REPORT TO CONGRESS: COASTAL BARRIER RESOURCES SYSTEM

Coastal Barriers of Hawaii and American Samoa: Summary Report

APPENDIX C

U.S. Department of the Interior

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COASTAL BARRIERS OF HAWAII AND AMERICAN SAMOA: SUMMARY REPORT

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PREFACE

When the Coastal Barrier Resources Act was passed in 1982, Congress did not address the possibility of including barriers along coastlines other than those of the Atlantic Ocean and Gulf of Mexico. In 1983, the Coastal Barriers Study Group was directed by the Secretary of the Interior to identify and delineate the undeveloped coastal barriers on all U.S. coastlines. Other information concerning these barriers was also gathered. This appendix presents information about barriers along the coasts of Hawaii and American Samoa.

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INTRODUCTION

The State of Hawaii and the Territory of American Samoa are located in the central Pacific Ocean (Figure 1). The coastal barriers of Hawaii and American Samoa are very different from those of the continental Atlantic and Gulf of Mexico coasts because of the tropical climate and volcanic origin of the islands. To simplify the discussion of coastal barriers in Hawaii and American Samoa, all coastal barriers were categorized according to type (Table 1). These types of coastal barriers include bay barriers, beach barrier/fish ponds, barrier beaches, and barrier spits.

Bay barriers are defined in Volume 1 of this report as "coastal barriers that connect two headlands and enclose...aquatic habitat." In Hawaii and American Samoa, bay barriers are frequently seasonally breached by river flow. Beach barrier/fish ponds are naturally occurring wetlands that are protected by a depositional barrier beach. They have been modified somewhat for aquaculture use and are termed "loko puuone" or "loko haukuone" in Hawaiian (Apple and Kikuchi 1975). Barrier beaches refer to landward aquatic habitats that are protected by sandy beaches, but that are not confined by headlands. Barrier spits are defined in Volume 1 of this report as "coastal barrier units which extend into open water and are attached ... at only one end." This definition is also used in this appendix.

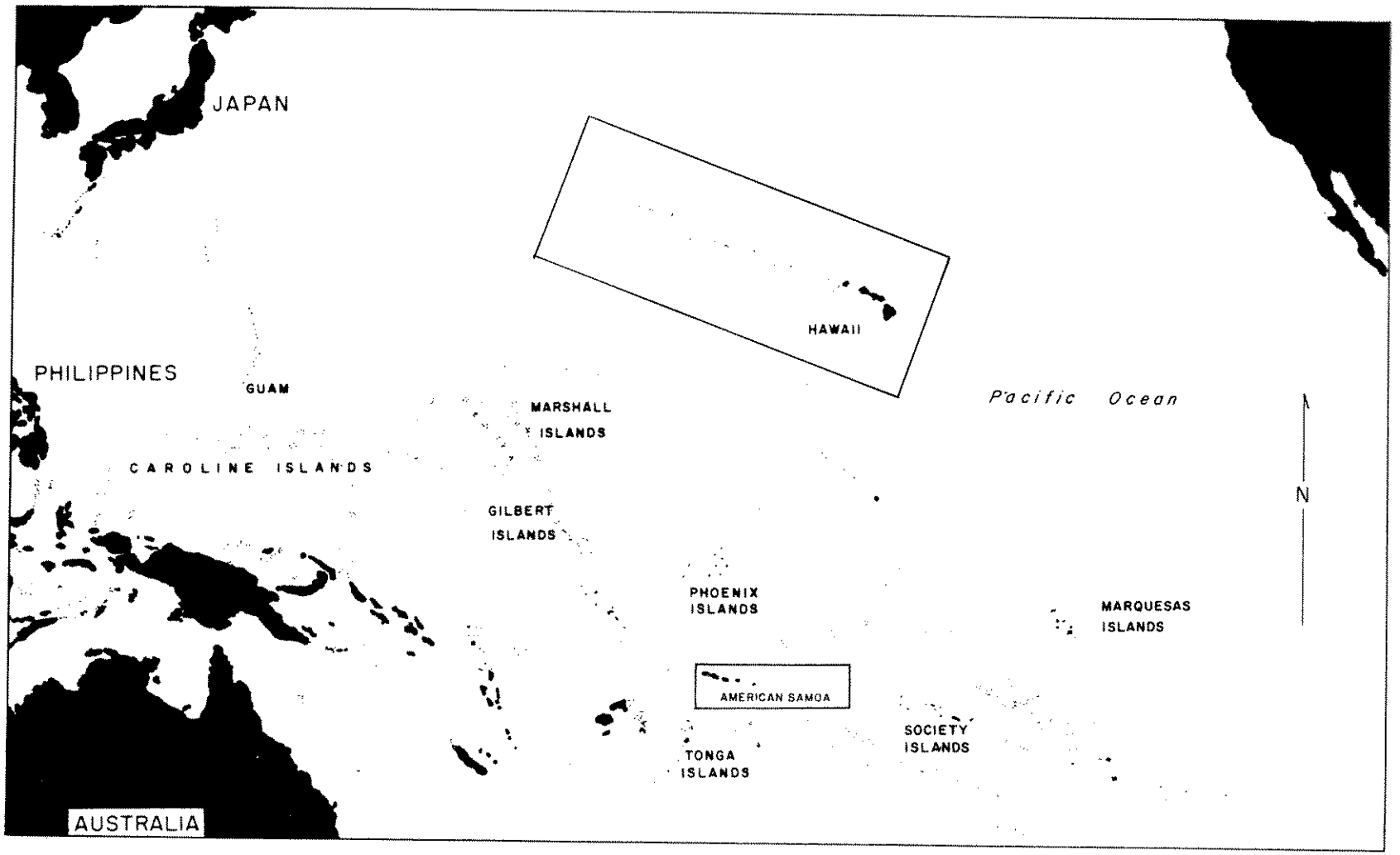


Figure 1. Location of the Hawaiian Islands and American Samoa.

