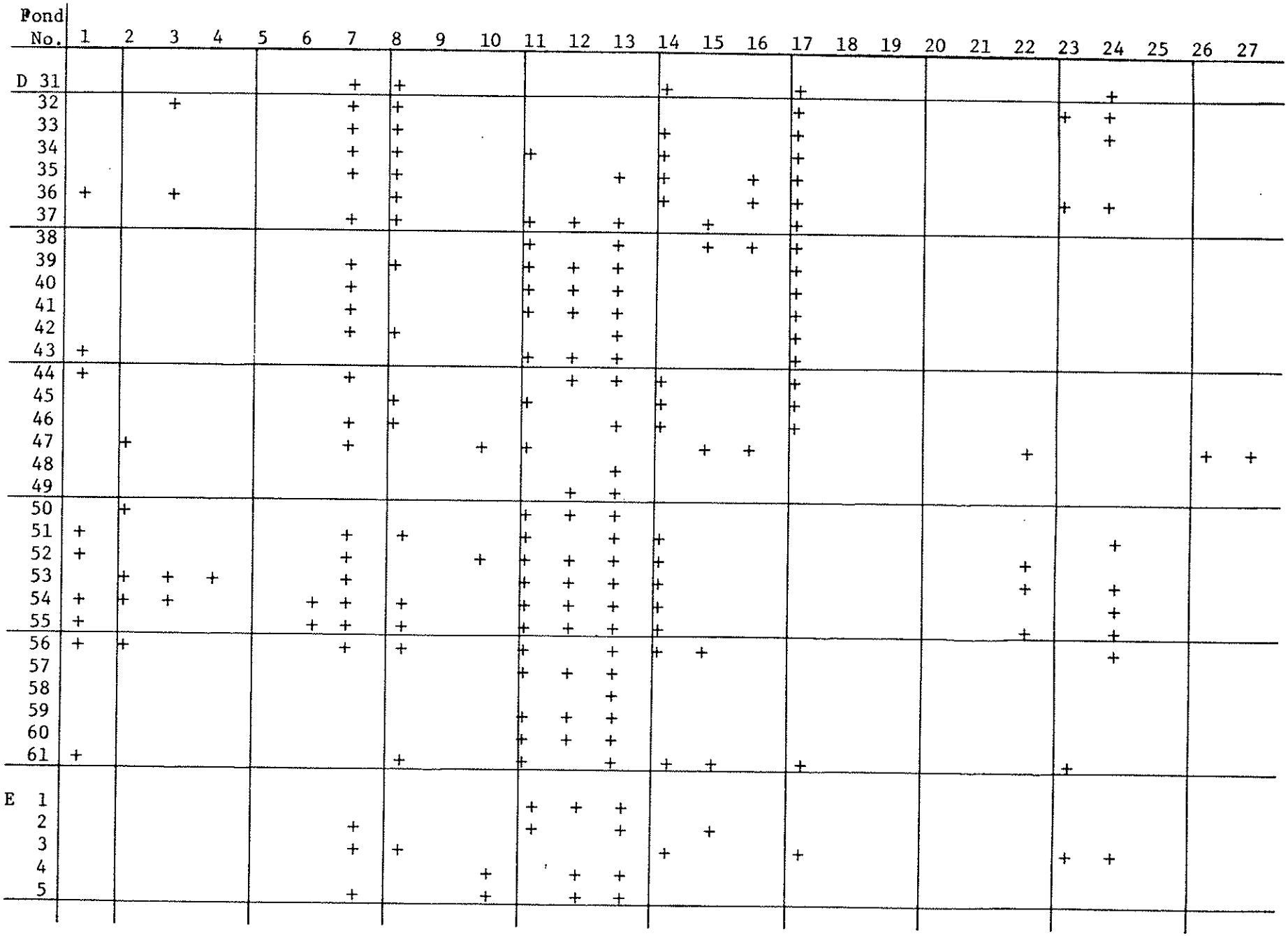
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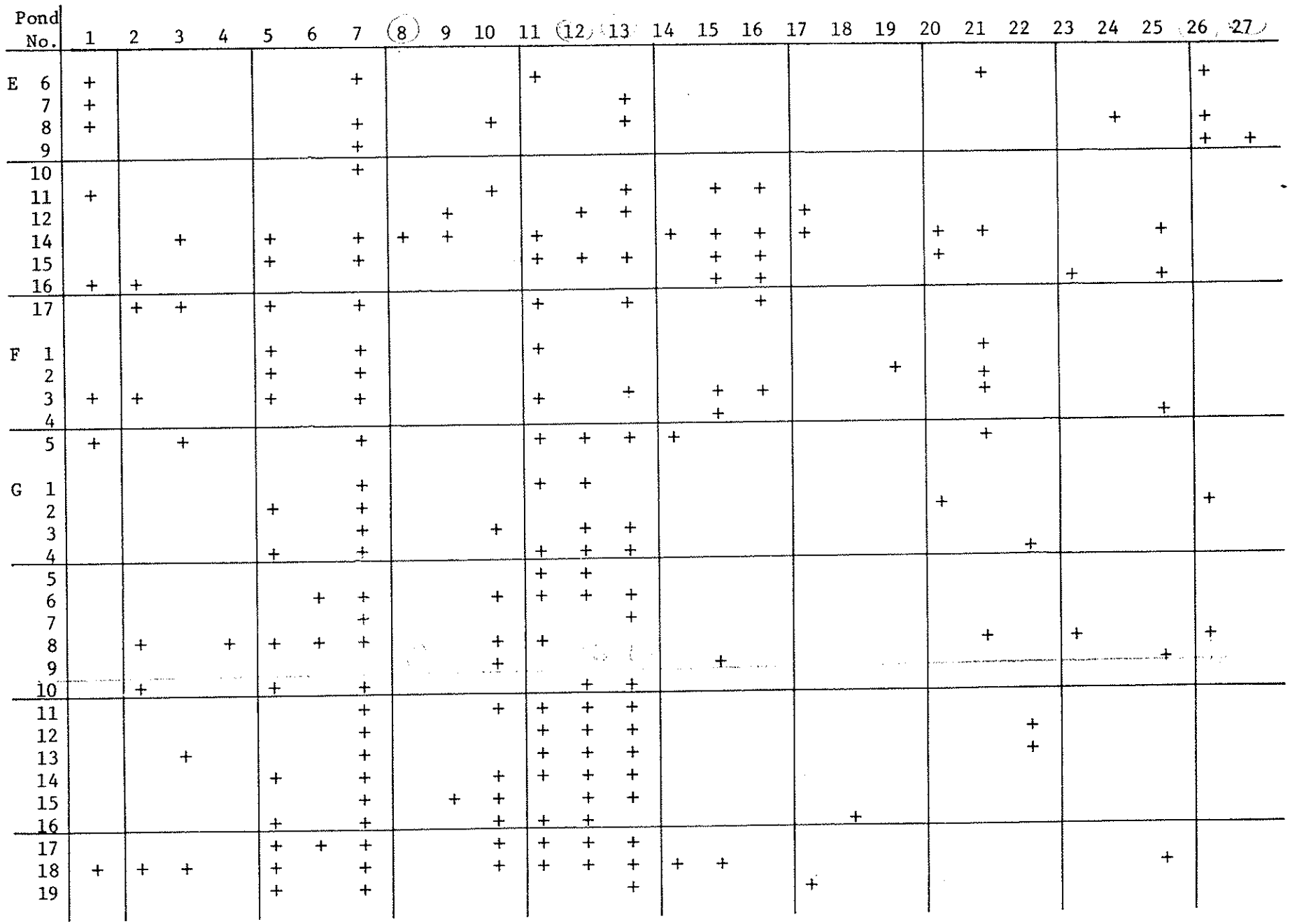
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APPENDIX C.

