Hawaii Coastal Zone Management Program

Hawaii : Coastal Zone Management Program

technical supplement 1

Technical Considerations in Developing a Coastal Zone Management Program for Hawaii

HAWAIIAN COASTAL WATER ECOSYSTEMS: AN ELEMENT PAPER FOR THE HAWAII COASTAL ZONE MANAGEMENT STUDY

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June, 1975

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ABSTRACT

This report describes the general characteristics of ecosystems inhabiting fresh or marine waters of Hawaii's Coastal Zone. Each of the approximately 25 types of coastal water ecosystems can be conveniently placed under inland, shoreline, or offshore categories. The distribution, status, and importance of human derived impacts on each type are described. These stresses are used as the criteria for purposes of defining the inland boundary with respect to coastal water ecosystem management. The distinction is made that natural ecosystems are in a sense capable of perpetuating themselves and that it is man's influence on these systems which require control or management. This requirement is needed if we wish to preserve the natural ecosystems because most of man's activities have been detrimental or have modified these ecosystems.

A majority of the principal sources of human impact on coastal water ecosystems are derived from adjacent land areas - more specifically within the watersheds which drain towards the coast. Since most of the drainage basins in Hawaii are coastal, then most land areas within the State have the potential of supporting activities capable of modifying coastal water ecosystems. For these reasons, the most logical boundaries for the coastal zone in Hawaii, based upon the above argument, include all land areas in the islands.

I. GENERAL CLASSIFICATION: HAWAIIAN COASTAL WATER ECOSYSTEMS

Hawaiian coastal water ecosystems obviously have one point in common - they depend upon bodies of water in one way or another for their existence. These ecosystems can be classified according to differences in physiography and biological composition. For each category of coastal water ecosystem, certain organisms will live mostly upon or near the bottom while certain others prefer to live suspended within the water column itself. The scheme of classification used here depends heavily upon bottom dwelling organisms (or benthos) and fish because we know more of the distribution of these organisms compared to others such as the plankton and bacteria in Hawaiian waters. Nevertheless, other groups of organisms are important components of most ecosystems and the optimum classification scheme would include all major groups.

In attempting to summarize the distribution of the thousands of species of organisms which inhabit water masses in the coastal zone, it is more convenient to speak in terms of assemblages, communities or ecosystems containing a variety of different species, rather than the individual species themselves. Most species in nature tend to be associated in their distribution with certain others because of the dependence upon one another for food or shelter and because the species common to individual assemblages tend to exhibit the same patterns of tolerances to the physical environment in which they live.

The bottom dwelling or benthic assemblages of coastal waters are traditonally described in terms of zonation patterns based upon wave and tidal action. In the Hawaiian Islands, where tidal range is limited to about one meter and where wave action may effectively submerge tide pools and benches, the zonation patterns of coasts in higher latitudes such as in the continental United States are not sufficient or appropriate. It is more convenient to describe benthic communities in Hawaii in terms of shoreline and submarine topographic features as well as wave and tide-induced factors. Because this report includes freshwater ecosystems of the coastal zone, then it also becomes important to include as a factor the degree of mixing between fresh and salt water bodies. There are at least 22 major types of coastal water ecosystems in Hawaii which can be conveniently grouped into (I) Inland, (II) Shoreline, and (III) Offshore categories; a summary of the classification scheme is listed in Table 1.

Table 1. Classification of Hawaiian coastal water ecosystems based upon the physiography of bottom living organisms (benthos) and certain fish assemblages (indicated by *).

I. <u>Inland</u>

Coastal Wetlands (near sea level)

1. permanent ponds and marshes
2. seasonal ponds and marshes
3. anchialine pools

Perennial Streams

4. interrupted
5. continuous

II. <u>Shoreline</u>

Estuaries

6. embayments
7. stream mouths

Table 1. (continued)

Rocky Marine Beaches (rocky shorelines)

8. vertical basalt faces (cliffs, ledges, etc.)

   A. supra-spray zone

   B. spray or splash zone*

9. horizontal basalt faces (benches, etc.)*

10. boulder habitats*

11. tide pools*

12. limestone solution benches

Sediment Beaches (or depositional shorelines)

13. sandy beaches

   A. upper beach (including vegetation line)

   B. middle bench

   C. low beach (near tide level)

14. mud flats

15. mangroves

III. <u>Offshore</u>

16. coral reef flats*

   A. apron reef flats

   B. fringing reef flats

   C. barrier reef flats

   D. patch reef flats

   E. atoll reef flats

17. shallow wave-surge habitats

   A. basalt slopes

   B. coral reef slopes

Table 1. (continued)

18. rocky steep slope habitats
19. protected or calm water coral communities
    A. leeward coasts
    B. coral lagoons
20. sand deposits and channels
21. deep water terraces and slopes
    A. sea fans and black coral habitats
    B. gold, pink, bamboo and other coral habitats

II. INLAND WATER ECOSYSTEMS RELEVANT TO THE HAWAIIAN COASTAL ZONE

Freshwater--it begins as raindrops, as fog drip from leaves in a montane rainforest, or as snowflakes on a high mountain. Some of it returns to the atmosphere through evaporation and transpiration but most of it reaches the ocean sooner or later as either surface flowage or groundwater seepage. Groundwater, while not in itself constituting an ecosystem because it is nearly devoid of life, is essential to the maintenance of surface water environments especially during periods of low rainfall. The types of freshwater ecosystems occurring in Hawaii have been listed elsewhere (Maciolek, 1975a). The purpose of this report is to describe the status and significance of the two types that have direct influence on the Coastal Zone--coastal wetlands and streams.

Coastal Wetlands

Sea-level wetlands are directly a part of the coastal zone. They may take the form of open water (ponds) or heavily vegetated marshes, or a combination of the two. They are important ecologically as habitats for resident and migratory waterbirds, native plants and aquatic fauna, and several introduced animals such as tilapia, mosquitofish, frogs and crayfish. Besides representing a distinct class of aquatic ecosystem and essential habitat for endangered birds, coastal wetlands add esthetic diversity to our shorelines.

However, they have been greatly diminished in extent with urban growth and development that has been most intense in the shoreline areas. The lands immediately mauka from Waikiki, for example, were a vast marsh before man's recent influence. They were first developed into taro and rice fields, and later filled in completely. The first freshwater zooplankton described scientifically from Hawaii a century ago were said to have been taken in a marsh between Honolulu Harbor and Waikiki--presumably where the Ala Moana Center now stands. We have lost irretrievably the natural wetlands of upper Kuapa Pond (Hawaii Kai), Kaelepulu Pond (Enchanted Lakes), and many others. The few that remain should be preserved as sanctuaries for native species and examples of an ecosystem class that once was prevalent.

There are two types of pond-marsh wetlands, permanent and seasonal. Kawainui Marsh (improperly called a "swamp" by the cartographers) on windward Oahu is the largest example of the former type. Similar marshes occur elsewhere on Oahu (Kahana Valley, Kahuku area), leeward west Molokai, Kauai and windward Kohala (Plate 1) (Waipio and Waimanu Valleys). Kealia Pond on Maui, as described elsewhere (Maciolek, 1971), exemplifies the seasonal wetland. However, it is presently modified to a continuous flooded condition by the effluent of an aquaculture facility. The playa "lakes" of Niihau probably are the largest and best examples of this wetland type.

Anchialine Pools

In another type of coastal standing-water ecosystem are the "Anchialine pools", so named by Holthuis (1973) because of distinctiveness of their environment and fauna. Anchialine pools are defined as small coastal exposures of brackish water in lavas or elevated fossil reefs that have only subsurface connection to the sea (by seepage through sediments or fractures in the rock) but show tidal fluctuations. They differ from true estuaries (see later) in having no surface continuity with streams or ocean, which gives them a distinct biotic community dominated by small mollusks and unusual shrimps (Maciolek and Brock, 1974). Although anchialine pools occur variously throughout the world, in the U. S. this type of ecosystem is unique to Hawaii. Within Hawaii, anchialine pools exist only in geologically recent lavas of Maui and Hawaii Islands (Maciolek and Brock, 1974). Such pools once existed on the Ewa coral plain of Oahu; many on Hawaii Island have been filled or degraded. They are fragile environments that are easily obliterated by bulldozing and destroyed ecologically by pollution or the introduction of exotic species. Because of their uniqueness (some of their animal inhabitants occur nowhere else in the world), concerted effort should be made to protect the remaining Hawaiian anchialine pools of high natural quality as is being done on the Ahihi-Kinau Natural Area Reserve, Maui.

The aquatic vegetation of anchialine pools is dominated by benthic algae such as *Rhizoclonium*, the mineral encrusting *Schizothrix*, and the vascular plant *Ruppia maritima*. Four decapod crustaceans, two mollusks, and two native fishes are characteristic fauna. As on rocky coasts, there is a high degree of endemicity: the mollusks *Theodoxus neglectus* and *T. cariosus*, the small red shrimps *Metabetaeus lohena* and *Halocaridina rubra*, and certain fish are all endemic to the islands.

Streams

Streams are Hawaii's principal freshwater ecosystem resource. Although they orginate inland, it is obvious that they terminate at the coastline and have profound effects on inshore marine waters. In an overall view, two basic types of streams occur: intermittent streams that discharge only as a result of heavy rainstorms, and perennial streams that are true ecosystems in which many native species have evolved. The general character and resource importance of perennial Hawaiian streams has been described in a previous paper (Maciolek, 1975a) and a recent manuscript on West Maui streams (Maciolek, 1975b).

To demonstrate the quantitative importance of perennial streams in Hawaii, a comprehensive inventory was made. It was based on a careful study of the U.S.G.S. quadrangle maps interpreted with a background of statewide field surveys over a nine-year span. This inventory is summarized in Table 2, and major stream systems for each island are shown on the maps (Figures 1 - 8).

The inventory distinguishes two classes of perennial streams as they would occur naturally, apart from human intervention. Continuous streams, usually the larger ones in terms of mean annual flow, are those discharging year-round. Interrupted streams have perennial water in their upper courses but discharge seasonally to the ocean. Both classes provide habitat for native fauna (fishes, crustaceans, mollusks, insects, etc.--see Maciolek, 1975b) but continuous streams are the superior ecosystem expression. The inventory includes a number of streams of indefinite nature, most of which would be of the interrupted class if verified as perennial by field check.

The tally shows 204 continuous streams and 77 interrupted streams statewide. Considering those of indeterminate status, the total number of perennial streams in Hawaii probably exceeds 300. On an island basis, the number of streams is proportional to the island size. But the distribution of streams on a given island varies considerably. On Kauai, they are well dispersed; on Lanai and Hawaii, they are severely restricted in location.

It has been pointed out (Maciolek, 1975b) that many of Hawaii's perennial-continuous streams have been dewatered for agricultural, industrial and domestic purposes. Some continuous streams thus have now become interrupted streams and this consideration will modify the foregoing inventory classification if it is interpreted realistically. However, diverted water still reaches the ocean--that used for irrigation mainly through the ground water system and the remainder through industrial and domestic (sewage) discharge.

Table 2. Summary Inventory of Perennial Hawaii Streams by Island and Discharge Class[1]

Island	Number of Streams			
	Continuous	Interrupted	Indeterminate	Total
Kauai	33	6	11	50
Oahu	34	4	15	53
Molokai	8	12	11	31
Lanai	0	2	0	2
West Maui	14	3	2	19
East Maui	36	15	22	73
Hawaii				
Windward Mauna Kea	52	29	11	92
Windward Kohala	26	5	11	42
Other	1	1	1	3
	204	77	89	365

[1]Continuous streams = natural discharge to the ocean year-round;

Interrupted streams = natural discharge to the ocean seasonal;

Indeterminate streams = require field check to verify discharge class.

Biological Significance of Streams

Few people realize the reciprocal relationship of stream and marine environments to native freshwater fauna, or the significant contribution of larval animals that streams provide to the marine waters. Most of the large stream animals are diadromous; they live and spawn in streams but the hatchlings require marine larval development before they can return to colonize freshwater. Native diadromous species (cf., Maciolek, 1975b) include five fishes (o'opu) two shrimps (opae) and at least one mollusk (hihiwai). In addition, an introduced diadromous prawn (*Macrobrachium lar*) has established itself in nearly every perennial stream in Hawaii (Maciolek, 1972). These animals not only need good quality streams for adult survival but their larvae also require coastal waters of good quality.

Another marine-related faunal element is the sporadic or itinerant ocean fishes that dwell in the lower reaches of streams as juveniles. These include the aholehole that is commonly found in good quality streams, and the amaama (mullet) that once occurred in many Hawaiian streams but is now restricted to a few remote locations.

The quantity of diadromous larvae discharged from streams into coastal waters apparently has never been noted or estimated. Diadromous species are noted for their high fecundity. Female shrimps and prawns produce up to 40,000 eggs per batch and reproduce several times per year; female o'opu produce up to 200,000 eggs per year; hihiwai deposit about 100 egg capsules per year, each containing up to 200 eggs. Using much lower average values for fecundity, assuming total hatching success and discharge to the ocean, and applying realistic estimates of the abundances of reproducing females of the nine diadromous species, it is possible to estimate escapement of larvae to the ocean where they become marine zooplankton.

An "average" size stream such as Kahana or Punaluu on windward Oahu would have about five stream miles containing diadromous species. The lower two miles of stream would be dominated by larger species producing about 25,000 larvae/female/year. In the upper three miles, smaller but more abundant shrimps and fishes could produce 10,000 larvae/female/year. If the lower stream reaches had populations of two reproducing females per lineal foot and upper reaches had five females per lineal foot (all species considered), about 10^9 larvae would be discharged per year into the inshore marine waters from one medium-sized stream. Considering this estimate is probably conservative, the contribution of diadromous larvae from all streams of good environmental quality to the zooplankton trophic base of coast waters is impressive and surely significant to the marine ecosystem. Therefore, the maintenance of stream quality is of considerable importance to the ecology of coastal waters.