Table 1. Coastal barriers of Hawaii and American Samoa.

Island	Coastal barrier	ID code[a]	Coastal barrier type
HAWAII			
Kauai	Wainiha Bay	HI-22	Bay Barrier
	Lumahai Valley	HI-22A	Bay Barrier
	Pohakuopio (Waioli and Waipoa Streams/W. Hanalei Bay)	HI-23	Bay Barrier
	Hanalei (Hanalei River/Wilcox Fish Pond)	HI-24	Bay Barrier, Beach Barrier/Fish Pond
	Puu Poa Marsh/E. Hanalei Bay	HI-24A	Bay Barrier
	Kilauea Bay	HI-24B	Bay Barrier
	Moloaa Bay	HI-24C	Bay Barrier
	Anahola Bay	HI-24D	Bay Barrier
	Hanamaulu	HI-26	Bay Barrier
	Lawai Bay	HI-26A	Bay Barrier
Niihau	Halalii Lake	HI-32A	Barrier Beach
	Leahi	HI-38	Barrier Beach
	Nonopapa	HI-37	Barrier Beach
	Paliuli	HI-36	Barrier Beach
	Haao	HI-35	Barrier Beach
	Kaununui	HI-34	Barrier Beach
	Keawanui Bay	HI-33	Barrier Beach
Oahu	Waimea Bay	HI-27A	Bay Barrier
	Kalou Marsh	HI-27B	Barrier Beach
	Kahuku Ponds/Dunes	HI-27C	Barrier Beach
	Kahana Bay	HI-28	Bay Barrier
	Nuupia	HI-31	Beach Barrier/Fish Pond
Maui	Paukukalo Marsh	HI-11	Barrier Beach
	Kanaha Pond	HI-12	Barrier Beach
	Kealia	HI-13	Barrier Beach
Hawaii	Pololu Valley	HI-01	Bay Barrier
	Waimanu Bay	HI-02	Bay Barrier
	Waipio Bay	HI-03	Bay Barrier
	Honokohau (Amikapa Fish Pond)	HI-06	Beach Barrier/Fish Pond
	Opae Ula Fish Pond	HI-06A	Beach Barrier/Fish Pond
	Kiholo Bay (Wainanalii Fish Pond)	HI-08	Beach Barrier/Fish Pond
	Anaehoomalu (Kahapapa and Kuualii Fish Pond)	HI-09	Beach Barrier/Fish Pond
AMERICAN SAMOA			
Tutuila	Pala Lagoon		Barrier Spit

[a]This ID Code refers to the identifier assigned to the barrier by the coastal Barriers Study Group in its 1985 inventory.

PHYSICAL CHARACTERIZATION OF HAWAII AND AMERICAN SAMOA COASTAL BARRIERS

HAWAII

Geological Processes

The Hawaiian Islands are the exposed tops of large undersea volcanic mountains formed by successive flows of basaltic lavas that erupted from vents in the ocean floor. Layer upon layer of lava was added as the broad volcanic domes (shield volcanoes) rose above sea level and continued to erupt (MacDonald et al. 1983). Each volcano was formed over the same "hot spot" of magma in the earth's crust. This hot spot is now located under or just south of the island of Hawaii.

The Hawaiian Islands are situated in the middle of the Pacific Plate, one of the largest of the crustal plates that make up the earth's surface. The motion of the Pacific Plate has moved the ocean floor relative to the hot spot, displacing the volcanic islands to the northwest after formation. This has resulted in a sequence of island ages, from the oldest, in the northwest, to the youngest, in the southeast (Figure 2, Table 2). The islands differ considerably in size and shape, reflecting the size and location of the original island-forming volcano, or volcanoes, the length of time since island-building volcanism ceased, and the amount of erosion which has taken place. In addition, long after the original island-building had stopped, small volcanic eruptions occurred throughout Hawaii. This later volcanism created small, scattered volcanic cones. Some of these filled stream-cut valleys with lava flows; others impinge directly on the current shoreline (MacDonald et al. 1983).