TAXONOMIC LIST AND DISTRIBUTIONS OF LESS-COMMON FAUNA

OF CLOSED PONDS, KONA COAST, HAWAII

A. Porifera (sponges)
   Unidentified species: X-5
B. Coelenterata
   Hydrozoa (hydroids). Ostromouvia horii: K-1
   Anthozoa (anemones, etc.) Unidentified species: J-7
C. Mollusca
   Gastropoda (snails)
   Melampus parvulus: H-4; J-45; K-22
   Theodoxus vespertina: E-14,16; H-9; K-3,10,24
   Nerita polita: K-16,30; X-2
   Neritilia sp.: F-5; J-45,47
   Unidentified red species: E-15
   Pelecypoda (clams, etc.)
   Isognomon californicum: D-17
   Unidentified species: S-1
D. Anthropoda
   Isopoda (pill bugs, etc.)
   Unidentified cymothoid species:
   Decapoda (shrimps, crabs)
   Alpheus crassimanus: J-46
   Antecaridina lauensis: V-1; X-5
   Procaris hawaiana: X-5
   Calliasmata pholidota: X-5
   Unidentified xanthid crab: D-60
   Insecta
   Unidentified beetle: F-1; G-15; H-23
   Unidentified mosquito: F-1; O-1
   Unidentified midge: D-47
E. Chordata (vertebrates)
   Pisces (fishes)
   Abudefduf abdominalis (Mamo): D-61; F-5
   Abudefduf sordidus (Kupipi): D-3,54; E-3; H-1,20,30; U-4
   Acanthurus achilles (Pakuikui): H-9
   Acanthurus sandvicensis (Manini): D-2,3,56; H-2,8,20,21; U-3
   Adioryx sp. (Alaihi): D-55
   Awaous genivittatus (Oopu kanio): D-36
   Bathygobius fuscus (Oopu kai): D-32; H-8,30; J-46; M-6
   Chanos chanos (Awa): E-3
   Conger sp. (Puhi uha): C-10
   Cyprinus carpio (Koi-exotic): E-3,9
   Kelloggella oligolepis: D-32,33,45
   Neomyxus chaptalii (Uouoa): H-9,20
   Sphyraena barracuda (Kaku): E-14
   Reptilia (turtles, etc.)
   Chelonia mydas (Honu): E-14,17; H-23

APPENDIX D.

TAXONOMIC LIST OF AQUATIC MACROFAUNA FOUND IN 13 OPEN PONDS, KONA COAST, HAWAII, JULY 1972 TO MAY 1973. List includes only species that do not occur in closed ponds. Open ponds (with surface connection to the sea) are: B-1; C-28, 30; D-7, 8, 14-16, 27, 28; E-13; J-40; K-23.

Phylum Porifera

Two unidentified sponges

Phylum Coelenterata (anemones, etc.)

Anthozoa: *Aiptasia* sp.

Phylum Annelida (worms)

Polychaeta-Errantia

Eurythoe complanata
Namalycastis sp.
Protula atypha
Spiophanes bombyx

Polychaeta-Sedentaria

Janua knightjonesi
Janua nipponica
Leodora knightjonesi
Mercierella enigmata
Pileolaria militaris
Pileolaria pseudomilitaris
Salmacina dysteri

Phylum Mollusca

Gastropoda (snails, nudibranchs)

Dolobrifera olivacea
Hipponix sp.
Littorina pintado (pipipi akolea)
Mitra auriculoides
Morula granulata (pupu makaawa)
Natica marochiensis
Nerita picea (pipipi)
Teredo parksi
unidentified nudibranch
unidentified vermetid

Pelecypoda (clams, oysters, etc.)