Physiochemical Effects of Streams

In contrast to the two-way biological relationship of streams to coastal waters, the physiochemical influence essentially is one way, stream-to-ocean. The discharge of freshwater in terms of volume and its load of dissolved and particulate matter reflects natural terrestrial processes as well as those induced by man's activities. It is the latter that are of particular concern in coastal zone management.

Excessive silt loading above that due to natural erosion is an all-too-obvious result of agricultural practices, overgrazing, and land development in many coastal areas. Less obvious are the dissolved and adsorbed contaminants reaching coastal waters such as fertilizing nutrients, heavy metals, and toxic hydrocarbons. For the past few years, Waikele and Manoa Streams have been monitored for heavy metals and pesticides as part of a national program.

Both show high levels of these materials in the bodies of fishes analyzed. Surprisingly, Manoa Stream which drains a residential area generally shows higher levels of the substances analyzed. In the most recent analysis reported (1973 collection) the chlordane level in stream fish tissue prompted an EPA authority in Washington, D. C., to inquire if there was an insecticide factory on Manoa Stream. Presumably, this chlordane came from ground termite treatment which reentered the stream via ground water seeps. Discharge of such toxic materials must have significant effects on inshore marine waters, but the nature of these effects on aquatic life are not immediately obvious.

Legislation in the past decade has caused us to examine our discharges and mount programs to improve their quality. Nonetheless, a degradation in the quantity and quality of stream waters continues with growth and development and causes an increased deterioration in the inshore marine ecosystem. There are many gaps in our knowledge as to the nature and effects of adverse stream quality--it is one of the principal environmental problems in coastal zone management that should be given investigational priority.

III. SHORELINE ECOSYSTEMS

Estuaries

Much of the following discussion is taken from Smith (1974). In simplest terms, an estuary is an area in which fresh and salt waters come together.* This mixing of waters generally leads to the development of a rich and productive coastal ecosystem with an influence that extends far beyond the physiographic boundaries of the estuary. A useful working definition for Hawaiian estuaries is 1) bays or drowned river valleys that receive freshwater discharge from streams or subterranean seepage and 2) the tidal portions of the mouths of streams.

If both definitions are utilized, as many as 50 estuarine ecosystems can be identified in the Hawaiian Islands (Cox and Gordon, 1970). The locations and types of Hawaiian estuaries are shown on the enclosed maps. The two largest estuaries are embayments, Pearl Harbor and Kaneohe Bay, both located on the Island of Oahu, and both having been the subject of intensive study (Evans, et al., 1974; Smith et al. (ed), 1973 and others). The largest of stream-type (tidal) estuaries include Nawiliwili, Kilauea, and Hanalei on the Island of Kauai; Kahana on the Island of Oahu, and Waimalu and Hilo on the Island of Hawaii. The greatest number of stream estuaries occur on Kauai, with both Oahu and the windward coast of Maui also showing many estuaries. In contrast, Hawaii Island contains few estuaries for its size because of the

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*". . . the term 'estuarine zones' means an environmental system consisting of an estuary and those transitional areas which are consistently influenced or affected by water from an estuary such as, but not limited to, salt marshes, coastal and intertidal bays, harbors, lagoons, inshore waters, and channels, and the term 'estuary' means all or part of the mouth of a navigable or interstate river or stream or other body of water having unimpaired natural connection with open sea and within which the sea water is measurably diluted with fresh water derived from land drainage." (P.L. 89-753)

development of only a few stream systems in the young and porous basalt rocks characterizing most of the island. The smaller islands of the Hawaiian chain support few estuaries because of the corresponding reduced level of rainfall and size of drainage basins and streams.

Water quality data is the most frequent type of information gathered in Hawaiian estuaries, but these contribute little to the understanding of the structure and function of the components of these systems. The most detailed biological surveys have been conducted in the large embayments, but the information is not really systematized, directly useful, or accessible to the general public in its present form. Studies in Kaneohe Bay have been extremely comprehensive but have emphasized coral reef rather than estuarine components (Smith et al. (ed), 1973; Cox et al., 1973; Gordon, 1970; Gordon and Helfrich, 1970). Studies in Pearl Harbor (Evans et al., 1974) are in unpublished status and not yet available for public use. Both Kaneohe Bay and Pearl Harbor have been the subjects of system modelling efforts (Water Resources Engineers, Inc., 1974; Caperon, in prep.) which have attempted to predict the cause and effect relationships in these estuarine systems. The Army Corps of Engineers (1975) is committed to developing a comprehensive water resources plan for Kaneohe Bay with the goal that State, Federal, and County agencies will adopt their recommendations. In addition, the Hawaii Environmental Simulation Laboratory has developed some ability to predict the stream delivery to Kaneohe Bay.

Some Hawaiian estuaries contain beautiful quiet-water coral reef assemblages unlike any biotic community found elsewhere in the United States (Smith et al. (ed), 1973). The estuaries are breeding and spawning grounds for a variety of commercially valuable fishes (Miller, 1973). Several species of waterbirds, listed as threatened or endangered, inhabit the nearshore environment

Berger, in Armstrong, 1973). The estuaries are popular areas for fishing, boating, swimming, and camping. One estuary (Kaneohe Bay) also serves as the site for ongoing research by both the State (at the Hawaii Institute of Marine Biology) and the Federal government (at U. S. Naval Undersea Center).

The total estuary area of the State is estimated here to be about 100 km^2. It is impossible to judge accurately the coastal area outside the estuaries but within the legally defined estuarine zone; however, some limits can be imposed. If the mean width of the estuarine zone is 50 meters (surely an overestimate for most of the Hawaiian coastline), then only another 100 km^2 of estuarine zone are added to the 100 km^2 estimated for the true estuaries, bringing the total Hawaiian estuarine zone to less than 200 km^2.

Most Hawaiin estuaries are small with water areas well under 1 km^2. Even the two largest estuaries are small in comparison with their North American (or other continental) counterparts. Estuarine ecosystems in the Hawaiian Islands support an endemic biota, but of far fewer species than their continental counterparts; an inventory of 38 species has been recorded in the estuarine reaches of Kahana Bay, a figure which may be contrasted with the 470 for Morrumbene and 370 for Knyssa, both in Africa (John Maciolek, personal communication). The importance of Hawaii's estuaries can be argued, nonetheless. Because these features are small, they are vulnerable when subject to relatively low absolute levels of environmental insult; that is, the tolerance of these features is relatively low.

Most estuarine species in Hawaii are euryhaline (i.e. adapted to wide variations in salinity or salt content of the water) and are derived from marine rather than freshwater ancestors. Typical native estuarine species include fishes such as the o'opu naniha *(Awaous genivittatus)*, o'opu okuhe *(Eleotris sandwicensis)*, aholehole *(Kuhlia sandvicensis)*; a praw, opae oeha'a *(Macrobrachium grandimanus)*; and the mollusks, hapawai *(Theodoxus vesperitinus)* and wi, *(Theodoxus cariosus)*. Estuaries also harbor a few species utilized for food such as the Samoan crab, *(Scylla serrata)* and are nursery areas for other inshore marine fishes such as the ama ama (*Mugilcephalus*), awa (*Chanos chanos)*, kaku *(Sphyraena bariacuda)*, and aholehole. Many estuaries in Hawaii are now affected by the invasion of exotic species such as the Tahitian prawn *(Macrobrachium lar)* and the water hyacinths which are replacing the native biota (Maciolek, 1972).

Estuarine Circulation

Knowledge of the circulation of an estuary is of particular importance in assessing environmental integrity, because the characteristics of water circulation determine the nature of the estuarine system and the residence time of pollutants in the system, or portions thereof, and hence determine the possible damage those pollutants may do to the system. There is limited information describing some aspects of circulation in numerous Hawaiian estuaries.

The most comprehensive survey to date on this subject is that of Laevastu et al (1964), dealing with the general currents of Hawaiian inshore waters. Much of that information, plus some additional observations, are reported in the recent Marine Atlas of Hawaii (Grace, 1974). Detailed circulation studies of a few Hawaiian estuaries are available (e.g., Bathen's 1968 description of Kaneohe Bay; and Busek's 1974 description of Pearl Harbor). Most available studies of Hawaiian estuarine circulation are far less comprehensive than the ones cited above, involving current measurements at only a few localities within any particular estuary and under a narrow range of oceanographic conditions.

Tidal ranges are relatively small in Hawaii (about 1 meter), and river input into estuaries is generally small. Largely lacking these energy sources of tidal flushing and major river flow, the circulation of the estuaries is strongly related to wind patterns (e.g., Buske, 1974), to wave-driven flow into the estuarine areas (Bathen, 1968), and to tidal and wind-driven ocean currents sweeping by, outside of the estuaries (Wyrtki et al., 1967).

Despite their small size, Hawaiian estuaries generally flush rather slowly, chiefly because water movement depends to a large extent, on the less effective of the above-mentioned energy sources. Buske (1974) has estimated that some of the water in Pearl Harbor may have a residence time of more than four days. Dr. J. Caperon (Hawaii Institute of Marine Biology, personal communication) has suggested that water may reside in the more enclosed parts of Kaneohe Bay for up to several weeks. These relatively long residence times for estuarine waters and their included pollutants have obvious implications for the biota of Hawaiian estuaries and emphasize the importance of intelligent, informed estuary management.

Importance and Status of Hawaiian Estuaries

Because the State of Hawaii as a whole is a small watershed in comparison with the North American continent, the zone of freshwater influence about the Hawaiian Islands is small when compared to the zone of such influence off North America. The zone vulnerable to impact from activities on land may not be greatly different from Hawaii to the mainland of North America. Table 3 helps to put the scale of Hawaiian estuaries into proper perspective; the ratio of estuary area to the state's land area is only about half the equivalent ratio for the total United States. However, the ratio of tidal shoreline length to total land area is an order of magnitude larger for Hawaii than for the rest of the nation. That is, there is a close spatial relationship between the land of the state and the coastline. The distribution of population is also instructive. It can be determined from the recent Atlas of Hawaii (Armstrong, 1973) that about one-third of the state's population lives immediately adjacent to one of the major estuaries in the state. Both culture and climate have acted to enhance the utilization of estuaries by the people of Hawaii, so that even those persons who do not live near the water are likely to frequent it.

Because of the general lack of adequate information, the attempt to document the environmental status of Hawaiian estuaries has proven to be a frustrating undertaking. Some aspects of this problem for the state as a whole have been recently summarized by Cox and Gordon (1970). That report dealt with estuarine water quality, a subject for which there is a great deal of information. However, that data base is, for the most part, insufficient for establishing trends through time. The available information on circulation patterns in several Hawaiian estuaries have been already briefly described although these data have not been as recently summarized as water quality. Quantitative information about the biological status of most Hawaiian estuaries is almost totally lacking except for Pearl Harbor and Kaneohe Bay. Much of the information which has been collected is difficult or impossible to obtain because it is buried in private or government files. It would well be worth the expense to retrieve this information (refer to Appendix A).

Water Quality

Water quality is surely the best documented general environmental parameter of Hawaiian coastal water ecosystems including estuaries. The fact is undoubtedly true because water quality standards can be objectively spelled out, routinely measured, and thus easily legislated. Table 4 gives the state's definitions for the three coastal water classes: from best to worst, these are AA, A, and B. Cox and Gordon (1970) have summarized the water quality of Hawaiian estuaries relative to those standards, and a modified version of their summary is presented as Table 5. Several important aspects of water quality emerge from these data.

Most of the waters supposed to be pristine (AA) are considered by Cox and Gordon (1970) to be so. Kaneohe Bay is probably the most conspicuous exception to this generality. It is obvious from the data presented by Cox and Gordon that as soon as some deterioration of water quality is permitted or occurs (to Class A or B), there is little chance that even those lower standards will be met. Over half the estuaries assessed by Cox and Gordon apparently fail to meet the legislated water quality standards, and most of the violations involve class A waters. Most of the class B waters for which data are available fail to meet even these very permissive standards. Even though water quality has been cited as the best-known environmental aspect of Hawaiian estuaries, with rare exception, the knowledge of water quality is also, in itself, insufficient to point to either trends of water quality change with time for a particular estuary or spatial trends within the estuary.

Some of the failure to meet legislated standards lies with the standards themselves; they are arbitrarily imposed water quality limits with little

Table 3. Comparison of Hawaiian Estuarine Dimensions With the Scale of Estuaries Found in the Remainder of the U. S.

	U. S. exclusive of Hawaii	Hawaii
Total Area (km^2)	9,350,000	16,700
Estuarine Area (km^2)	117,000	100
Tidal Shoreline (km)	136,000	1,700
Estuarine Area/Total Area	0.013	0.006
Tidal Shoreline/Total Area	0.015	0.10

Table 4. Water Quality Standards Pertinent to Hawaiian Estuaries. From Cox and Gordon (1970).

Substance		AA	A	B
		Class of Water		
A. BASIC				
1. Settleable materials forming objectionable deposits		0	0	0
2. Floating debris, oil, scum, etc.		0	0	0
3. Substances producing objectionable color, odor, taste, or turbidity		0	0	0
4. Materials, including radionuclides, in concentrations or combinations which are toxic or produce undesirable physiological responses in human, fish and other animal life and plants		0	0	0
5. Substances, conditions, or combinations producing undesirable aquatic life		0	0	0
6. Soil from controllable accelerated erosion		0	0	0
B. SPECIFIC				
1. Microbiological				
A. Coliform bacteria (/100 ml)				
Median	≤	70	1000	
Upper decile	≤		2400	
Maximum	≤	230		
B. Fecal Coliforms				
30-day mean	≤	200	400	
30-day upper decile	≤	400	1000	
2. pH				
Departure from natural	≤	0.5	0.5	0.5
Maximum except from natural causes	≤	8.5	8.5	8.5
Minimum except from natural causes	≤	8.0	7.0	7.0
(except fresh tidal water)	≥	7.0		
3. Nutrients (mg/liter)				
Total Phosphorous	≤	0.020	0.025	0.030
Total Nitrogen	≤	0.10	0.15	0.20
4. Dissolved Oxygen (mg/liter) (except from natural causes)	≤	6.0	5.0	4.5
5. Total dissolved solids, salinity and currents				
TDS departure from natural (% of natural fluctuation)		10		
TDS (mg/liter)	≤	28,000		
6. Temperature (°F)				
Departure from natural	≤	1.5	1.5	1.5
7. Turbidity				
Secchi disk extinction coefficient, departure from normal (5)	≤	5	10	20
8. Radionuclides				
(MPC_w values by NBS)	≤	1/30	1/30	1/30
(concentration)	≤	USPHS values for drinking water		
(concentration in harvested organisms)	≤	Federal Radiation Council recommended limits		

Table 5. Summary of Water Quality Relative to Standards for Coastal Waters. Modified from Cox and Gordon (1970).