Many Pacific volcanic islands sink relatively rapidly due to the weight of the newly formed land mass on the ocean floor. It was originally thought that the Hawaiian Islands were sinking very slowly and that the subsidence was not critical to the formation of the present coastal features (Moberly et al. 1963; MacDonald et al. 1983). More recent evidence suggests that while Oahu is relatively stable, Hawaii and, to a lesser extent, Maui are subsiding rapidly enough to have "drowned" previous coastal features (Apple and MacDonald 1966; Moore 1970; Moore and Fornari 1984). Climatically induced and glacially controlled sea-level changes during the Pleistocene (the period from about 2 million years to 10,000 years before present) also have left evidence of many former shorelines around Hawaii (Moberly and Chamberlain 1964). These include stream-cut valleys which extend far below present sea level. The valleys now form drowned embayments with sediment-filled floors at the present-day coast. Sand dunes were formed when calcium carbonate sediments, such as coral and shell rubble, were blown inshore from coral reefs exposed

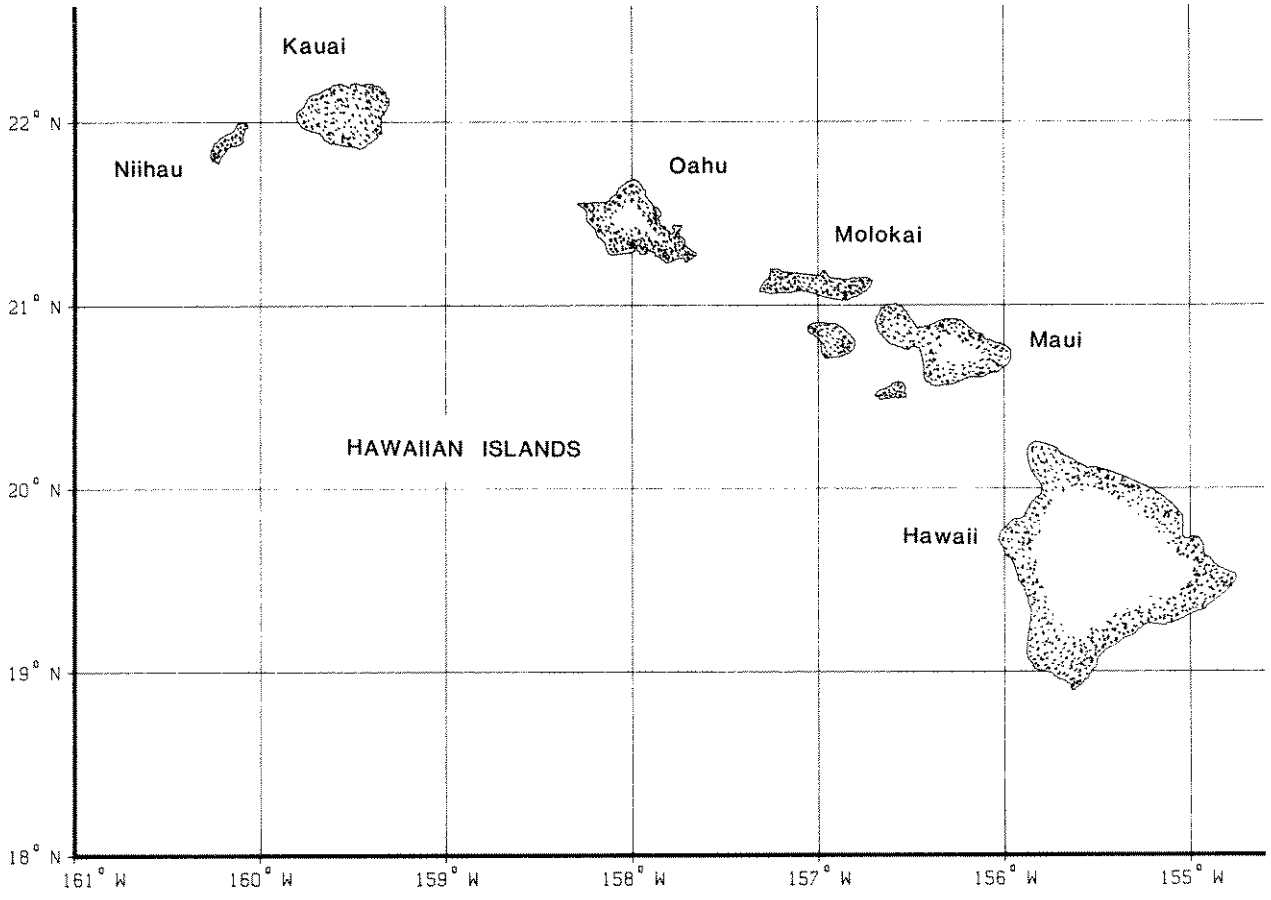


Figure 2. The major Hawaiian Islands.

Table 2. Characteristics of the principal Hawaiian Islands (from MacDonald et al. 1983).

Island	Age (millions of years before present)	Area (mi^2)	%	Shoreline (mi)	%	Highest point (ft)
Niihau	5.5	45.6	1.2	50.3	5.1	1,259.9
Kauai	3.5 - 5.7	343.6	8.6	110.0	11.1	5,161.0
Oahu	1.8 - 3.8	378.0	9.5	208.8	21.1	3,963.4
Molokai	1.2 - 1.8	162.2	4.1	106.3	10.7	4,892.0
Lanai	0.8 - 1.2	86.9	2.2	52.2	5.3	3,317.1
Maui	0.4 - 1.6	453.3	11.4	149.1	15.1	9,866.0
Hawaii	0.2 - 0.5	2,510.0	63.1	313.2	31.6	13,580.1
Total		3,979.6	100.1	989.9	100.0	

exposed by a lower sea level. These dunes have solidified into sandstone features at the coast and in nearshore waters (Moberly and Chamberlain 1964; Stearns 1978). Sea level has risen gradually during the last 6,000 years to a relatively steady state at the present time.