Hormomya crebristriatus
Isognomon costellatum (papaua)
Isognomon sp.
Ostrea sandvicensis (olepe)
Spondylus zonalis
Tellina rugosa

Phylum Arthropoda

Crustacea-Cirripedia (barnacles)
Chthamalus sp. (pioe)

Crustacea-Decapoda (shrimps, crabs)
Calcinus laevimanus
Carpilus maculatus
Clibanarius zebra
Epixanthus sp.
Grapsus grapsus (ama)
Leptodius sanguineus
Palaemonella burnsi
Portunus pubescens
Thalamita crenata
unidentified Xanthidae

Phylum Echinodermata

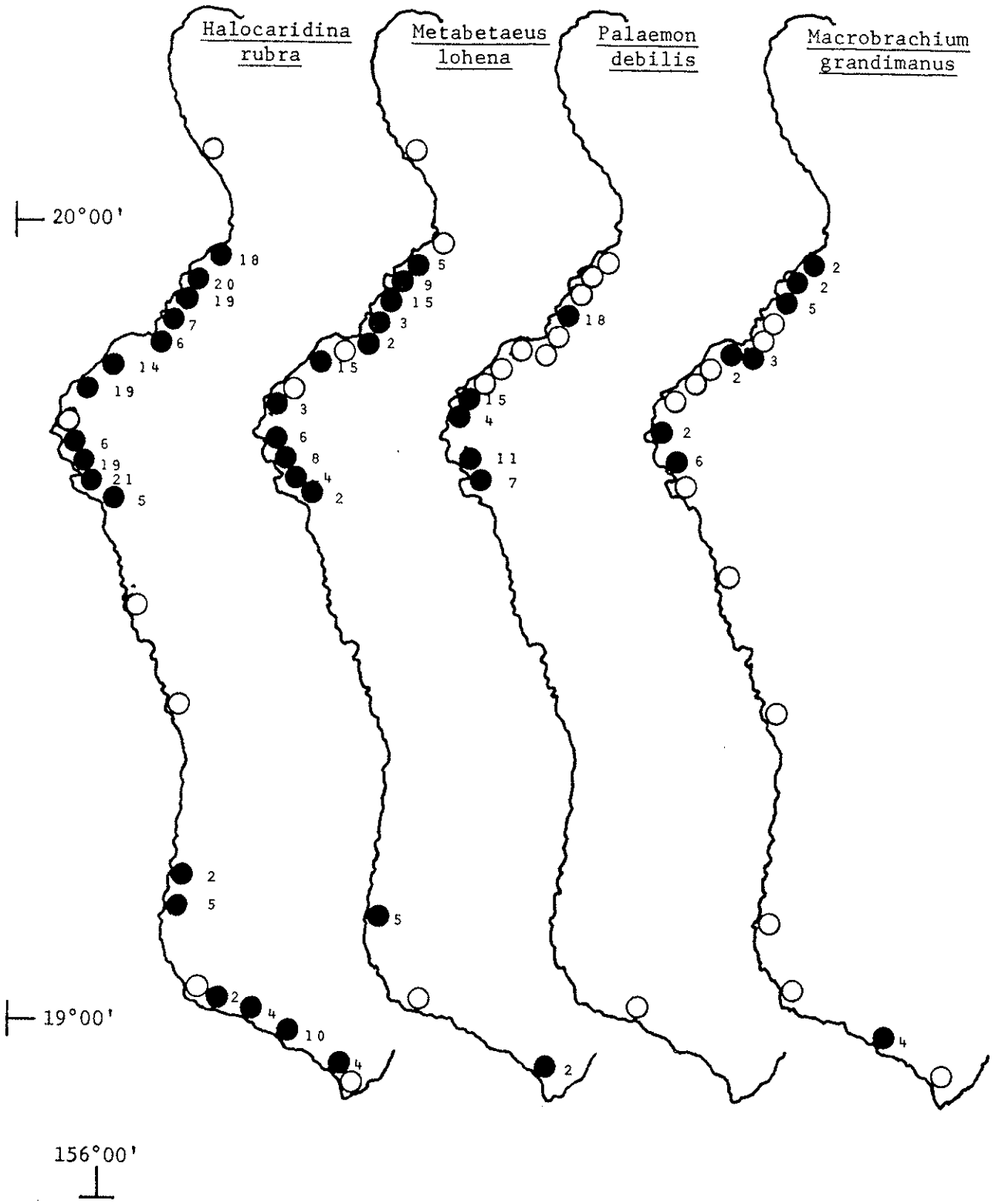
Opiuroidea (brittle stars)
Ophiocoma erinaceus
unidentified species

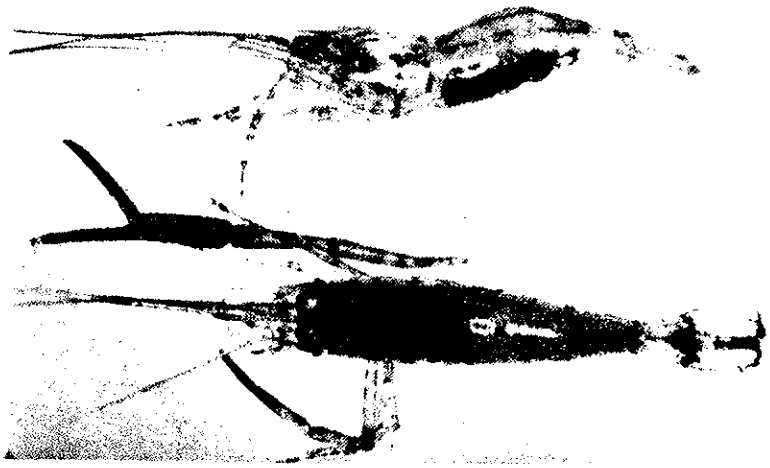
Holothuroidea (sea cucumbers)
unidentified species