Class of Water	Total* Estuaries	#Probably Meeting Standards	#Probably Not Meeting Standards	#With Insufficient Data
AA	14	11	3	0
A	65	5	39	21
B	10	1	5	4
TOTAL	89	17	47	25

*Estuaries with two or more classes of water quality receive multiple listing in this table.

allowance for natural variations within those limits. For example, some nearshore areas with natural freshwater seeps may locally exhibit salinities and nutrient levels outside the legislated limits (e.g., Honaunau Bay; Doty, 1968). Natural freshwater seepage may contain, for instance, many times as much phosphate as open ocean waters, which form the basis for legislation. Moreover, departures from legislated limits may not harm particular environments. In other instances these standards are probably too permissive for maintaining biological integrity. We must conclude that water quality standards are not adequate measures of estuarine biological integrity.

Resource Development Related to Hawaiian Estuaries

Cox and Gordon (1970) summarized the resource development pertaining to Hawaiian estuaries. Their list, divided into various estuarine types within each estuarine system, is summarized here in terms of the 45 major estuarine systems within the State. The resource developments can be broadly divided into water, agricultural, industrial, urban, and estuary; and each of these divisions can in turn be subdivided. It should also be pointed out that many of these developments also apply to other kinds of coastal water ecosystems in Hawaii.

Water development, almost entirely in the form of irrigation or storage, appears to be the least disruptive development of the resources. It simply involves reduction of water flow into the estuaries, with consequent potential alteration of salinity and circulation patterns. Most of the estuaries in the State experience some water loss or diversion for irrigation. Channelization of streams may also seriously alter the structure and function of some freshwater and estuarine biological communities.

A variety of agricultural developments impact the estuaries of the State. Moreover, the open-coast, non-estuarine zones are subject to much the same developments. Ranching and sugar-cane cultivation are the two most recurrent agricultural developments affecting Hawaiian estuaries. Most Hawaiian estuaries receive materials from one or more of the agricultural activities.

Industrial developments are about as diverse as the agricultural developments but are much more localized. The three major discrete categories of insults from industrial developments are thermal discharges, discharges from sugar factories, and discharges from pineapple factories. It should be emphasized that these three activities also exert profound influence on the open coastline. The major thermal effect is simply that of heating the receiving water. Discharges from sugar factories include sediment, bagasse and other cane trash, nutrients, soluble organics, and bacteria. The pineapple factory discharges include pineapple wastes and soluble organics.

Urban discharges affect most Hawaiian estuaries. Even those areas served by sanitary sewage disposal systems will nevertheless contribute trash, detergents, miscellaneous industrial pollutants, nutrients, and bacteria during any period of runoff (i.e., heavy rains). Areas served by cesspools will contribute all of the above pollutants, at higher levels. Most urban areas, but particularly the multiplying housing developments less than 10 years old, are particularly susceptible to the erosion and runoff of large volumes of water and sediment.

The last category of resource development is the development of the estuaries themselves. In terms of numbers of estuaries affected, various recreational uses prevail. These activities, which include fishing, introduce miscellaneous boat sewage and trash into the waters. The uses of estuaries in the State for commercial/military harbors and small boat harbors contribute the same kind of wastes (but in much larger amounts than recreational uses) plus oil, bilge discharges, industrial pollutants of various forms (including heavy metals), and the disruptive activities from dredging. The stirring of the water column and sediment have been recently reported to be important (Evans et al., 1974) but it is not clear whether the net effect of this activity is beneficial or deleterious.

Rocky Beaches (rocky shorelines)

Rocky beach systems are among the most widespread of Hawaiian shoreline ecosystems. There are at least six separate categories based upon elevation, orientation, and composition of the bottom substrata.

Rocky basalt sea cliffs, ledges or other vertical faces near the shoreline harbor a diverse assemblage of seaweeds, mollusks, crustaceans, and sea urchins which can be divided further into supra-spray and spray or splash zones.

The Supra Spray Zone

At least six species of mollusks and as many crustaceans are associated with the supra spray zone of Hawaiian shorelines, those areas which are found along the vegetation line fringing the interface between land and sea which are characterized by boulders and/or broken limestone and conditions of high humidity. Among the mollusks, *Melampus*, *Laemodonta*, *Pedimes*, and *Assiminea* are the most frequently encountered forms. The isopod *Ligia* and the talitrid *Orchestria* are characteristic arthropods of the assemblages. The assemblages are patchy in their occurrence and mixed in species composition; only occasional colonies of a single species have been found. Two of the mollusks may be endemic to the Islands, and at least one species of *Ligia* is thought to be endemic. Some of the mollusks may have suppressed veliger larval stages and hence are tied to the sea by their mode of reproduction.

Splash Zone or Spray Zone

This zone is found on rocky benches at or above the mean tide level; it consists of pools caused by intermittent waves or spray. Examples are most common on open, windward shores such as Makapuu Point, Oahu, and southwestward. Other examples include Pupukea, Oahu, Hanauma Bay, Oahu, and some windward shores of Kauai, Maui, and Hawaii. Puako, Hawaii, is an additional example. Few species of fishes are found here as permanent residents; these usually include one holocentrid, one acanthurid, one labrid, and several species of blenny and goby.

Gosline (1965) stated that large fishes are rarely found in such pools but that this zone does often serve as "an incubator" for juvenile fish.

On rocky coasts above the reach of either tides or waves, but seaward of the pulmonate molluscan colonies, the shoreline is dominated by two species of littorines, *Littorina pintado* and *Nodilittorina picta*. The former is widespread in the Indo-West-Pacific, the latter is endemic to the Hawaiian Islands. The littorines are succeeded seaward by the black nerite or pipipi, *Nerita picea*, a mollusk which is found in large numbers in archaeological middens, suggesting its importance in the food economy of pre-western and pre-eastern Hawaii. The grapsid crab, *Pachygrapsus pheatus* is also a common inhabitant of this zone.

The seaward face of lava beaches and cliffs is characteristically covered with a thin veneer of a coralline alga, *Porolithon*. Near sea level, cliff faces are studded with stubby growths of *Sargassum* and slow-moving invertebrates such as the shingle urchin *Colobocentrotus atratus* and the opihi *Cellana sandwichensis*. Lower down, the face of the frontal slope is riddled with borings of the sea urchin *Echinometra mathaei*, and a variety of mollusks are found in pockets and crevices of the cliff face: the cowry *Cypraea caputserpentis*, the vermetid *Petaloconchus keenae*, and the bivalve *Isognomon costellatum*. Several carnivorous fish are also associated with this ecosystem, among them the damsel fish *Abudefduf imparipennis*, the wrasse *Thalassoma umbrostigma*, and the goby *Bathygobius cotriceps* (Gosline, 1961).

Marine mollusks of basalt benches and cliffs exhibit a high degree of endemism compared with that in other ecosystems: the polymorphic littorine *Nodilittorina picta* extends into the upper regions of this zone, the predatory thaidids *Nucella harpa* and *Purpura harba* which feed on nerites and opihi, and two species of opihi, *Cellana exarata* and *C. sandwichensis*. A third endemic opihi, *C. talcosa*, occurs at the seaward edge of benches and subtidally to depths of 20 meters.

Shallow Lava Benches

This zone is composed of the horizontal faces of shallow surge swept remains of ancient lava flows, consisting of a solid pavement of basalt with numerous cracks and crevices. Good examples occur at Napali to Kapaa and Poipu to Waimea on Kauai; Lanikai to Makapuu and Kaena Point on Oahu; the Hana coast and Cape Kinau on Maui; the north coast of Molokai, and along practically the entire coastline of Hawaii Island. Hobson (1974) reported 54 total species of fishes in this habitat off the Kona Coast of Hawaii. Only one reef coral is commonly found in the zone (*Pocillopora meandrina*), but the soft zoanthid corals, *Palythoa* and sometimes *Zoanthus*, are also notable.

Boulder Habitats

This zone occurs from shore to depths of about 15 meters off exposed shorelines where the sea floor is strewn with basalt boulders. These rocks usually appear bare but often are dotted with corals (mainly *Pocillipora meandrina*) and encrusting algae. Examples are Honaunau Bay and Alahaka Bay, both on the Island of Hawaii. Hobson (1974) reported a total of 77 species of fishes in this habitat.

Marine Tidepools

Tidepools occur on sea level basalt outcrops, some formed by depressions in the water-level benches, others formed by massive boulders fronting the sea. Physical conditions in marine pools vary with exposure, those pools furthest from the sea undergoing striking variations in temperature and salinity, those at the seaward edge exhibiting essentially marine conditions. The most exposed pools are characterized by a sand substrate bound with blue-green algae. In these are found two or three small mollusks, occasional grapsid crabs, and two fish, the blenny *Istiblennius zebra* and the goby *Bathygobius fuscus*. Seaward pools are progressively more densely turfed with a variety of worms, mollusks, crustaceans, and echinoderms in them. Seaward pools also serve as incubators for juvenile fish such as the manini, *Acanthurus sandvicensis* and the aholehole, *Kuhlia sandvicensis*.

Inshore of mean tidal level are also found mixohaline ponded waters; Brock (1975) gives the major characteristics, and describe 37 fish species from such ponds. Some ponds are probably important nursery grounds for larvae of reef fishes; others have been modified and augmented by man for the culture of certain fishes, such as mullets. Examples are found along the Kona Coast of Hawaii and the south coast of Molokai.

Limestone Solution Benches

Calcareous or carbonate shorelines are dominant features along the coasts of all of the major high islands of the Hawaiian chain except Hawaii and form 52 miles or 31% of the coastline of Oahu and lesser portions of the shoreline of Kauai and Maui. They are comprised predominantly of solution benches (Wentworth, 1939).

Topographically solution benches resemble atoll reef flats, consisting of sea level platforms extending from 1 to 30 meters seaward from the shore. The benches are separated from shore by a raised, sharply pitted limestone zone and a nip. Seaward of the nip the flat-topped surface is densely matted with an algal turf. At the sloping outer edge calcareous algae, and, to a lesser extent, corals, contribute to the structure of the bench. Because of their height above sea level, the surface of the bench may be exposed at low spring tides for periods of several hours to several days.

The biota of calcareous shorelines is distinguished from that of basalt by its cover of thick algal turf. Most information on the biota is confined to the mollusks. The turf is interspersed with grazing herbivorous mollusks such as *Cypraea caputserpentis* and *Haminea aperta*, by mats of the suspension feeding mollusks *Drachidontes crebristriatus* and *Dendropoma gregaria*, and by active carnivorous snails such as cones, mitres, and *Morula*. Both the flora and fauna are conspicuously zoned. The pools of the pitted zone are inhabited by the small littorine snail *Peasiella tantilla* and the blenny *Istiblennius zebra*; on the bench itself the cone snails especially form a series from *Conus abbreviatus* at the shoreward edge to *C. chaldaeus* at the seaward edge (Kohn, 1959).

Sandy Beach Systems

The sandy shorelines of the windward Hawaiian Islands are, in general, low, sloping beaches backed by a wall or raised platform. Except on Hawaii, the sand is largely calcareous, comprised of foraminiferan tests, mollusks, echinoderms and coralline algae (Moberly and Chamberlain, 1969). On Hawaii, there are large green sand or olivine beaches and many black sand beaches. Other green sand deposits are found off Ulupau Head near Mokapu Peninsula and Hanauma Bay, both on Oahu. Black sand beaches also occur on Maui. Long stretches of sandy beaches are rare in Hawaii and are predominantly found on Kauai, particularly white sand beaches. The shorter stretches of sandy beaches (pocket beaches) are more characteristic of the Hawaiian Islands.

Hawaiian beaches may be divided into three zones with respect to organisms: an upper beach including the vegetation line; a mid-beach between the high tide line and the vegetation line, its extent dependent on slope and tide; and the lower beach which is continually awash by waves. The biota of sandy beaches is associated both with grain size and slope. In general, however, the upper beach is characterized by amphipods, isopods, and males of the ghost crab *Ocypode laevis* which burrow in the area (Fellows, 1965). Females of *O. laevis* and males of another species *O. ceratophthalmus* burrow in the mid-beach area. The low beach is characterized by the male crab *Hippa pacifica*, spionid polychaetes, and four species of *Terebra* which prey on the polychaetes (Miller, 1970). The color of *Emerita*, *Ocypoda* and *Terebra* is associated with the color of the beach sand; lighter crabs and shells are found on the yellow sand beaches of Oahu, darker forms on the darker sand beaches of Maui and Hawaii (Wenner, 1972; Fellows, 1965; Miller, 1970).

Mud Flats

Mud flats are common habitats in some protected coastal areas such as the shoreline of Kaneohe Bay and Paiko Lagoon, both on Oahu. Little is known of these habitats other than to note that the biota inhabiting such environments differs substantially from that of the coarser sand environments described above (see Worcester, 1969; Higgens, 1969). Some mud flats are particularly important nesting and feeding habitats for migratory shorebirds such as the endemic Hawaiian stilt, Pacific Golden Plover, Ruddy Turnstone, the Wandering Tattler, and the Sanderling (Lum, 1970; Allen and Lum, 1972). Seagrass beds are usually conspicuous components of inshore sand or mud flats for many tropical islands, but they are nearly absent from Hawaii.