The volcanic basalt which forms the Hawaiian Islands weathers more rapidly than other rock, especially in the warm, humid climate of the tropics. Quartz, the predominant beach sand material of most continental coastlines, is not a component of basalt and is therefore absent from Hawaii (Moberly et al. 1963). Stream erosion removes and transports weathered basalt to the coast where it fills lower valley floors to help create wetlands, contributes to barrier beach formation, or is carried into coastal currents or submarine canyons (MacDonald et al. 1983).

Coastal Materials

Present-day coastal materials in Hawaii can generally be classified into three categories: volcanic rock, terrigenous sediment (mainly weathered basalt), and biological sediments (mainly calcium carbonate sand). About two-thirds of Hawaii's coastline is composed of sea cliffs, rocky basalt shores, and other material of volcanic origin (Titcomb 1972). Volcanic activity inhibits the development of sandy beaches by (1) covering existing sand beaches with lava, (2) destroying coral reefs and their calcareous sediment-producing organisms, (3) creating permeable surfaces which reduce surface runoff and subsequent sediment generation, and (4) forming steep,

solid basalt shorelines which must undergo extensive erosion before beaches can form (Moberly et al. 1963). Therefore, coastal barriers are less likely to be found along coastlines dominated by recent volcanic material.

The weathering and erosion of island interiors result in the deposition of terrigenous sediments at the coastline. These dark-brown basaltic sediments, primarily removed and transported by streams, are important in the formation of wetlands and bay mouth barriers in drowned river valleys. This is the most common type of coastal barrier system in Hawaii, especially on the older islands such as Kauai, which have been exposed longer to erosional processes. At the shore, terrestrial sediments that were deposited by streams may be redistributed by wave activity or transported from the coast by nearshore currents (Moberly et al. 1963).

Biologically derived sediments are produced from the calcareous skeletons of corals and other organisms. They are generated on coral reefs by a variety of means. Waves break off pieces of corals and other organisms with calcium carbonate skeletons and work the rubble into beach sand. Live coral is eaten by some reef fish (for example, scarids) and a fine sediment is defecated. Other organisms bore into the reef, creating fine calcareous debris and making the reef more susceptible to breakage. Foraminifera, one-celled protozoans with sand-sized calcium carbonate shells, occur in abundance on many reefs, and their shells contribute to coralline sediments. The skeletons of various other invertebrates, the shells of mollusks, and the skeletal fragments of coralline algae (particularly the genus Halimeda) all add to the calcareous sediment generated by coral reefs.

The distribution of coastal barriers in Hawaii, their calcareous sand supply, and their protection from erosion is related to the distribution, size, and status of the coral reefs around each island. Of the common reef types, those that are attached directly to the shore (fringing reefs) are dominant in Hawaii. They are better developed on the older islands, especially Kauai and Oahu, which consequently have more calcareous beaches. Conversely, the youngest island, Hawaii, has relatively fewer reefs and a much lower percentage of sandy beaches (Table 3).

Wave exposure, which is a function of coast orientation and configuration, is a dominant factor in coral reef development. Reefs are generally wide and shallow off coasts exposed to the northeast tradewinds, wide and very shallow along some leeward (south and west) or otherwise protected coasts, and deeper and more irregular off northern coasts exposed to seasonally large surf (U.S. Army Corps of Engineers 1971). Locally, beach deposits may be protected by outcrops of beach rock or raised reef. Beach rock is cemented beach sand that, when exposed, can form solid ramps along the shore. Raised reef is coral reef which developed during earlier, higher sea level stands or was raised by land emergence, and is now exposed.

Coastal Processes

The movement of materials along the Hawaiian coast is accomplished by four major forces: (1) ocean waves, (2) currents, (3) winds, and (4) tsunamis (Gerritsen 1978). Ocean waves and currents are the dominant forces in the

transport of coastal sediments and the formation of beaches along Hawaiian shores. The waves may be categorized into four types: (1) northeast trade-wind waves, (2) North Pacific swells, (3) Kona storm waves, and (4) southern swells. The characteristics of each of these wave types are shown in Table 4.

Table 3. Coastal barrier conditions for the principal Hawaiian Islands.

Island	Sandy shoreline (mi[a])	% Island coast sandy shoreline[a]	Number of coastal wetlands[b]	Number of coastal barriers
Niihau	-	-	7	7
Kauai	50	44	21	10
Oahu	56	28	20	5
Molokai	25	24	13	0
Lanai	18	35	0	0
Maui	34	21	6	3
Hawaii	22	7	11	7

[a]from Campbell and Moberly (1985).

[b]Wetland sites identified below 500-ft contour line (Ahuimanu Productions 1977).

Table 4. Characteristics of ocean waves affecting the Hawaiian Islands (Moberly and Chamberlain 1964).

Wave type	Source	Most common months of occurrence	Height range (ft)	Average period (sec)	Direction of approach
Northeast trade waves	Northeast tradewinds	May-Oct	3-10	5-8	N, NE, E
North Pacific swells	Low pressure systems off Alaska	Oct-May	6-33	10-17	NW, N, NE
Kona storm waves	Low pressure systems near Hawaii	Oct-May	10-16	8-10	SW, variable
Southern swells	Antarctic storms	May-Oct	3-6	14-22	SE, S, SW

Hawaii is in the path of the North Equatorial Current. Closer to the islands, the coastal currents are controlled by submarine topography, coastal configuration, and tidal currents. Inside the reefs and along the beaches, wind and waves generate the nearshore current. Both the coastal and nearshore currents are responsible for the transport of reef sediments to the shore, the movement of suspended sediments along the shore, and the removal of sediments to offshore deposits.