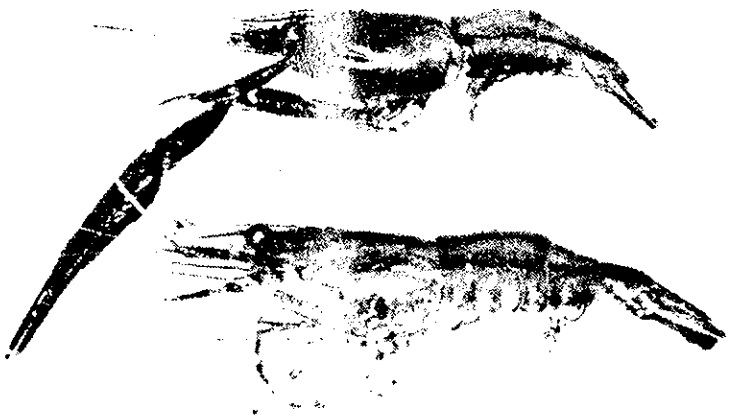
Phylum Chordata

Osteichthys (bony fishes)
Acanthurus nigrofuscus
Adioryx lacteoguttatus (alaihi)
Asterropteryx semipunctatus
Awaous stamineus (oopu nakea)
Chaetodon lunula (kikakapu)
Diodon hystrix (oopu kawa)
Flammeo sammara
Gomphosus varius (akilolo)
Gymnothorax hilonis (puhi)
Istiblennius sp.
Microcanthus strigatus
Mulloidichthys samoensis (weke)
Oxyurichthys lonchotus (oopu kauleloa)
Parupeneus multifasciatus (moano)
Parupeneus porphyreus (kumu)
Polydactylus sexfilis (moi)
Pomacentrus jenkinsi
Scarus dubius
Scarus perspicillatus (uhu)
Stethojulius axillaris (omaka)
Stolephorus purpureus (nehu)
Thalassoma duperryi (hinalea lauwili)
unidentified Gobiidae

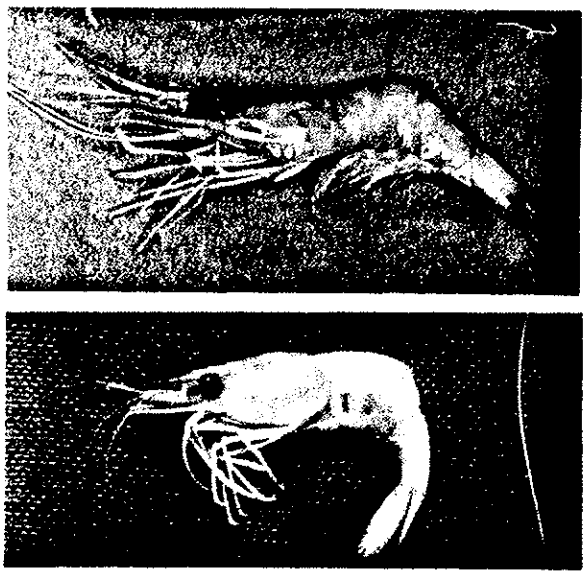
APPENDIX E. KONA COAST DISTRIBUTIONS OF REPRESENTATIVE CLOSED-POND FAUNA: CRUSTACEA--*HALOCARIDINA RUBRA, METABETAEUS LOHENA, PALAEMON DEBILIS, MACROBRACHIUM GRANDIMANUS*. Open circles on maps are single pond locations, solid circles are multiple-pond locations; numerals indicate numbers of ponds at each location.







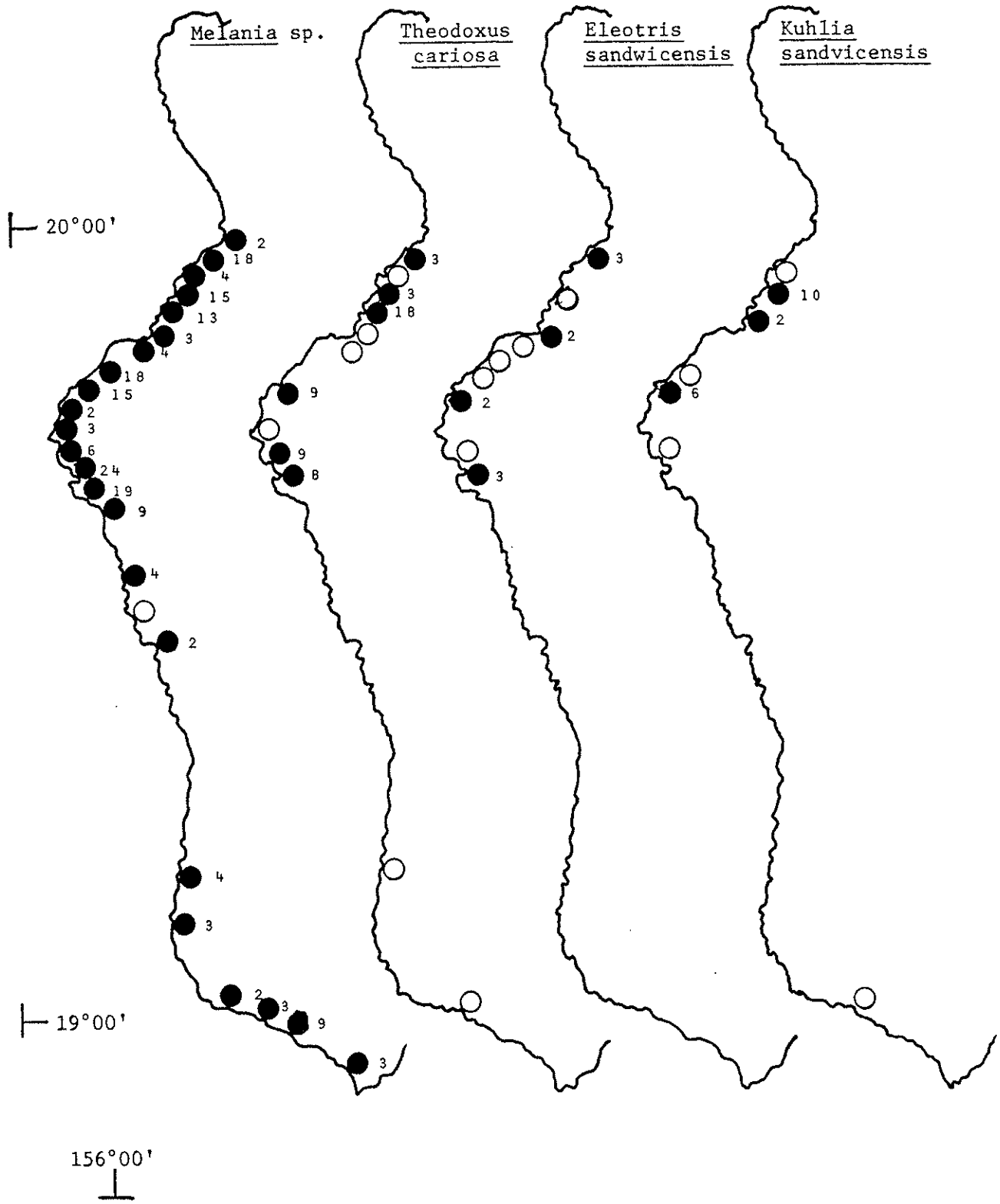
Left. Two endemic red shrimps; the alpheid, *Metabetaeus lohena* (upper pair), preys on the atyid, *Halocaridina rubra* (lower pair), which is herbivorous. About 4 times life size.