Mangroves

Mangroves were introduced on Molokai in 1902 and on Oahu in 1922. On both these islands there are several developed stands which now exhibit many of the properties attributed to mangrove swamps in other tropical areas. The Hawaiian stands are unique, however, in that they lack the extensive fauna and botanical seral aspects of typical large mangrove stands, because of their relatively recently development (Walsh, 1967). Mangroves are spreading rapidly to new coastal areas in Hawaii (see figs. 1-8).

Status and Importance of Shoreline Ecosystems

Shoreline ecosystems (excluding the estuaries) are subjected to many of the same uses and perturbations by man as described in detail earlier for the estuaries. Some relatively common uses and modifications in these systems include the collection of limu (benthic algae or seaweeds) and littorine snails such as the opihi and pipipi, and the harvesting of certain fish, a subject which will be described more fully at the end of the next section.

The construction of artificial structures such as jetties, groins, mole revettments and breakwaters will result in the modification of circulation and currents potentially causing the erosion and accretion of beaches, the deposition of silt in harbor basins and the subsequent elimination of certain species and their replacement by others more tolerant of the new conditions. Other potentially significant activities in the shoreline zone include "reclamation" of land by filling at shallow flats, construction of fishponds; the quarrying of rock resulting in the excavation and modification of previously existing shoreline habitats; and the disposal of scrap, garbage and junk along some shorelines.

Increased erosion resulting from agricultural cultivation and irrigation; sugar cane cleaning and milling; grazing by livestock and game animals; and land development activities in watersheds may result in the accumulation of sediments along the shoreline causing modification in both habitats and species composition of communities.

IV. OFFSHORE ECOSYSTEMS

Offshore ecosystems in Hawaii are all truly marine and are collectively the most widespread of the coastal water ecosystems.

Coral Reef Flats

Hawaiian reefs are neither so spectacularly developed nor so biologically diverse as are the reefs of other more tropical Pacific Islands, a circumstance associated with the location of the islands at the northern edge of the vigorous coral reef zone of tropical seas and perhaps also associated with the relative geographic isolation of the Hawaiian Islands from other island groups and continents. Only 14 reef coral genera and subgenera have been described from Hawaii (Maragos, 1975), a figure which may be contrasted with the nearly 60 genera and subgenera recorded from the Marshall Islands (Wells, 1954), and the 35 genera and subgenera reported from the Line Islands, which are located only 1200 miles south of Hawaii (Maragos, 1974a).

More than half the shoreline of Oahu, comparable portions of Kauai, the south coast of Molokai, and the northwest coast of Lanai are fringed by extensive reefs. Only small apron reefs are reported off some coasts of Maui while structural reefs are nearly absent from the island of Hawaii; the best example occurs near Kawaihae. The reefs are usually wide shallow platforms extending as much as 1,000 meters seaward from the shore. If the reefs grow and develop for sufficient time periods, they will reach the level of the sea surface and extend laterally to form the reef flat habitat, which differs substantially from the reef slope habitats. Reef flats or platforms in Hawaii are typically subtidal, one to three meters below mean sea level, although occasional sections may be exposed at low spring tides.

The characteristics of the reef flat habitat are largely dependent upon the type of and degree of development of the reef. Apron reefs are the smallest and most discontinuous reefs growing along shallow coastlines. These may fuse and grow out laterally with time to form the broad fringing reefs which characterise Lanai, Molokai, and Oahu. Barrier reefs frequently form from fringing reefs, if the reef itself becomes separated from the coast by a deep lagoon. There is only one extant barrier reef in Hawaii (Kaneohe Bay, Oahu) and this structure many have developed directly without the "intermediate" stage of a fringing reef. Atoll reefs in the Hawaiian archipelago are confined to the northwest end of the Hawaiian chain; good examples include Kure, Midway, Laysan, and Pearl and Hermes Reef. Within the lagoons of atolls or barrier reefs are commonly found patch reefs which resemble inverted truncated cones. The only example of patch reefs among the main (windward) Hawaiian Islands is located in Kaneohe Bay, Oahu. All these categories of reefs may show the shallow reef flat habitat.

The reef flat consists predominantly of sand, coral rubble, and coralline and fleshy benthic algae. Reef corals are not important components of the reef flats presumably due to unfavorable temperature, wave, and salinity conditions near the level of the sea surface (Edmondson, 1928; Maragos, 1972; Littler, 1973).

It is important to make the distinction between coral reefs, the physical <u>structures</u> produced over thousands of years from the remains of calcareous organisms, and coral <u>communities</u>, the biological assemblages which may or may not cover the upper surface of the reef. While many of the Hawaiian Islands show extensive reef development, few show flourishing coral communities.

suggesting that many reef structues are relict (formed during previous time intervals). Only the outer slopes or faces of the reefs on leeward coasts or within protected lagoons show extensive growths of live coral. An illustrative example is the Kona coast of Hawaii which shows perhaps the most flourishing and extensive of living coral assemblages (Dollar, 1975) but where structural coral reefs are nearly non-existent.

Reef flat assemblages are perhaps the most diverse of those occurring along Hawaiian shorelines, reflecting a variety of habitats; solid substrata of calcareous algae and reef and soft corals, and stands of fleshy (frondose) algae such as *Sargassum* and the introduced alga *Acanthophora*, rubble and sand patches. Other infaunal organisms include *Conus pulicarius* and species of *Terebra* especially in the sand. Rubble and live corals are sometimes common, especially on deeper reef flats; also present are varieties of mollusks, fish and several species of sea urchins and sea stars. The number of fish species is generally low, particularly on windward reef flats and the zone is in need of more study.

Shallow Wave Swept Slopes and Faces

Below and beyond the reef flats and tidal benches is found a habitat subjected to nearly continuous surge currents and wave action; usually to depths of about 5 m or more. Examples include Kaena Point and Makapuu Point, Oahu, and most other rocky coastlines. Reef corals include *Pocillipora meandrina* and *Porites lobata*, but these corals do not appear to dominate the substratum in this environment because of the inhibiting effects of waves (Gosline, 1965; Maragos, 1972; Dollar, 1975). Benthic algae and the sea urchins *Echinometra*, *Echinothrix*, and *Tripneustes* are often noted. Fifty or more species of fish are typically found here.

Deeper Slope Habitats

Typically, this zone is found below depths of 5 - 10 m at the edge of a drop off which frequently occurs at depths of about 20 m or more. The zone was referred to as the drop-off habitat by Hobson (1974). The bottom is frequently dominated by the massive coral *Porites lobata* but may also be overgrown with the finger coral *Porites compressa* along some leeward coasts. Many varieties of invertebrates are common in the habitat, and plankton feeding species dominate the fish fauna. Hobson (1974) reported 78 fish species and high fish biomass in studies off Kona, Hawaii.

Protected [Calmwater] Coral Communities

Reef corals achieve their greatest abundance on the slopes of reefs in protected leeward coasts of some of the larger islands [e.g., Hawaii, Molokai, Maui, Oahu] or within small protected bays [e.g., Molokini Island and La Perouse Bay, Maui]. Usually the finger coral *Porites compressa* is found to dominate the bottom substrata in most of these habitats (Maragos, 1972; Dollar, 1975); however, there appear to be distinct fish faunas for lagoons and leeward coasts.

The leeward protected coast habitat probably harbors the greatest diversity of fishes especially where coral cover is highest. Hobson (1974) further subdivided the fish fauna into a number of smaller zones. At depths between 2 - 15 m Hobson reported 82 species and high biomass of fishes. This zone may extend to about a 30 meter depth (Dollar, 1975).

The shallow lagoon fish fauna is best represented in the leeward islands particularly at Midway, Pearl and Hermes, Lisianski, Laysan, and French Frigate Shoals. It is not found in the main island chain except for small protected bays such as found off Molokini and the barrier reef lagoon in

Kaneohe Bay. Little study of fishes in these areas has been accomplished aside from a few brief reconnaissance surveys (Taylor, 1973) and studies by Key (1973).

Submerged Sand Communities

Little information is available on the composition of marine communities which inhabit sand channels and deposits at these same depths. Carnivorous mollusks such as the cones (*Conus*) and the mitres (*Terebra*) and the pen clam (*Pinna*) are common inhabitants of sand deposits (Hemmes, 1975; Environmental Consultants, 1974). Micromollusks are also common inhabitants (see Appendix B).

Deep Water Terraces and Slopes

This zone typically begins at the base of steep slopes at depths greater than 25 m. Well developed terraces have been reported at depths of about 50 m, 60 m and 75 m. Large boulders and coral rubble cover the bottom and live reef corals and benthic algae are reduced or absent. Black corals and sea fans (gorgonians) are conspicuous bottom invertebrates. Fishes in the zone include plankton feeding species in midwater, small anthiine serranids, long-nosed hawkfish, and Tinker's butterflies.

Examples which have been studied include the Kona and Kohala coasts of Hawaii and the Waianae Coast of Oahu. Studies are needed to learn more of this habitat.

At still deeper depths (200 m or more) are found the precious corals such as gold coral, bamboo coral, pink coral (*Corallium*) and others (Grigg, 1974). Little is known of the other biological organisms at these depths (see Brock and Chamberlain, 1968).

Status and Importance of Offshore Marine Ecosystems

Many of the uses and activities of man described for inland and shoreline ecosystems also apply to offshore marine ecosystems. Additional modifications and stresses which are significant include the discharge of cane trash and sediment, such as the Hamakua Coast of Hawaii (Grigg, 1972; Russo, 1973). The discharge of thermal effluent from power plants, such as off Kahe, Oahu (McCain and Peck, 1973; Jokiel and Coles, 1973), the discharge of raw sewage, such as off Sand Island, Oahu (Grigg, 1975) and treated sewage, such as into Kaneohe Bay (Cox and Gordon, 1969; Maragos and Chave, 1973; Banner, 1974), onshore land developments such as off Hawaii Kai, Oahu, (Lau, 1974), and sediment erosion off Kaneohe Bay (Roy, 1970) and south Molokai (Moberly, 1963), channel and harbor dredging such as within Kaneohe Bay (Maragos, 1972; 1974) and a host of additional activities which have the potential to affect these ecosystems, but for which there is little conclusive evidence. The aesthetic and economic importance of these systems cannot be overemphasized. For purposes of convenience, the discussion of the uses of offshore ecosystems are described separately in more detail for fishes and coral reefs.

Stress on Fishes

Stresses on fish populations are generally the same as those which affect the benthic communities. In addition, overfishing is a substantial stress. Much information is needed on catch effort and standing crops for most species caught by sport fishermen, many of whom probably sell portions of the catch. The maximum sustainable yield of certain populations may be exceeded in certain regions and the balance of some reef fish communities may be threatened by the selective harvesting of some species. Introduction of exotic species is reviewed in Randall and Kanayama (1972).

Values of the Fish Resources

The values of the nearshore fish fauna are manifold and difficult to estimate in dollar amounts. Two value categories can be defined arbitrarily for the sake of discussion; there is a good deal of overlap between them.

a. Aesthetic Value

The beauty of tropical fishes in their native habitats has been highly praised. The growing popularity of SCUBA diving, snorkeling, and the keeping of marine fishes in home aquariums also attest to interest in nearshore fishes.

Although economic units can be ascribed to these categories (for example, in estimating purchase of diving equipment, etc.), assigning subjective measures are preferred. An area with a large diversity of fishes occurring in clear water and surrounded by natural cover is considered by most people higher aesthetic value than an area with few species of fishes in turbid water strewn with manmade structures.

b. Economic Value

A reliable analysis of the value of the nearshore fish fauna cannot possibly be made in such a short report. Only a superficial summary is attempted here.

1. Recreational Diving

There are no comprehensive studies of the economic value of this category although it must be large. Oahu dive shops sold about $70,000 in equipment in 1974 (Mike Owens, Dan's Dive Shop). A reliable estimate of the industry's value would include air sales, transportation costs, hotel expenses, etc.

2. Recreational Fishing

Hoffman et al (1973) have estimated that annual expenditures [for 1969] "by all recreational fishermen in the State totalled about $16.1 million." They break down the expenditures by county and by category, e.g., transportation, food, beverages, gear, etc. Their study also included fresh water fishing but apparently concentrated primarily on pole-fishermen. Gill-netting is a popular fishing method and probably has a significant effect on nearshore fish communities. Hawaii requires no license for marine sportfishing; thus it is difficult to estimate the total number of sportsfishermen.

3. Commercial Fishing

Hawaii Division of Fish and Game catch statistics (Anonymous 1974) for Fiscal Year 1974 indicate a total wholesale value of the mixed catch at $6,234,933. This figure includes shellfish as well as fish species caught in offshore fishing grounds such as aku (*Katsuwonus pelamis*) and ahi (*Thunnus albacares*), and in deeper waters (200 m+) such as opakapaka (*Pristipomoides microlepis*) and ula ula (*Etelis marshi*). Such species should be excluded from the nearshore fauna sensu strictu although their larvae may enter the nearshore zone, and the bait fishes on which the fishery is dependent also occur there.

If only nearshore fish species are included in the wholesale estimate, the annual catch value is reduced to less than $1,000,000. (It should be noted that the aku catch comprises 51% of the total value and that high-priced ahi comprises about 24% of the value). It is interesting to note that although commercial catch value exceeds $6,000,000, less than $20,000 is collected by the State for commercial fishing licenses.