Hawaii experiences a mixed diurnal and semi-diurnal tidal cycle, with a tidal range of generally less than 3 ft. The tides have little direct effect on the movement of shore sediments, but are important in shifting the surf zone across the beach face and exposing a wider zone to wave activity (Moberly et al. 1963).

Winds, especially the northeast tradewinds and Kona (west) winds, are also important in structuring the coastal environment. The northeast tradewinds generally prevail from April to November. They have average velocities of 10-20 mi per hour and can blow sand inland to form dunes. Kona storms are low-pressure systems near Hawaii that move eastward through the State. Kona winds occur irregularly between November and March and can reach velocities in excess of 25 mi per hour. However, Kona winds are less common and persistent than other winds and therefore are less important in the movement of coastal sediments (Moberly et al. 1963).

Hurricanes very rarely reach Hawaii. When hurricanes do strike, strong winds, high waves, and storm surge result in considerable movement of coastal sediments, inshore and offshore, and the breaching of beach berms.

Tsunamis ("tidal" waves) are trains of long-period waves generated by seismic or volcanic activity in the ocean basin, along continental margins, or in major island groups. Although tsunamis occur infrequently, they can result in significant shoreline alteration or destruction in Hawaii (Moberly et al. 1963).

Coastal Barrier Characteristics

Kauai Island. The island of Kauai consists of a single large shield volcano which has been deeply eroded by stream-cut valleys (AECOS, Inc. 1982; Manoa Mapworks 1983). More recent, smaller eruptions in the eastern portion of the island have filled many low-lying areas with lava. During Pleistocene glacial periods, river valleys were eroded down to lower sea level and sand dunes were formed. As sea level rose during interglacial periods, the lower ends of stream-cut valleys were drowned and terrestrial sediments were deposited on the lower valley floors. During the gradual ocean rise to present sea level, terrigenous material was deposited at the mouths of drowned valleys, forming wetlands and estuaries (Moberly et al. 1963). Broad beaches of coral reef-derived sediment formed coastal barriers protecting the wetlands in the low-lying valley mouths. Bay mouth barrier systems account for nearly all the coastal barriers on Kauai, which are almost half of those in Hawaii.

The coastal barrier units on the north-facing shore of Kauai are exposed to large northerly swells. Those barriers without protective reefs or

embayments, especially Lumahai Beach, undergo severe seasonal erosion and redeposition. Where reefs do occur, in protected areas and away from stream mouths, they are well developed and shallow, with strong currents sweeping over them. Windward coastal streams are subject to periods of flooding and discharge large amounts of sediment during high flow episodes.

Hanalei Bay, the largest on Kauai, is the drowned lower end of three valleys, the Hanalei, Waipoa, and Waioli, which link to form a broad floodplain. Between the last bend in the Hanalei River and the bay, two freshwater fish ponds and an adjoining marsh represent natural drainage features which have been altered considerably (Ahuimanu Productions 1977; Elliott and Hall 1977; Madden and Paulsen 1977). The entire crescent of Hanalei Beach is apparently prograding, although some erosion has occurred along the western beach in front of Waioli and Waipoa Streams (Moberly et al. 1963; Campbell 1972). A very small valley containing Puu Poa marsh and a small perennial stream is protected by a narrow beach, which is located at the extreme northeast end of Hanalei Bay.

Three embayments on the northeast coast of Kauai (Kilauea, Moloaa, and Anahola Bays) contain drowned river valleys with stream estuaries protected by bay barriers. The beach barriers appear relatively stable and some have exposed patches of beach rock. Further south, on the eastern shore of Kauai, there is a semi-enclosed embayment (Hanamaulu Bay) which is a drowned river valley and coastal bay barrier that is well protected from erosion (Moberly and Chamberlain 1964). On the south shore of Kauai, a number of small drowned valleys form embayments and bay barriers, but only one, Lawai Bay, has much of a wetland.

Niihau Island. Niihau is the deeply eroded remains of a single shield volcano, of which only the lower western flank remains. A wide terrace was formed around the remnant volcano on its south, west, and north sides by wave erosion during lower sea-level stands. Extensive coral reef development occurred on this platform as sea level rose during the late Pleistocene (MacDonald et al. 1983). The long period of erosion, which removed a large portion of the original island-building volcano, was followed by a series of smaller eruptions. Cones from these Pleistocene eruptions dot the wave-cut, coral-topped terrace, building it up and widening it (MacDonald et al. 1983). Much of the coastal plain is now covered with solidified calcareous sand dunes, which formed during lower sea stands and extend below present sea level. Coral reefs surround most of the coastal plain, supplying calcareous sand for the plentiful beaches of Niihau.

All the coastal barriers on Niihau are of the beach barrier type, with open coast sandy beaches and dunes separating brackish lagoons from the ocean. The lagoons have a limited supply of rainfall and runoff, and are reduced in size during dry periods, exposing the salty reddish clay of their bottoms (U.S. Fish and Wildlife Service, n.d.).