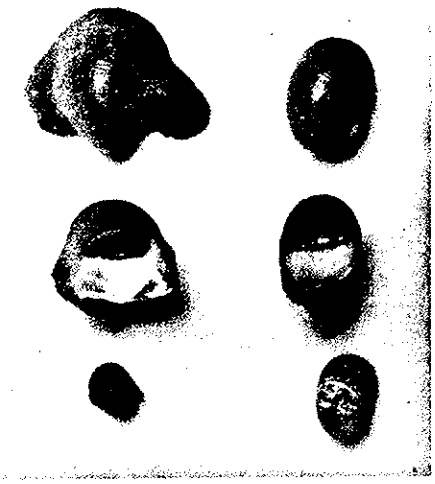
Right. Ecotypes of *Palaemon debilis* (opae huna). Upper specimen with long rostral spine is the normal type, usually found as transparent "glass shrimp" in clear water. Lower specimen from turbid Kapoikai (H 23) has an opaque body and short rostrum. Both about twice life size.

Above. Ecotypes of the palaemonid prawn, *Macrobrachium grandimanus* (opae oehaa). Left pair (female above, male below) is a delicate, aberrant type characteristic of anchialine pools (shown about life size). Pair at right (male above, female below) is the normal, robust (shown about one-third life size), heavily-pigmented type found in some coastal pools but more characteristic of streams.

APPENDIX E, CONTINUED. KONA COAST DISTRIBUTIONS OF REPRESENTATIVE CLOSED-POND FAUNA: MOLLUSCA--*MELANIA* SP., *THEODOXUS CARIOSA:* PISCES--*ELEOTRIS SANDWICENSIS, KUHLIA SANDVICENSIS.* Open circles on maps are single pond locations, solid circles are multiple-pond locations; numerals indicate numbers of ponds at each location.