The two most important inshore commercial species are carangids: akule (*Trachurops crumenophthalmus*) and opelu (*Decapterus pinnulatus*). These fish are important members of nearshore communities, usually in shallow bays or slightly offshore over sandy bottoms. Total value for Fiscal Year 1974 was about $325,000 with a weight of 828,000 pounds. The combined yield of opelu and akule in 1900 exceeded the 1974 yield with a total weight of 989,000 pounds (Cobb, 1903). There is a need to compare effort figures between these years to assess the reasons for the apparent drop in catch.

A good review of nearshore fishing methods and marketing factors is found in Peterson (1973).

4. Aquarium Fish Trade

The collection of live marine fishes for sale to aquarium hobbyists has increased greatly in the last decade. About 95% of the fishes collected are sold commercially and the wholesale value of the catch exceeds $250,000 (Taylor, 1975). Fishes are shipped to retailers on the mainland and to Europe. It is estimated that Hawaii provides the United States with over 10% of the marine fishes sold per year (the remainder comes from foreign importers, principally the Philippines).

The Importance of Hawaiian Coral Reefs

A comprehensive review of the uses and impacts to Hawaiian coral reefs is presently being compiled and will be published by the end of 1975. This review is a part of an effort to establish CORMAR, a Coral Reef Management and Research Program for Hawaii (Maragos, in preparation). Some aspects of the importance of reefs are summarized briefly here.

Coral reefs provide shelter and food for many reef organisms including fishes, the importance of which has been described in the previous section. Other reef organisms harvested by man include species of algae (limu) for use as food, edible species of mollusks and sea urchins, ornamental mollusks and corals collected for curios, certain soft corals collected to extract chemicals for use by medical scientists and edible species of shellfish including lobsters, shrimps, and crabs.

The breakdown of the skeletons of reef organisms to sand size particles continually offers replenishment to white sand beaches along Hawaiian coasts which are constantly losing sand by the natural processes of chemical dissolution and deep water transport. Coral rock and sand are dredged from offshore reefs for use as components in concrete for the construction industry. Shallow coral reefs also act as natural breakwaters in protecting coastal lands or lagoon waters from large waves and storms. In fact, many of the coastal lands around Oahu (and to a lesser extent Kauai) are the uplifted remains of reefs produced thousands of years ago when sea level was higher. Reef habitats also provide recreational and aesthetic enjoyment and value to swimmers, divers, surfers, and spear fishermen. The promise of clear warm waters and flourishing pristine reefs attract many visitors to the islands each year.

We still know little of the status of many Hawaiian reef systems, either because they exist along remote sect-ons of Hawaiian coastlines or because we are only now beginning to understand the interactions and functioning within these complex ecosystems. Many of the specific kinds of stresses resulting from resource development and other activities have been previously described in other sections of this report, particularly for the estuaries. Even with our limited knowledge, we do now, however, that once coral reef ecosystems are destroyed the full structural recovery of reefs may not be possible and biological recovery may take several decades or more. There is the need to understand more of the circumstances under which coral reefs will recover and the time required in order to give proper consideration to their conservation and management. We are approaching the point where certain human activities have resulted in the modification and destruction of reefs while many other activities may also have the potential to do so but their effects have not been adequately studied. Thus we need to establish a comprehensive information base for these and other coastal water ecosystems so that Coastal Zone Management will commence from a knowledgeable perspective.

V. SELECTION OF INLAND BOUNDARIES WHICH WILL SET COASTAL WATER ECOSYSTEM RESOURCES APART FOR MANAGEMENT PURPOSES

Many of the human activities and resource developments in Hawaii affect more than one category of coastline water ecosystem, and available information is inadequate for providing an accurate assessment for most of the ecosystems. Thus it seems appropriate to combine the various impacts for use in setting the inland boundaries for the Coastal Zone. More detailed impact effects on estuaries, freshwater ecosystems, coral reefs, and fisheries in Hawaii can be found in Smith (1974), Maciolek (1975a,b), Maragos (1972), Smith et al (ed), (1973), Evans et al (1974), Banner (1974), Taylor (1975), Cox and Gordon (1970), Lau (1973, 1974) and Cox et al (1973).

Table 6 provides a summary of the categories of environmental modification to coastal water ecosystems which result from various activities (i.e. resource developments) of man. Approximately 30 categories of impact sources can be classified among agricultural, commercial or industrial, residental, or urban, and recreational developments. Although the specific effects of each of these impact types are equally variable, these in turn can be summarized as affecting coastal water ecosystems in one of two ways: 1) modification of the physical environment of the ecosystems - either by removing, changing or adding specific components or any combination thereof and 2) modification of the biological environment of the ecosystems - either by promoting the addition of new species, the elimination of others, variations in the population levels of certain species, or any combination of the above. It should also be emphasized that several major stresses (including freshwater, sedimentation, and nutrient enrichment) are actually amplification of processes which occur under "natural" conditions - i.e., their significance is one of degree rather than type. Moreover, these are the major stresses (quantitatively) occurring in the Hawaiian Coastal Zone.

In order to choose objectively the inland boundaries for the management of coastal water ecosystems, it is necessary to locate spatially the sources for the various impact on these systems resulting from human activities. For when we speak of "managing" natural ecosystems, we must remember that natural occurring ecosystems have managed to manage themselves for thousands of years (at least since the recession of the last ice age) without the intervention or "assistance" from man. The ecosystems themselves are the end products of millions of years of evolution which in a sense led to increased probabilities for their existence and perpetuation. Thus, when we speak of the "management" of coastal water ecosystems we really mean the "management of human activities" which affect these ecosystems, because it is these activities which have disrupted the normal functioning and processes within the systems. It should not be implied that man is incapable of improving upon nature - he has yet to demonstrate that capability, probably because his knowledge of natural ecosystems is yet insufficient to modify them without adverse effects.

After reviewing the categories of stresses on coastal water ecosystems (Table 6), it becomes immediately clear that the most logical boundaries for coastal zone management purposes includes the highest ridge boundaries of the watershed which drain towards the ocean for each of the islands in the chain. This choice is obvious because most of the environmental insults imposed by man on coastal water ecosystems are directly or indirectly derived from the drainage area. For example in Table 6, a total of 17 of the 31 stress categories occur in watersheds.

Table 6. Categories of sources of environmental modification or stress resulting from the activities of man, and their corresponding effects on naturally occurring coastal water ecosystems in Hawaii. Examples are given where documentation exists. An asterisk (*) indicates origin or substantial activity within watersheds.

SOURCE	NATURE	EFFECT	EXAMPLES
AGRICULTURAL			
*1. Milling and washing of sugar cane	Discharge of soil, bagasse, sugar, and other wastes	Burial of marine life and reduction of photosynthesis and oxygen content on bottom	Hamakua Coast, Hawaii (Grigg, 1972)
2. Canning of pineapple	Discharge of pineapple waste	Potential stimulation of the growth of some species (via nutrients) and inhibition of others (via toxins, bacteria, etc.)	Honolulu Harbor
*3. Land cultivation	Soil erosion and sedimentation	Burial and reduction of light penetration	Many areas (summarized in Smith, 1974)
*4. Crop irrigation using stream water	Diversion of stream water	Reduction of runoff into some environments and possible increase to others (causing changes in salinity, temperature and others)	Many islands, (Cox and Gordon, 1970; Timbol, 1972)
*5. Irrigation using reclaimed sewage	Leaching and runoff of sewage or nutrients	Possible nutrient enrichment and stimulation of some species and inhibition of others (less tolerant or competitive of the new conditions)	Kaneohe Bay (Marine Corps Air Station), Kaanapali, Maui

Table 6 (continued)

	SOURCE	NATURE	EFFECT	EXAMPLES
*6.	Chemical control of insects, weeds and pests (biocides)	Leaching and runoff of chemicals	Selective removal of certain species (lethal or sublethal concentrations)	Hawaii Kai (Lau, 1974)
7.	Ranching and livestock grazing	Deforestation, grassland cultivation causing greater levels of erosion	Burial and reduction of light penetration causing removal of certain forms, especially photosynthesizers	South Molokai (Moberly, 1963)
*8.	Intentional establishment of new crop or fish species	Introduction of exotic or non-native species	Displacement of native species and addition of new species (such as the Tahitian prawn)	Many islands (Maciolek, 1972)
COMMERCIAL AND INDUSTRIAL ACTIVITIES				
9.	Dredge spoil disposal	Deposition on existing submerged substrate and benthic ecosystems	Physical burial of habitat and destruction of associated species	Kaneohe Bay (Roy, 1970)
10.	Offshore mining	Removal of sand or rock	Physical removal of substrata and associated organisms	Keauhou, Kona (Maragos *et al.*, 1975)
11.	Harbor and channel dredging, quarrying for fill material	Removal of rock or sand	Removal of substrata, associated organisms, and modification of physical environment	Kaneohe Bay (Roy, 1970; Maragos, 1974b)

Table 6 (continued)

	SOURCE	NATURE	EFFECT	EXAMPLES
12.	Jetty and breakwater construction	Erection of structures	Burial of habitat under structures and modification of physical environment both landward and seaward of structure (circulation, substratum, etc.)	Waianae (Maragos, 1974)
13.	Land reclamation	Building of new land by extending shoreline	Burial of habitat and modification of physical environment (circulation, substrata, etc.)	Sand Island; Mikiola, Kaneohe
14.	Cooling of power plants	Discharge of thermal effluent	Removal of some species and possible addition of others	Kahe (Jokiel and Coles, 1974)
*15.	Municipal wastes	Sewage discharge including treatment chemicals	Destruction of some species and stimulation of others	Sand Island (Grigg, 1975) Kaneohe Bay (Banner, 1974) (Caperon *et al.*, 1972)
*16.	Industrial wastes	Discharge of miscellaneous chemicals	Selective removal of certain species	
17.	Oil spills and leaks	Accidental leaks and intentional discharge from ships and docking facilities	Selective destruction of certain species	
18.	Ship disturbance	Heavy metal input and alteration of circulation (ship stirring). Discharge of petrochemicals and sewage	Modification of habitat. Selective removal of species	Pearl Harbor (Evans *et al.*, 1974)

Table 6 (continued)

	SOURCE	NATURE	EFFECT	EXAMPLES
19.	Accidental introduction of fouling organisms via ship hulls	Introduction of exotic or non-native species	Displacement of native species and addition of new species	Pearl Harbor (Evans et al., 1974) Other harbors (Brock, 1975)
RESIDENTIAL AND OTHER URBAN ACTIVITIES				
*20.	Storm and flood control	Construction of channels, gutters, drains, resulting in greater runoff and sedimentation rates	Burial of habitat, reduction of light and selective removal of certain species	Kaneohe Bay (Banner, 1968; Maragos, 1972)
*21.	Land clearing and grading	Removal of vegetation cover and subsequent lack of or improper replanting programs	Burial, sedimentation and light reduction	Kaneohe Bay (Roy, 1970)
*22.	Stream modifications	Dewatering, channel straightening; defoliation channelization	Stream environmental degradation, loss of diadromous species, increased silt discharge	Many islands (Maciolek, 1975)
*23.	Miscellaneous chemical additives	Leaching and runoff of certain chemicals from garden sprays, fertilizers and termite wood preservative and ground termite treatment	Selective removal of certain species (possibly directly lethal). Sublethal physiological effects	Hawaii Kai (Lau, 1974)

Table 6 (continued)

	SOURCE	NATURE	EFFECT	EXAMPLES
*24.	Miscellaneous runoff and leaching of chemicals	Removal of surface petrochemicals from asphalt during rainstorms, etc.	Selective removal of certain species (lethal or sublethal concentrations)	Kaneohe Bay?
*25.	Construction of roads and buildings	Reduction of groundwater percolation and increase in runoff	Selective removal of some marine species and stimulation of others more tolerant to variations in salinity	Urban regions in Hawaii
*26.	Cesspool seepages	Leaching of sewage	Nutrient enrichment causing removal of some species and stimulation of others (especially phytoplankton and certain benthic algae)	Waimanalo Bay, Oahu Kaanapali, Maui
RECREATIONAL ACTIVITIES				
27.	Collection of shells and coral and other ornamental species	Removal of living organisms	Selective removal of certain species and possible indiscriminate destruction of others (via crowbar destruction of coral substrata)	Many areas (Grigg, in prep.)
28.	Collection of aquarium fish	Removal of live fish	Selective removal of certain species, especially rare and beautiful fish. Over collecting	Waianae Coast (Taylor, 1975)

Table 6 (continued)

	SOURCE	NATURE	EFFECT	EXAMPLES
29.	Recreational fishing for consumption	Removal of live fish	Selective removal of certain species, especially larger forms (reef fish). Overfishing	Many areas (Taylor, 1975)
*30.	Game mammals (Feral and Wild) esp. goats, pigs and deer	Overgrazing and disturbance of soil; bacterial contamination	Modification of submersed habitats through enhanced erosion and silt discharge and destruction of certain species by pathogenic bacteria	Kahoolawe
31.	Artificial reefs constructed of car bodies, tires, concrete, scrap, etc.	Leaching of heavy metals, unsightly "junk" and "corodoliths" near the shoreline	Covering and destruction of bottom habitat. Stimulation of some species (fish) and elimination of others (possibly via toxins in junk). Visual or aesthetic impacts	Kahala & Waianae (McVey, 1971; Morgenstein, in prep.)

It is also important to emphasize that the highest inland watershed boundaries for the coastal drainage basins or watersheds are, in most cases, the highest and generally the most centrally located points on the islands. This implies that for most all of the islands of the Hawaiian chain, internal watersheds, which do not drain directly towards the ocean, do not exist. The only possible exception to this generalization occurs on the island of Hawaii, the largest of the chain, where perhaps the slopes between the large mountains of Mauna Kea, Mauna Loa, Kilauea, Hualalai, and Kohala form rather high plateaus characterized by porous basaltic rocks and few stream systems. Yet even on Hawaii, the most "interior" location on the island occurs less than 30 miles from the sea.

comparison w/ Cal.