On the eastern side of the island, Niihau's largest water body, Lake Halalii (865 acres), is protected by wide, low dunes and beaches. Parallel to the beach, outcrops of beach rock 65-100 ft offshore indicate a long-term erosional trend (Moberly and Chamberlain 1964). A small intermittent salt

lagoon at Leahi on the southern shore is separated from the ocean by a barrier beach. On the western shore, Nonopapa Lake is separated from the ocean by a stable dune 13-16 ft high and 260 ft wide. The coastal barriers of the central west coast all contain low to high (up to 65 ft) dunes which extend inland several hundred yards (Moberly and Chamberlain 1964). Keawanui Beach, the longest single beach on Niihau, varies seasonally in width, experiencing up to 100 ft of winter erosion. The area is backed by a continuous strip of dunes that increases from 330 ft wide at the northern end to over 2,600 ft wide and 100 ft high in the south (Moberly and Chamberlain 1964).

Oahu Island. The island of Oahu consists of two major, deeply eroded shield volcanoes, which are linked by a broad central plateau. Large, drowned, stream-cut valleys and raised reefs from Pleistocene sea-level changes are found on Oahu. Secondary volcanic eruptions added smaller cones, particularly along the east side of the island, and created a geologically complex and diverse coast. The extent of sandy beaches on Oahu is second only to Kauai.

The northwest and northeast facing coasts of Oahu are indented by stream-cut valleys with estuarine marshes, wide bay barrier beaches, and drowned valley embayments at Waimea and Kahana Bays. Waimea Stream forms a marsh and brackish pond. The water from this pond seeps through the beach barrier, which blocks it from the ocean (Gerritsen 1978). The bay at Waimea experiences large winter swells that shift sand to the northeast end and remove it offshore, creating a steep foreshore. In summer, sand is moved back to the southwest end and replenished from offshore, resulting in a smooth, gradual foreshore (AECOS, Inc. 1979a; AECOS, Inc. 1981). Waimea Beach was mined until the mid-1960's. This may have contributed to beach retreat further south from Waimea and prevented the beach at Waimea from maintaining its natural dimensions (AECOS, Inc. 1979a; Cox and Gordon 1970; U.S. Army Corps of Engineers 1971). More recent investigations suggest that Waimea Beach has been cut off from Pleistocene sand supplies and will continue to erode as large storms wash sand out to offshore deposits (Campbell and Hwang 1982). Kahana Bay is protected from waves by extensive fringing reefs. Kahana Stream forms broad estuarine flatlands and is fronted by a low bay mouth barrier (Cox and Gordon 1970; Maciolek 1972, 1977; Timbol 1972).

The northern tip of Oahu, named Kahuku, is marked by a wide plain with broad depressions. The low-lying areas form marshes and ponds which are fed by springs, ground water, and runoff. Much of the original marsh has been altered, but three ponds with marshes persist (Ahuimanu Productions 1977). The wetlands are fronted by well-developed, vegetated dunes. The dunes are behind a narrow beach with extensive patches of beach rock and outcrops of raised reef (AECOS, Inc. 1979a, 1981). Nearby, on the northwestern facing side of Kahuku Point, a small marsh and pond are situated in a depression behind a narrow barrier beach.

Mokapu Peninsula, on the center of Oahu's northeast side, is connected to the main portion of Oahu by a wide platform of raised reef limestone. A series of eight connected depressions in this raised reef create wetlands. These wetlands were formerly used as fish ponds. Salinity and water level in the ponds fluctuate with rainfall and tidal influence (Ahuimanu Productions 1977). The easternmost ponds are protected from the ocean by low calcareous

dunes. In front of the dunes, a beach with beachrock outcrops and exposed reef limestone creates a coastal barrier (Wentworth 1939; Emery and Cox 1956; DeSilva 1966; AECOS, Inc. 1979a, 1981).

Maui Island. The island of Maui, second largest in the State, was built by two volcanoes, west Maui and Haleakala, whose lava flows coalesced to form a broad, low isthmus. Pleistocene sea-level changes affected Maui by forming sand dunes, now mostly solidified, on northwest portions of the isthmus. Long barrier beaches are found along portions of the north side of the isthmus and along the entire southern isthmus shore (U.S. Army Corps of Engineers 1971). These beaches are susceptible to erosion, although they have extensive beach rock formations in places. Wetlands are found in coastal depressions behind these barrier beaches. These have formed at present sea level and are fed by either surface drainage, freshwater springs, or both.

The north side of the isthmus, the location of Pauleukalo Marsh and Kanaha Pond, consists of stream-transported sediments and beach material. The marshes have formed in coastal depressions. Kanaha Pond formed in weathered lava. During floods, freshwater overflows the wetland and the barrier ridge and discharges directly to the ocean (Cox and Gordon 1970). The beaches along the north side of Maui's isthmus are discontinuous and fronted by beachrock outcrops. Beachrock up to 790 ft offshore from the present beach indicates a general trend of erosion over the last few hundred years.

The south side of Maui's isthmus supports a 4 mi long, gently curved barrier beach which separates Kealia Pond from the ocean. Water level fluctuates seasonally, forming a 400-500 acre shallow, brackish pond in winter and spring, and exposing extensive red-brown mudflats in summer (Maciolek 1971). The wetland is slowly filling with stream-transported deposits of terrigenous material and wind-blown beach sands (Moberly et al. 1963). The pond's drainage outlet is periodically blocked by sand, but clears during heavy streamflows (Ahuimanu Productions 1977). The beach averages 75 ft wide, has occasional beachrock exposures along its length, and is backed by low dunes. The beach is composed of both terrigenous and calcareous material. Overall sand volume changes little from season to season and the beach appears stable in the long term, as measured from aerial photographs dating from 1900 (Moberly et al. 1963; B-K Dynamics, Inc. 1972).