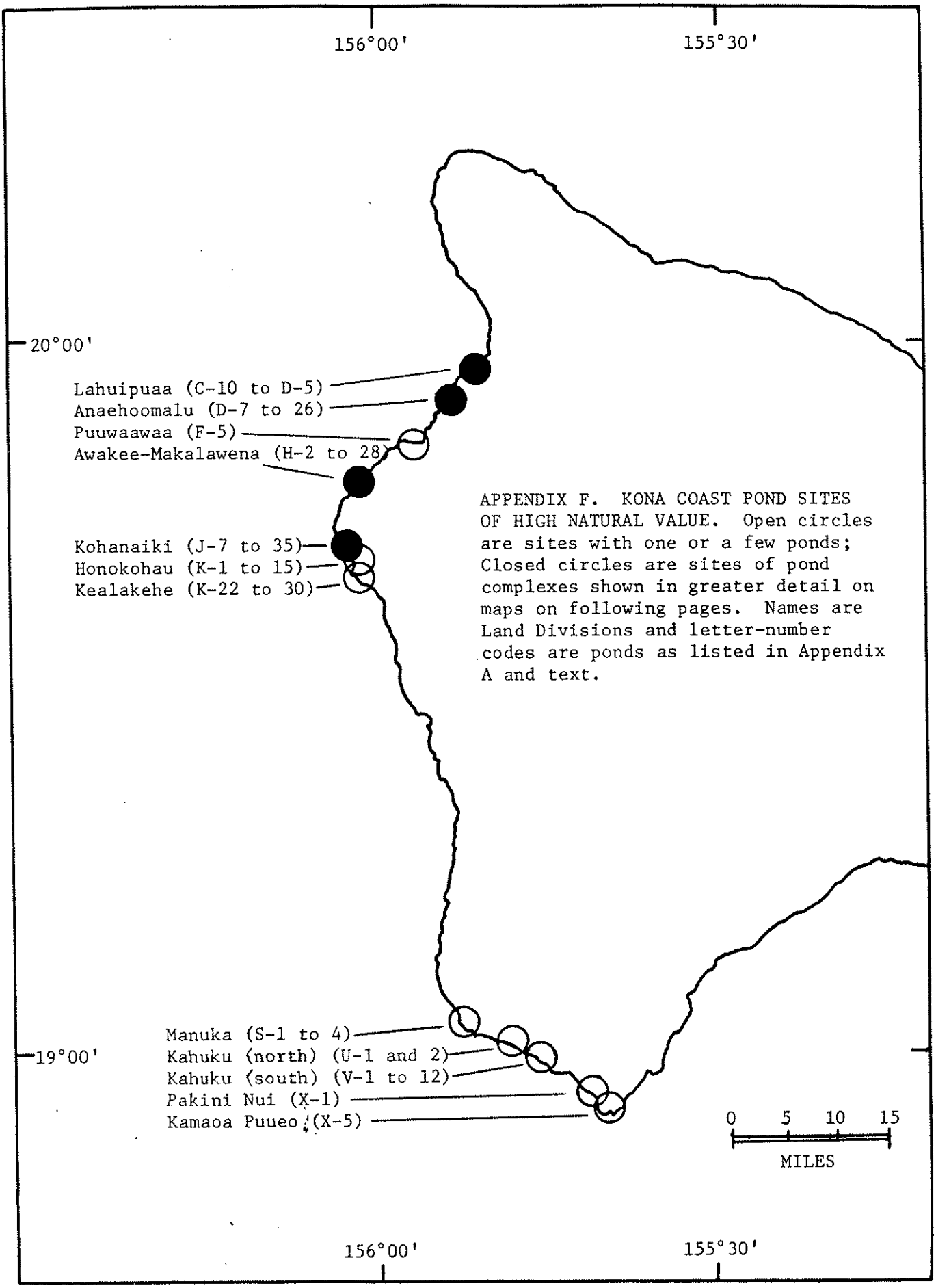


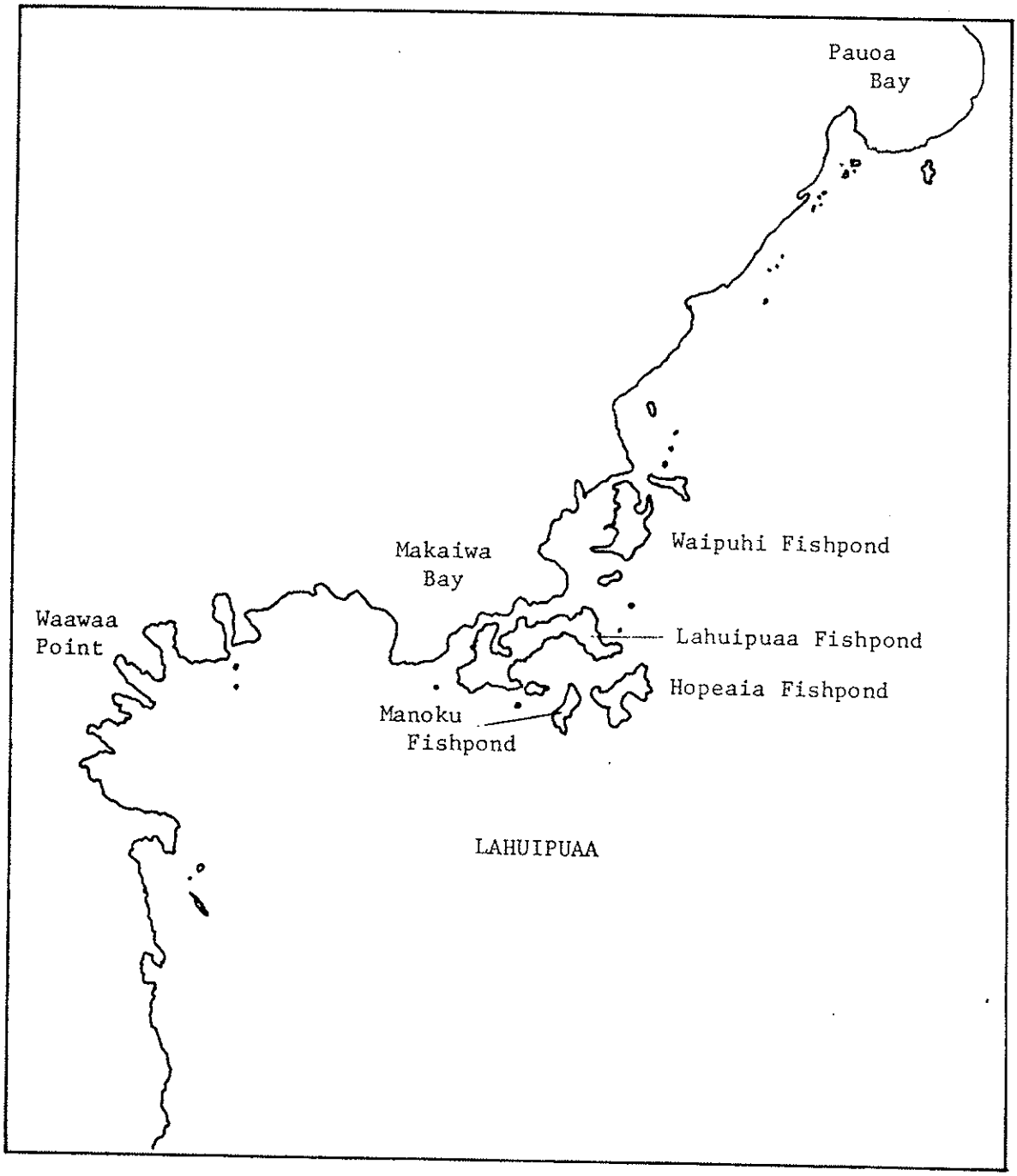
Right. Large shells are *Melania* sp., the most ubiquitous animal of Kona coast ponds. Often, shell tips are eroded severely. Small shells are *Assiminea* sp., a snail that co-occurs with *Melania* but is found in fewer ponds. Both about life size.