It is also useful to contrast the criteria utilized for appropriate inland boundary constraints which might be imposed for some of the continental states.* A pollutant introduced on the eastern flanks of the southern end of Sierra Nevada Mountains of California may never reach the ocean because the drainage systems run eastward, away from the Pacific. Even pollutants introduced on the western flanks may take days or weeks to reach the ocean because, first, they would have to drain towards the Central valley and then north towards San Francisco Bay or another outlet to the ocean. Thus, it could be argued that during the journey, the pollutant would be sufficiently degraded or would have been considerably diluted so that its impact on water ecosystems along the California coast would be negligible. In contrast,

*It is relevant to note that only the states and territories bordering the oceans and Great Lakes legally qualify for Coastal Zone Management Funds.

the same pollutant introduced into a waterfall in the Koolau Mountains of Oahu would reach the ocean in a day or less, or even within a few hours if a large rainstorm would occur at the same time.

This example serves to illustrate that the criteria which form the basis for establishment of coastal zone inland boundaries with respect to coastal water ecosystems for the Islands of Hawaii may not be appropriate for a larger mainland coastal state. Thus, it is important to include all coastal drainage basins, and hence nearly all land areas in the Hawaiian Islands within the coastal zone because the islands themselves are small and are intimately connected to the coastal waters. It is also relevant to note the traditional Hawaii concept of *ahupua'a* or land management divisions extended from ridge tops seaward to include reef areas and fishing zone. Such zones (improperly called "*konohikis*" today after the individual responsible for overseeing their use) were important management and conservation units. Many exist today on the tax key maps and the legal status of *konohikis* has been recognized in the State Supreme Court.

VI. STATUS OF EXISTING KNOWLEDGE ON COASTAL WATER ECOSYSTEMS AND THE IDENTIFICATION OF FUTURE RESEARCH NECESSARY FOR PROPER MANAGEMENT

It has been frequently emphasized throughout this report that our knowledge of most coastal water ecosystems in Hawaii is poor, superficial, and confined mostly to the structural (as opposed to the functional) aspects of these systems. The series of maps (Figures 1 to 8) illustrate this point, for many coastal areas around the islands remain "ecologically unchartered" to this day. Thus, it seems appropriate to acquire a more complete inventory of the status and development of coastal water resources, especially those which are or will imminently be subjected to environmental perturbations from human developments and activities. In addition, research is also needed on the tolerances and responses by the ecosystems to the various categories of stress. Research is also needed on the response of the ecosystems after the stresses have been removed or relaxed, both in terms of the nature of the recovery (if it occurs) and the time interval required. Finally, it should be noted that because most coastal water ecosystems are poorly accessible to the observations of men, that an information base will likely remain insufficient for a long time to come unless financial support for the various programs listed below are acquired. The management of any national resource cannot be implemented in the most practical and correct manner unless adequate knowledge of its nature, status and cause-and-effect-relationships are adequately known beforehand by the managers.

<u>Some Suggested Research Projects for Coastal Zone Management</u>

1. Complete inventory of the status and structure of aquatic and marine ecosystems (i.e., reconnaissance surveys).

2. Examination of the tolerances of important organisms to various types and concentrations of pollutants.

3. Studies of the rates and patterns of recovery of natural ecosystems after the removal or relaxation of human derived stresses (especially sewage, thermal, sediment, and freshwater discharges).

4. A complete bibliographic survey of published and unpublished information on coastal water ecosystems and its storage, retrieval, and analysis using a computerized system. The system should be designed so that both information gatherers and Coastal Zone managers both have adequate access to the system. (See Appendix A).

5. Evaluation of alternative parameters for water quality standards, especially those that which would reflect more closely the response of natural ecosystems to various human "insults." (See Appendix B for an example based on micromollusks).

6. Analysis of habitat destruction and potential overfishing pressures for selected fish and shellfish.

7. Analysis of procedures to increase communication between information gatherers and managers of the coastal zone.

8. Jurisdictional Analysis in order to review, reconsider or modify existing strategies established to enforce regulations and laws designed to protect the environment.

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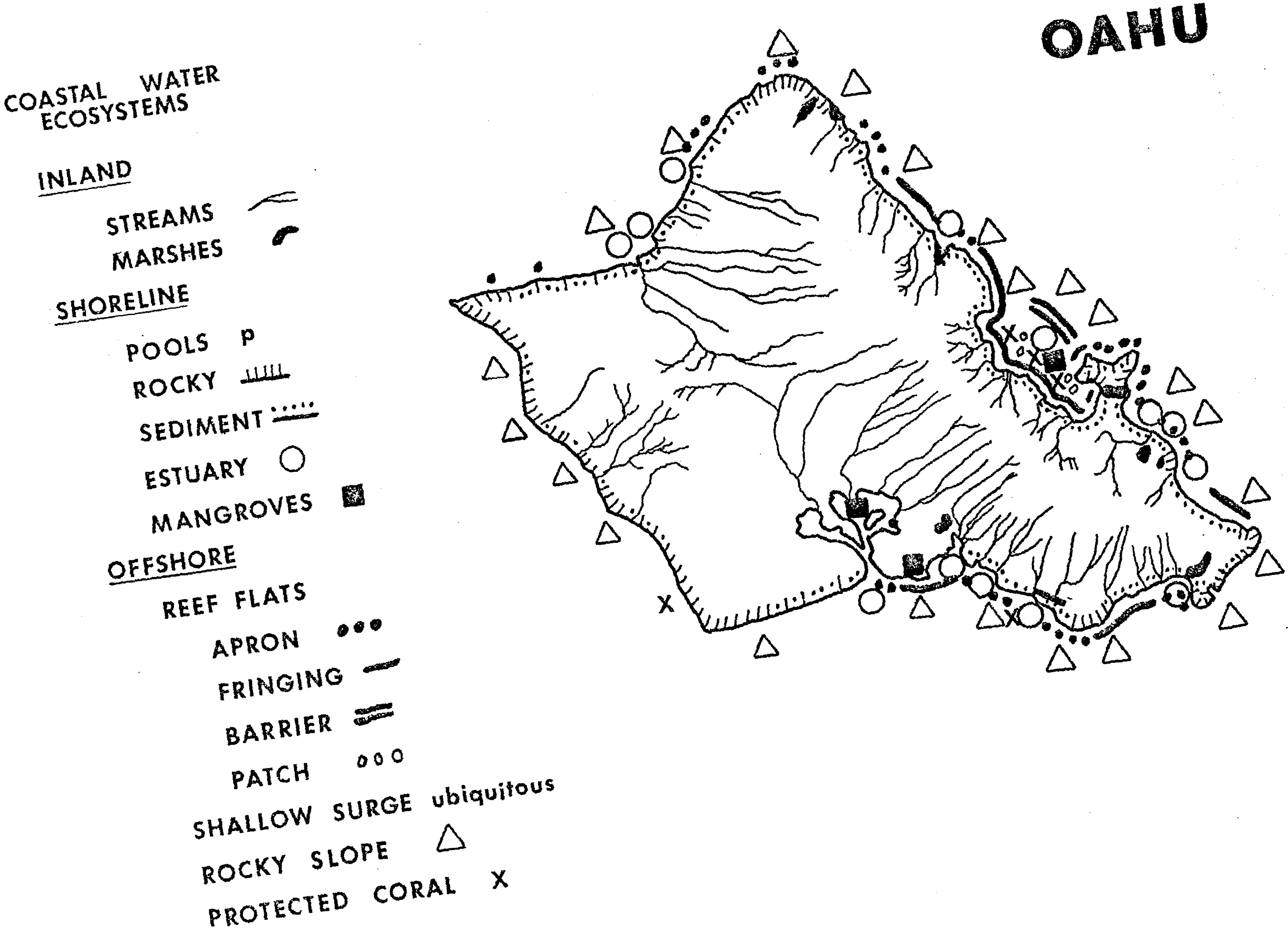
FIGURE CAPTIONS

Figures 1 - 8. The physiographic distribution of inland, shoreline, and offshore coastal water ecosystems in Hawaii based upon available information. The lack of symbols for most shoreline and inland areas implies an actual absence of the ecosystems for the specific areas. The lack of symbols for offshore ecosystems implies a general lack of information on the marine biology of the specific areas.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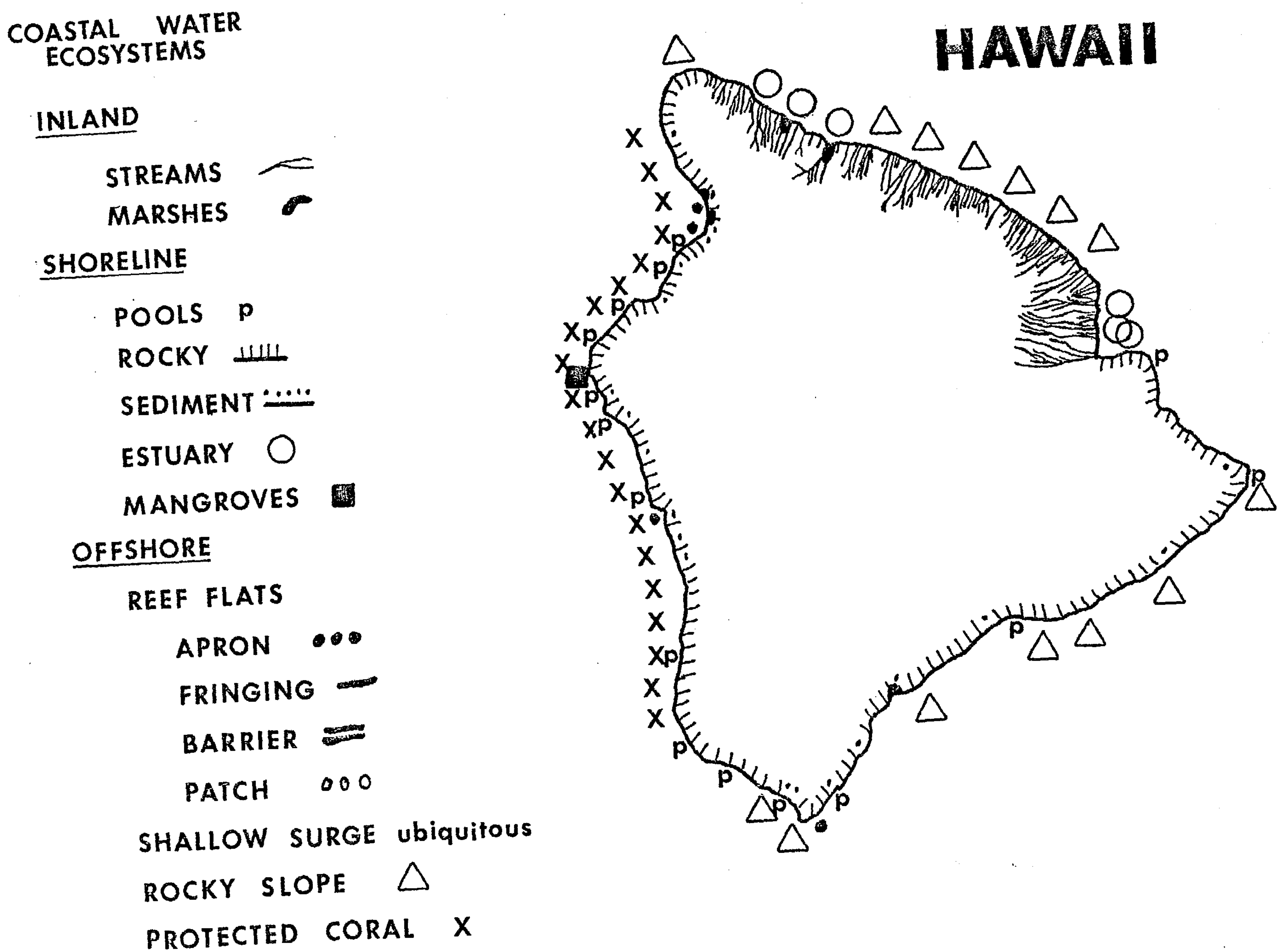
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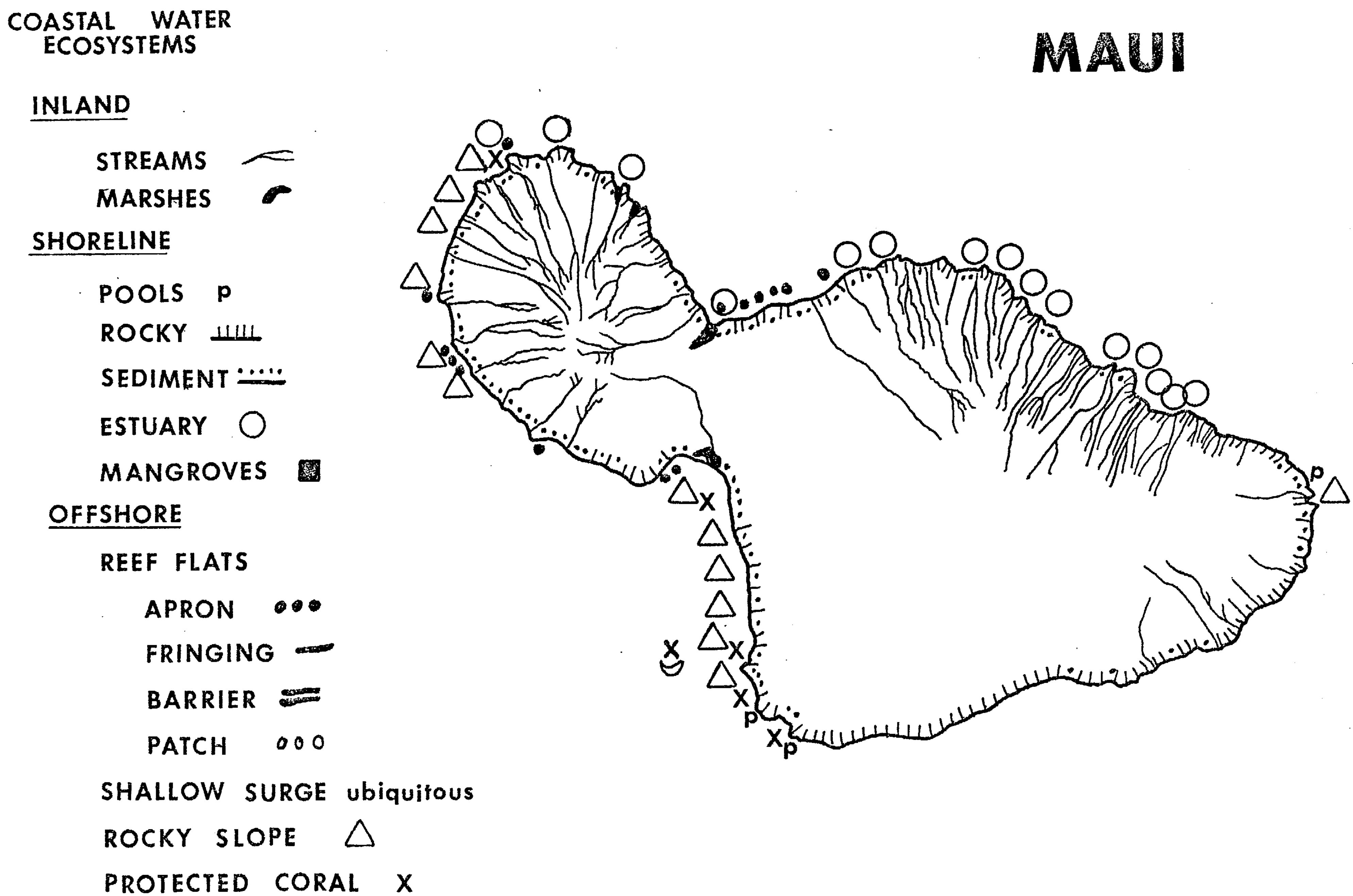
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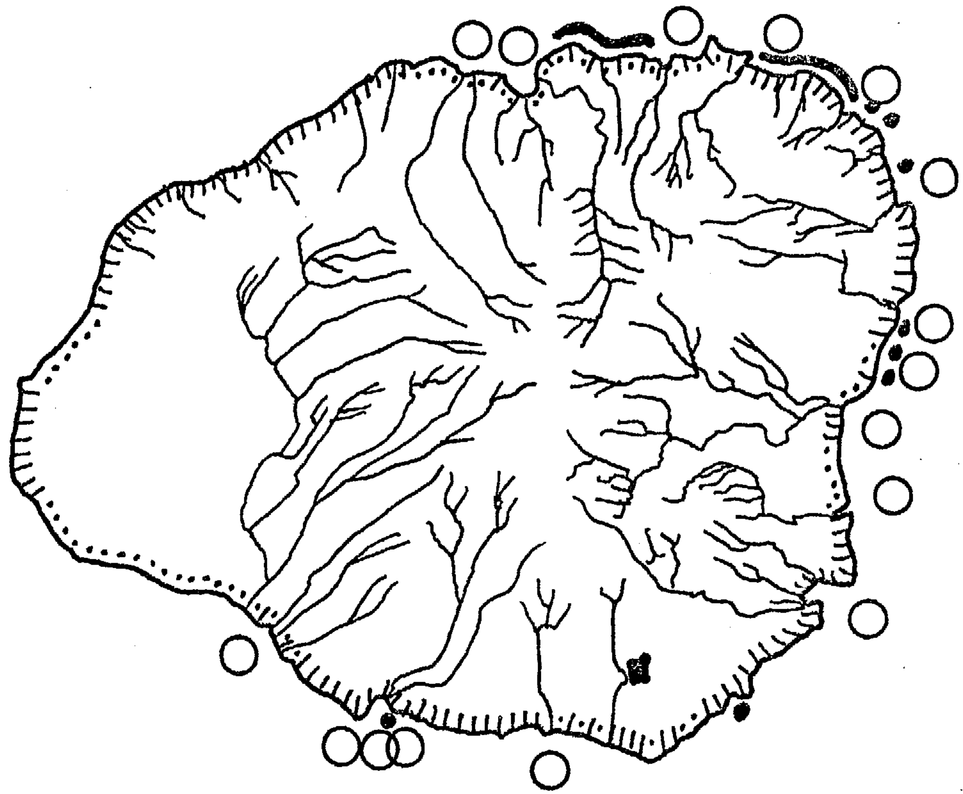