Hawaii Island. Hawaii is the largest and youngest island of the State (Table 2), and has the longest coastline. However, because the island is so young and has little coral reef development, it supports the fewest sandy beaches (Table 3). Five major shield volcanoes built the island, two of which, Mauna Loa and Kilauea, are still active. Coastal features vary around the island depending upon the local history of volcanic eruptions, and the extent of lava flows, faulting, and erosion.

The windward coast of the Kohala peninsula contains a number of deep valleys that were originally cut during a lower stand of sea level. The lower floors of Pololu, Waimanu, and Waipio Valleys are now filled with stream-deposited sediments. The valley mouths are obstructed by bay mouth barriers that protect the wetlands behind them. There is some water interchange between the freshwater marshes and the ocean, either by tidal action, seepage of

freshwater through the bay barriers, or saltwater intrusion into the groundwater. Open-water ponds of various sizes are found in some of the wetlands (Moberly et al. 1963). The beaches are composed of well-sorted terrigenous deposits, indicating the abundant supply of stream-borne materials and consistent wave activity on this windward coast. Kohala peninsula experiences persistent rainfall as moist ocean air is forced up the windward side of the peninsula by the northeast tradewinds.

The west side of Hawaii is dominated by lava flows and fault zones. Small embayments formed between adjacent lava flows that project into the ocean may be enclosed by low beaches of unconsolidated calcareous and basalt sediments (Moberly and Chamberlain 1964). Small, shallow marshes and brackish ponds fed by subsurface freshwater inflow occur behind some of these barrier beaches. Some ponds have surface connections to the ocean, and others show evidence of storm washover and sand deposits in the ponds. These beach barriers and ponds were modified by ancient Hawaiians for use as fish ponds, but their use for aquaculture has been discontinued.

AMERICAN SAMOA

Geological Processes

Tutuila (Figure 3), the largest island (54 mi^2 in area and 2,100 ft high) in American Samoa, is the result of overlapping eruptions from five centers of volcanic activity. The original volcanic land mass was subsequently shaped by streamflows, valleys, wave attack on its shores, and fringing reef development along the coast. More recent volcanic activity covered many valleys and coastal features with lava. One of the later lava flows formed the Tafuna/Leone Plain on Tutuila's southeast side and extended into shallow waters. The changes in current patterns that occurred after this lava flow created a spit (Coconut Point), which partially encloses Pala Lagoon (Stearns 1944; Stice and McCoy 1968).

Coastal Materials and Processes

In general, the coastal materials and processes described for Hawaii also apply to the coastal barrier formations in American Samoa. However, wave, current, and tidal characteristics are not as well known for American Samoa. Tutuila is subject to occasional hurricanes that approach primarily from the north. Tsunamis also strike the island occasionally but do not affect the coast much outside Pago Pago Harbor. In this shallow harbor, the wave is accentuated, while on the steep slopes of the rest of the coast, the wave run-up is negligible (U.S. Army Corps of Engineers 1977, 1978; AECOS and Aquatic Farms 1980; Aquatic Farms and AECOS, n.d.).

Coastal Barrier Characteristics

Pala Lagoon on Tutuila Island is roughly circular, with an area slightly greater than 1 mi^2. Two-thirds of the lagoon is less than 5 ft deep, with a bottom of silty sand (Helfrich et al. 1975). Several springs and seven streams supply freshwater to the lagoon. Circulation within the lagoon and