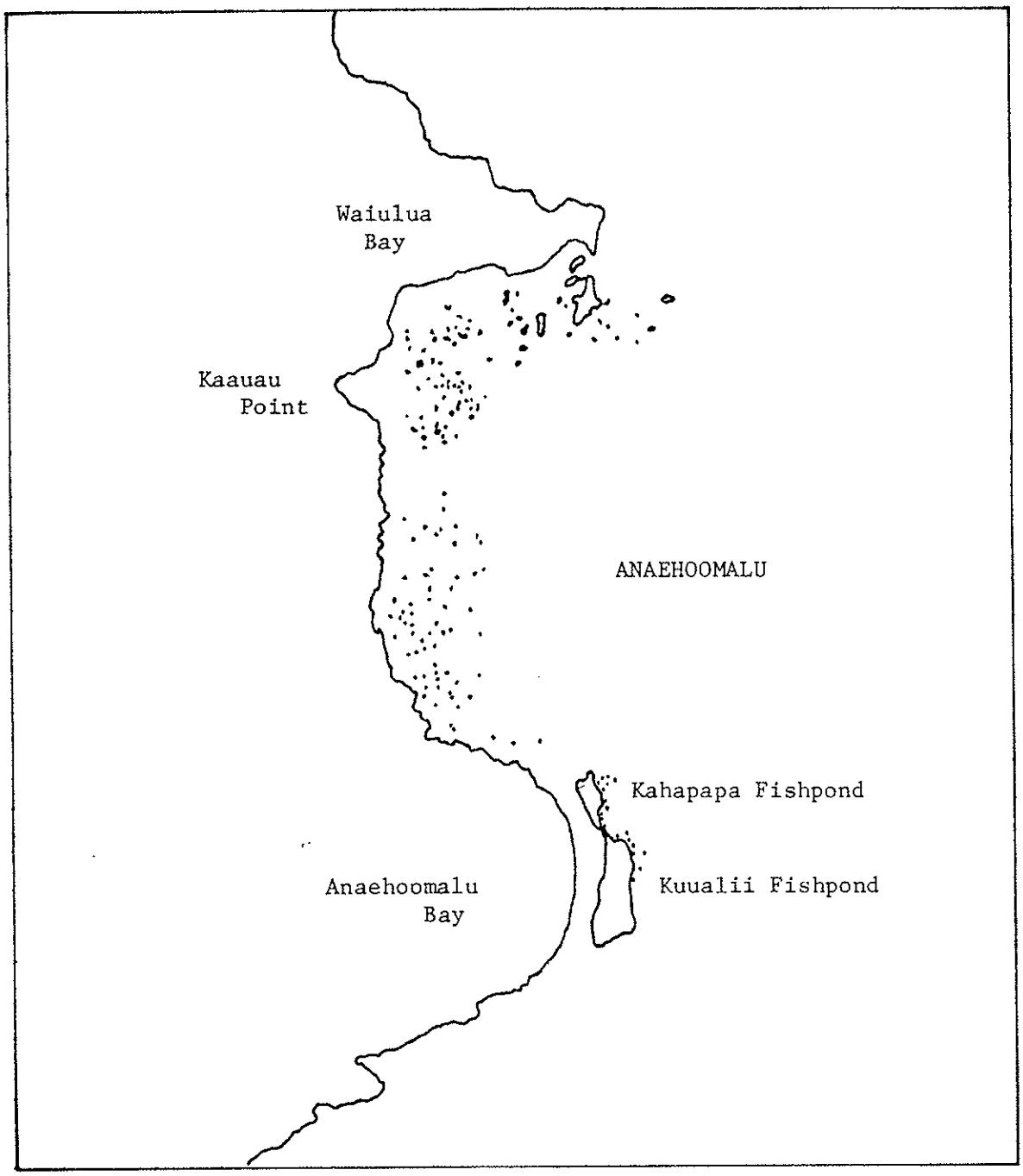
Left. Shell variants of *Theodoxus cariosa*, a limpet-like neritid snail. Differences in lateral development of shells is typical of variations in Kona coast ponds. Slightly smaller than life size.

Right. Juveniles of *Kuhlia sandvicensis* (aholehole) a silvery predaceous species that reaches a length of 30 cm in anchialine pools (specimens about one-half life size). Below. *Eleotris sandwicensis* (oopu akupa), a bottom-dwelling predator related to true gobies (specimen about life size).