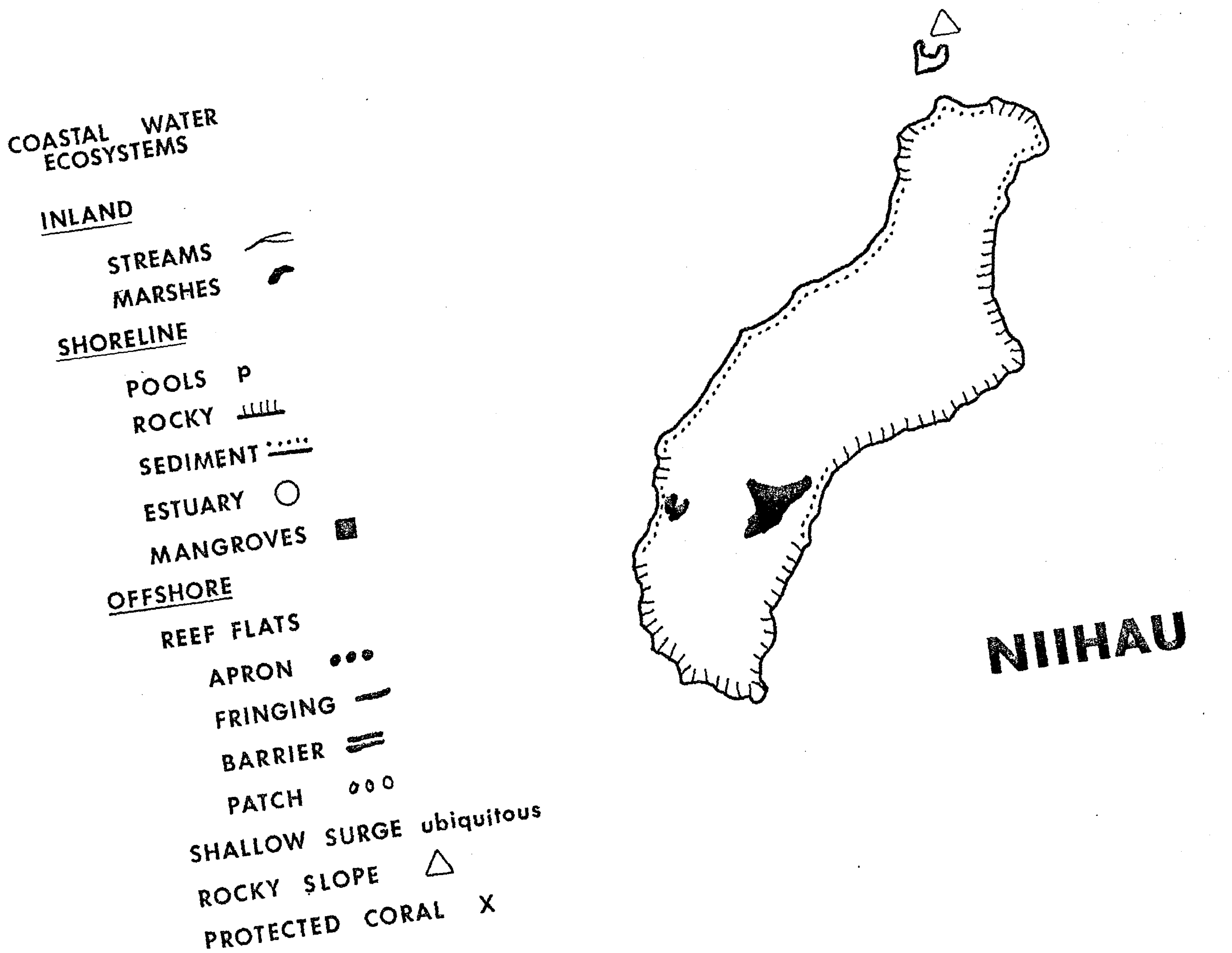
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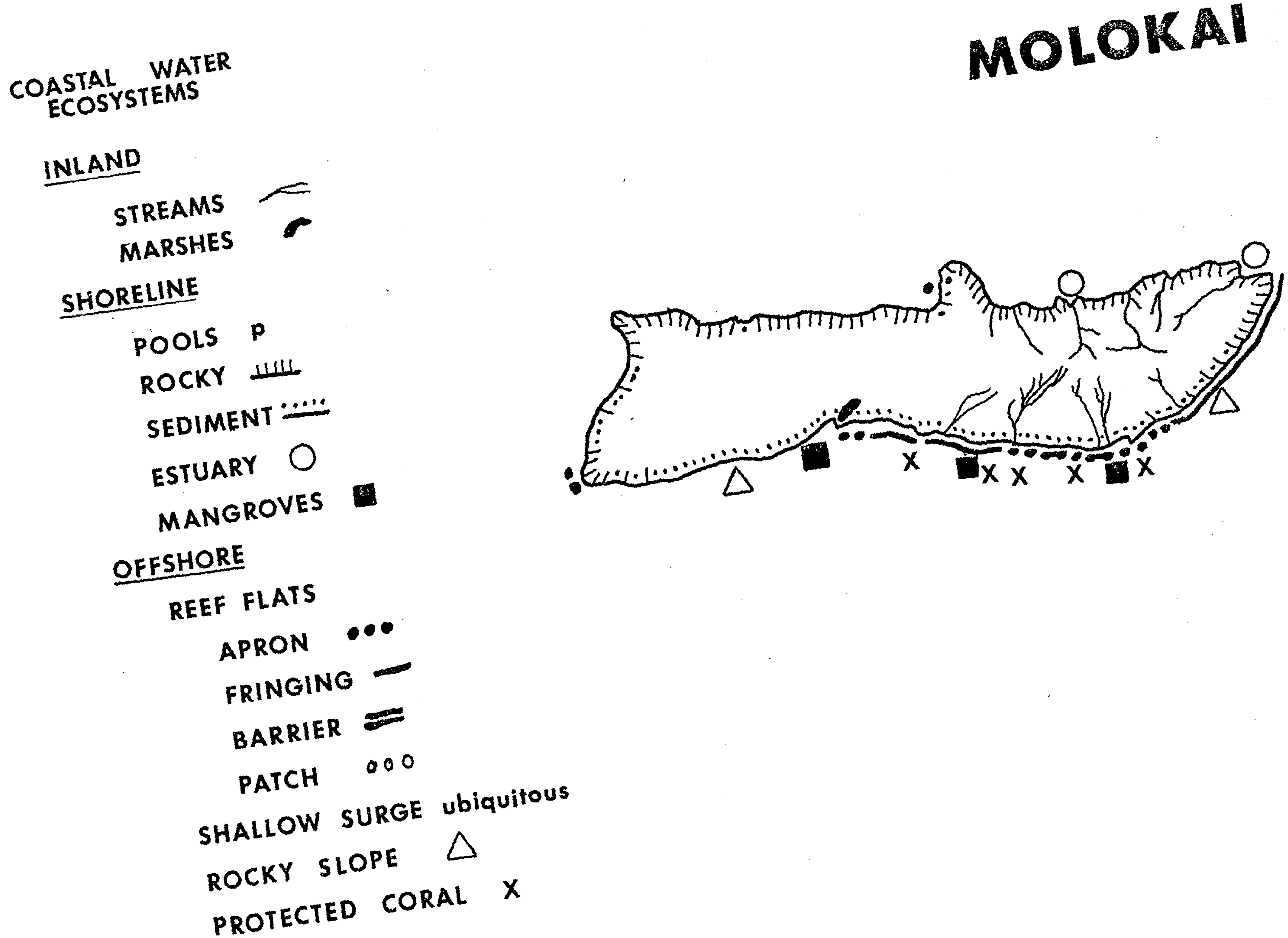
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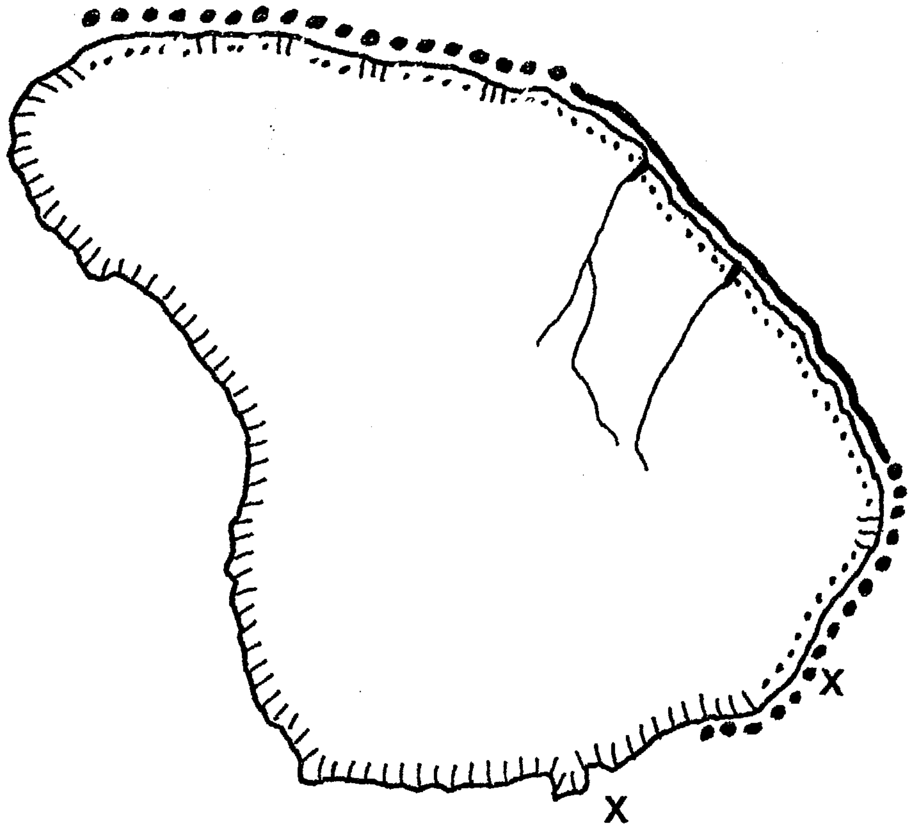

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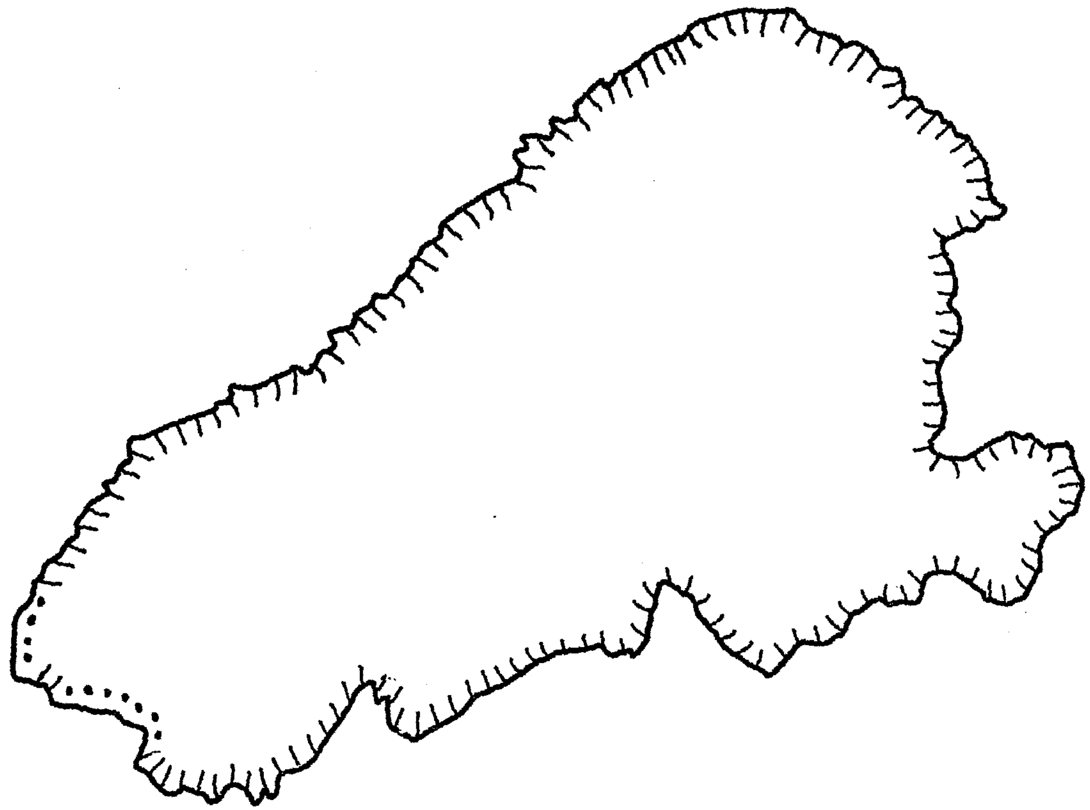

Appendix A

HAWAII COASTAL ZONE DATA BANK

by

D. T. O. Kam

Introduction

The coastal zone of the State of Hawaii is an extremely valuable resource which is being severely stressed by the activities of man. Coastal marine and aquatic ecosystems are particularly vulnerable, and yet we still know little of their distribution, development, and environmental status because of their relatively remote location in an environment unfamiliar to man and unamenable to his investigation. In order to compile information on these ecosystems, investigators frequently desire to have a listing of available information of the organism types and locations of past studies. The Data Bank is attempting to piece together available information on marine and aquatic resources in Hawaii. A large number of biological, geological, and chemical surveys have been conducted and recorded in unpublished environmental impact assessments, masters and doctoral theses, other reports as well as in a number of published articles. The ultimate objective of the Data Bank is to collect data obtained in all past, present, and future surveys of the coastal water environments and store it in a form so that it can be conveniently retrieved and analyzed at a later date. Also, it is anticipated that the HCZDB will be made compatible with other information storage and retrieval systems, both within and outside of Hawaii, which emphasize other aspects of the coastal zone.

Appendix A

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Purpose

In recent years, the increasing activity of development and alteration in the Coastal Zone of the State of Hawaii has resulted in a great increase in the number of surveys of this Zone. These surveys range from environmental impact statements to baseline research for inventory assessment and monitoring studies.

Many people thought that there was a need to find some way to record and make these data available for further analysis. Up to the present time, most of these data were turned over to the decision making body, subsequently stored, and for all practical purposes, lost. Since raw data of this type are not suitable for publication in the standard journals, it was felt that a library of data should be maintained to assure that all of the information obtained in the Coastal Zone would be preserved. Equally important as the storage of the data is access for further analysis. The only practical way to store such a voluminous amount of data is by the use of a large computer. The Hawaii Coastal Zone Data Bank was set up to meet these requirements.

Storage and Retrieval System

The HCZDB has developed a system of storage, retrieval and statistical programs specially designed for marine coastal zone data. In order to achieve compatibility between studies, a hierarchial identification numbering scheme based on the taxonomic classification of living organisms and other assets has been developed. This identification number list also serves as the checklist of organisms found in the Hawaiian Coastal Zone. A location identification numbering scheme is being used to store the HCZDB's numerous data sets in an orderly fashion. Because most of the use of the HCZDB is anticipated from the federal, state, and city governments, the location identification list is based on Hawaii's county and district boundaries.

Utilization is the purpose of storage, and retrieval is the vehicle for utilization. Biological and other Coastal Zone data require retrieval programs unlike any other computer programs available. The HCZDB has developed a system of retrieval programs that utilize the organism and location numbering schemes. In this way, data from studies done by different investigators at different times and at different locations may be easily merged and effectively analyzed. Retrieval of data can be conducted by referral to source lists, keyword lists (species and location), author lists, or bibliography lists.

Hawaii Transect Group

To insure compatibility between surveys, the Hawaii Coastal Zone Data Bank is advised by the Hawaii Transect Group, the Hawaii Coastal Zone Data Bank Advisory Committee, and other specialists. The function of the Group is to develop standardized methods of sampling, to screen older data in order to insure that its quality is sufficient to be included in the Data Bank, and to advise new investigators on methods of data collection. The Hawaii Transect Group is made up of members of the University community and representatives of the Water Resources Center, State Fish and Game, B. P. Bishop Museum and the Naval Undersea Center.

Statistical Analysis

The standard retrieval programs gives the investigator listings and summaries of data; however, some sort of statistical analysis is usually necessary. The investigator may request simple statistical treatments such diversity and similarity indices to more complex treatments such as correlation, regression, dendrograph analysis or factor analysis. The programs frequently used may be found in the List of HCZDB Programs.

Users of HCZDB

The Data Bank has been consulted for a number of studies including those supported by Sea Grant Programs of the University of Hawaii (Kaneohe Bay), the Army Corps of Engineers (Waikiki), Hawaiian Electric Company (Hilo, Honolulu, Kahe and Waiau), Naval Undersea Center (Pearl Harbor). In addition, present users include projects funded by the U. S. Environmental Protection Agency (Kaneohe Bay) and Hawaii State Department of Planning and Economic Development (Coastal Zone Management).

Future Objectives

Steps have been taken to place the water quality data bank developed by Miller (1974) within the HCZDB. The data bank may also be expanded to cover data on Hawaiian aquatic ecosystems. It is an eventual goal that the Data Bank be made compatible with information storage and retrieval systems contemplated by the State and which already exist elsewhere in the nation. This should provide a greater information base for government resource planning and management agencies having jurisdiction within the coastal zone in Hawaii. It is suggested that original data collected for environmental statements be stored via computer as part of routine procedure.

As indicated in the accompanying maps, the Hawaii Coastal Zone Data Bank has acquired and compiled a large amount of data on Hawaiian nearshore marine resources. However, many Hawaiian information sources have yet to be compiled including university theses, dissertations, research projects, published technical reports; and survey reports conducted by private environmental and engineering firms and consultants. In order to bring the HCZDB up to date on past studies, to keep abreast of new information sources, and to expand the types of information acquired from nearshore coastal water resources, a greater and more reliable mode of financial support will be required.

Bibliographic List of Sources: A comprehensive list of data sources may be obtained from HCZDB headquarters, which is located at the University of Hawaii Institute of Geophysics.

Appendix B

MICROMOLLUSKS AS INDICATOR ORGANISMS AND WATER QUALITY PARAMETERS IN BENTHIC ENVIRONMENTS

by

E. A. Kay

Many microscopic organisms or parts of organisms have been utilized by ecologists and paleontologists to determine ages, climatic conditions, and physical and chemical parameters associated with benthic environments. Chief among these organisms are diatoms and cladocerans in lakes, streams and rivers (Patrick, 1961; Frey, 1960; Whiteside, 1970) and foraminiferans and ostracodes in marine communities (Murray, 1973; Benson and Coleman, 1963). These organisms are useful determinants of benthic communities because they occur in numbers which enable statistical analysis of their assemblages; because they have life spans of a few days or a few weeks and hence can reflect rapidly changing conditions; and because their remains persist in sediments over long periods of time. Diatoms, foraminiferans, cladocerans and ostracodes do not, however, provide many clues as to the nature of the communities of which they are a part. All are epibiotal. And they represent, for the most part, single trophic levels in the communities: diatoms are photosynthetic, foraminiferans engulf small particles; cladocerans and ostracodes may be microherbivores. There is one group of microorganisms, however, which have all the advantages of the others (that is, short turn-over times, large numbers, and persistent remains), and which can, in addition, provide information on the structure of the community both in terms of habitat (whether epifaunal or infaunal and trophic structure. These are the micromollusks.

Micromollusks are here defined as those mollusks less than 10 mm in greatest dimension. They occur in more than 70 percent of the shelled gastropod and bivalve families which are found in the Hawaiian Islands. Their remains may comprise as much as one-third of the volume of a sand sample. Because they are so widespread in the taxonomic hierarchy, they are found in a variety of niches and they exhibit different trophic habits. Some species are epifaunal, living on rocks, rubble and algae; others are infaunal, living in sand or mud. Some are microherbivores, feeding on small algae; others are ciliary or suspension feeders, dependent on the primary productivity of the water column for their nutriment. Some are carnivores, scavengers or active predators; others are faunal grazers which feed on sponges and bryozoans; still others are parasites, associated with sessile invertebrates such as sponges and oysters.

Analysis of micromolluskan assemblages from sediment samples in the Hawaiian Islands during the past five years, largely as a part of the Coastal Water Qaulity Project of the University of Hawaii, indicates that a variety of patterns are identifiable. Some are associated with particular types of environments such as reef flats, tidepools and coral communities; others are associated with depth distribution. These assemblages are identifiable not only in terms of species composition but by standing crop, species diversity and trophic structure, all of which are interpreted as reflecting the environment of which the small mollusks were a part. Thus, given a handful of sand, one can identify its source, whether from reef flat, tidepool, or depths of 10, 50 or more meters. Additionally, these handfuls of sand indicate the types of changes which occur when the coastal zone is affected by land-generated pressures.

We have found, for example, that the major assemblages which have been identified exhibit several contrasting features for at least the dominant components. Reef flat assemblages are comprised of rather coarsely sculptured shells associated with either frondose algae or rubble. At shallow, subtidal depths rubble-associated species predominate. At greater depths there is an increase in the proportion of faunal grazers. At depths of more than 15 meters the assemblage is comprised of many small, fragile shells, and faunal grazers and bivalves play a more conspicuous role in the trophic structure of the communities than they do at lesser depths.

Standing crop and diversity values are fairly consistent for most stations which have not been affected by pressures generated on land. But there are noticeable differences among stations on different islands and in different ecosystems. Stations on Kauai exhibit lower standing crops than do those from other islands; those from the leeward (Kona) coast of Hawaii have the highest standing crops. Diversity values for subtidal stations are consistently higher at depths of more than 5 meters than for reef flats and shallow subtidal waters.

When ecosystems are affected by pressures generated on land, there appear to be at least four types of responses, each involving changes in the structure of the community. On reef flats where algal-dominated and rubble-associated communities are affected by silting, the change appears to be one in which a rubble-associated species (*Bittium zebrum*) becomes the dominant component of the fauna, and standing crop and diversity values are conspicuously depressed. When the change involves input of nutrients into relatively shallow water, as in Kaneohe Bay and in Pearl Harbor, the community changes toward one which is dominated by suspension feeding forms dependent upon the primary productivity of the water column. Where the reef front is affected by dredging and other activities as at Sand Island, Oahu, the assemblage shifts away from coral associated species to rubble dwellers. Where nutrients are dispensed at depths of more than 10 meters, as in Mamala Bay off the sewer outfall, banks of anaerobic sediments accumulate perhaps as deep as 100 meters and the assemblage is dominated by species characteristic of reducing sediments (*Obtortio pupoides*).

The work which has been done, utilizing micromollusks as indicator organisms both in shallow water and at greater subtidal depths, is only now beginning to take definitive shape. The information in hand comes only from those areas of the coastal zone which have been studied. As a result most of the information is centered on stations off the leeward coast of Oahu, and there remain long stretches of coastline for which we have no samples. There remains the need for basic data on the structure of communities elsewhere in the coastal zone of the Islands, data which can be utilized to show the range of variation within these communities so that baselines can be established. Eventually micromollusks may serve as water quality parameters, replacing some existing traditional parameters which do not reflect the status or responses of naturally occurring biological communities to various stresses.

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