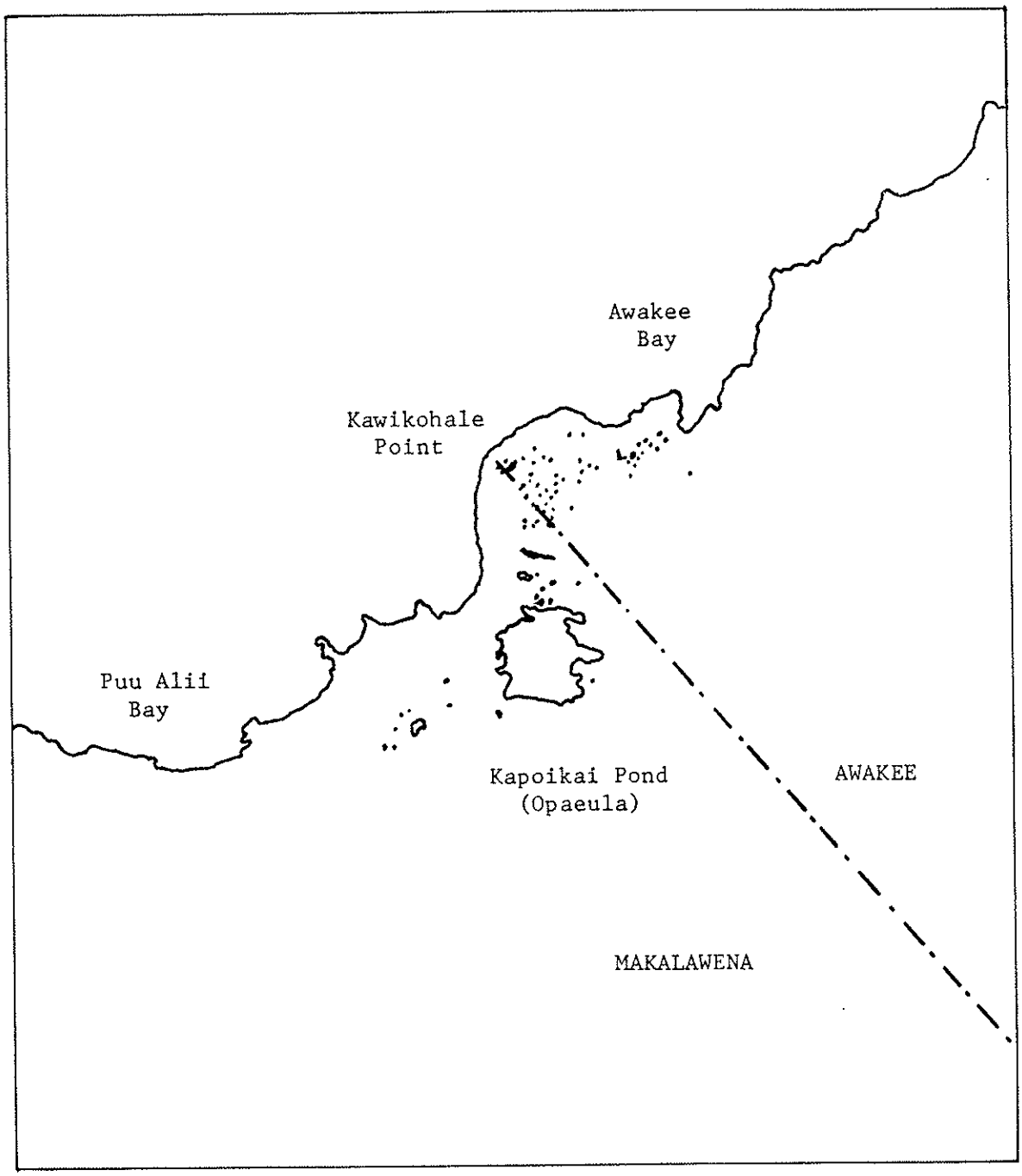

156°00'
155°30'
20°00'
Lahuipuaa (C-10 to D-5)
Anaehoomalu (D-7 to 26)
Puuwaawaa (F-5)
Awakee-Makalawena (H-2 to 28)
Kohanaiki (J-7 to 35)
Honokohau (K-1 to 15)
Kealakehe (K-22 to 30)
APPENDIX F. KONA COAST POND SITES OF HIGH NATURAL VALUE. Open circles are sites with one or a few ponds; Closed circles are sites of pond complexes shown in greater detail on maps on following pages. Names are Land Divisions and letter-number codes are ponds as listed in Appendix A and text.
19°00'
Manuka (S-1 to 4)
Kahuku (north) (U-1 and 2)
Kahuku (south) (V-1 to 12)
Pakini Nui (X-1)
Kamaoa Puueo (X-5)
0 5 10 15
MILES
156°00'
155°30'



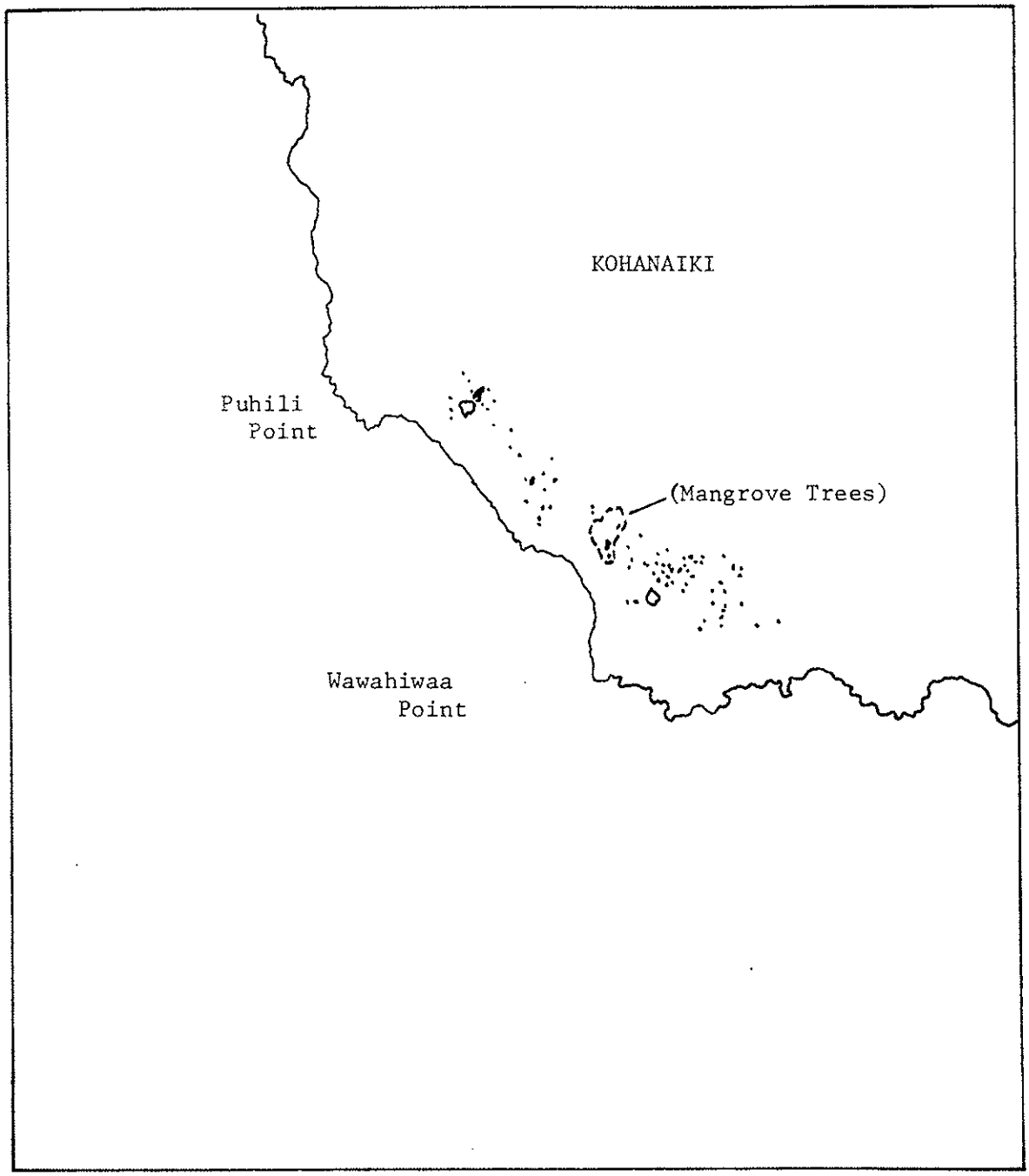
APPENDIX F, continued. Important Kona coast pond sites: ponds of Lahuipuaa Land Division, South Kohala District. Scale = 1:12,000 (1 cm = 120 m).



APPENDIX F, continued. Important Kona coast pond sites: ponds of Anaehoomalu Land Division, South Kohala District. Scale = 1:12,000 (1 cm = 120 m).



APPENDIX F, continued. Important Kona coast pond sites: ponds of Awakee-Makalawena Land Divisions, North Kona District. Scale = 1:12,000 (1 cm = 120 m).



APPENDIX F, continued. Important Kona coast pond sites: ponds of Kohanaiki Land Division, North Kona District. Scale = 1:15,000 (1 cm = 150 m).

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