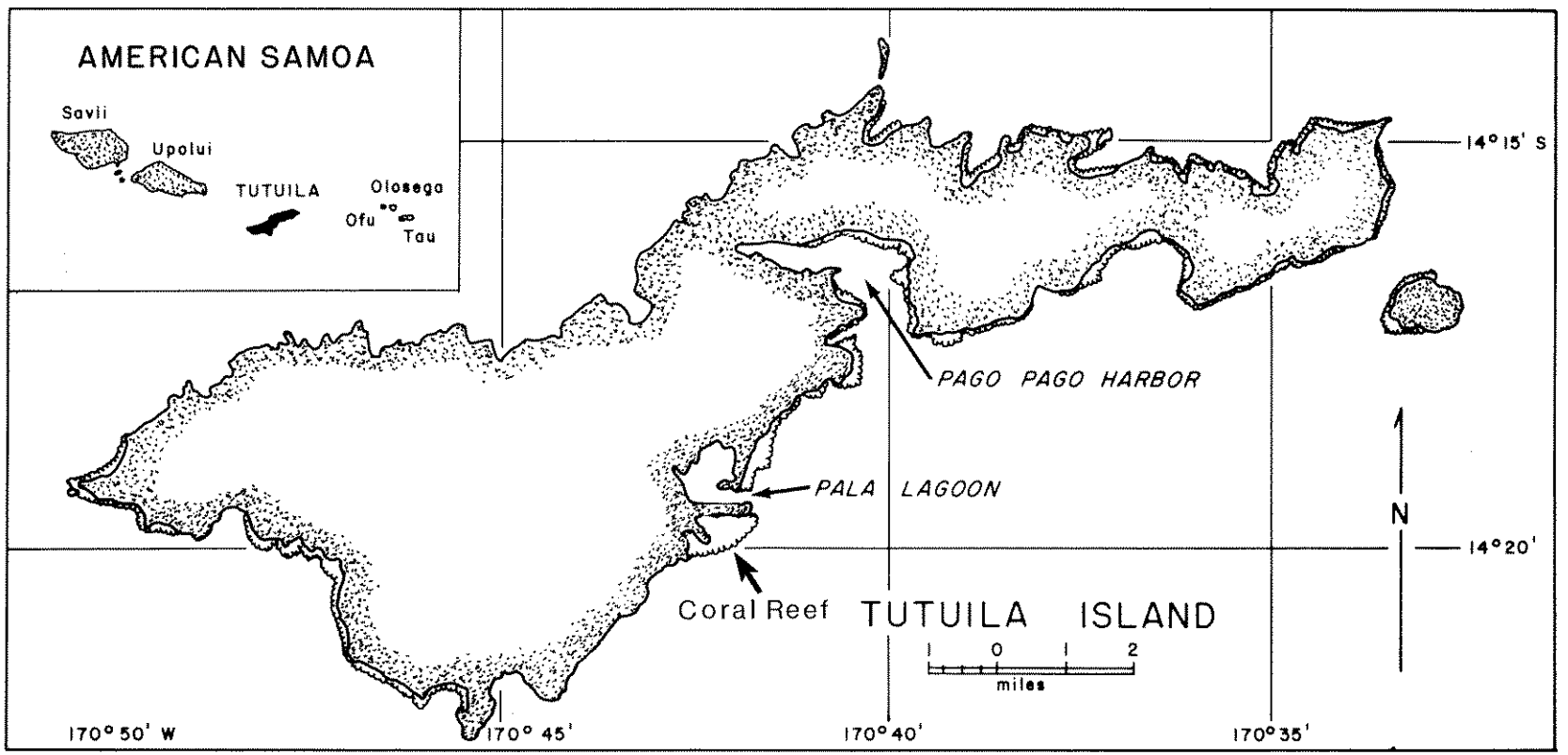


Figure 3. Tutuila Island in American Samoa.

tidal exchange with the ocean are restricted by the lagoon's narrow mouth (Stearns 1944; Helfrich et al. 1975). The lagoon is bounded by mangroves and rocky outcrops (north), airport runways (south), and residential areas and terrestrial vegetation (west) (AECOS and Aquatic Farms 1980; Aquatic Farms and AECOS, n.d.). On the east, Pala Lagoon is enclosed by Coconut Point, a 1 mi long, 200-1,000 ft wide natural sand spit with a seriously eroding ocean shoreline (Environmental Consultants, Inc. 1977; U.S. Army Corps of Engineers 1978). Outside the lagoon, a well-developed, 1,200-1,900 ft wide fringing reef fronts the barrier spit (AECOS and Aquatic Farms 1980; Aquatic Farms and AECOS, n.d.).

AN ECOLOGICAL EXAMINATION OF HAWAII AND AMERICAN SAMOA COASTAL BARRIERS

DESCRIPTION OF ECOSYSTEMS

Coastal barrier ecosystems in Hawaii have been classified by using the general categories described in Volume 1 of this report. These interrelated ecosystems are (1) coastal marine, (2) maritime, (3) estuarine, (4) freshwater (riverine, palustrine, lacustrine), and (5) coastal uplands. The coastal marine ecosystem begins just seaward of the beach dunes and extends 3 mi offshore. The maritime ecosystem consists of the land areas inland of the spring high-tide mark to the tidal marshes, creeks, or rivers, excluding wetlands and aquatic systems. This ecosystem can include dune communities behind the ocean beach, a zone of transitional shrub behind the dunes and bordering aquatic habitats, and a maritime forest that is exposed to marine influences, especially salt spray. The estuarine ecosystem consists of shallow-water tidal habitats and adjacent wetlands which are diluted by freshwater runoff and are open, partially open, or periodically connected to the ocean. Many different habitats, such as mud and sand flats, mangrove swamps, and tidal marshes are included in estuarine ecosystems. Freshwater ecosystems are defined by the U.S. Fish and Wildlife Service (Cowardin et al. 1979) as wetland systems with average salinities less than 0.5 parts per thousand. These ecosystems can contain a variety of habitats with considerable plant and animal diversity. Coastal uplands include all nonwetland areas inland of the estuarine and freshwater ecosystems.

Hawaii's coastal water ecosystems have been previously classified (Maragos 1975) according to physiography and water characteristics, and many portions of that classification scheme are applicable here. The coastal barrier environments common in Hawaii--bay barriers, barrier beaches, and beach barrier/fish ponds (Table 1)--are presented in schematic diagrams (Figures 4-6). The ecosystems, substrates, and vegetation commonly found in each coastal barrier type are shown in map view and along a hypothetical cross-section.

Coastal ecosystems in Hawaii and American Samoa, though similar to their continental counterparts, require special consideration because of their island nature. Because of the small land area, coastal watersheds often extend to the highest inland ridges. Also, oceanic and marine influences often extend far inland, especially during extreme weather conditions. Virtually all ecosystems in Hawaii and American Samoa are thus essentially coastal. In addition, these islands are isolated land masses where biological evolution has created endemic flora and fauna with special interactions between island species, and between the organisms and their physical environment.

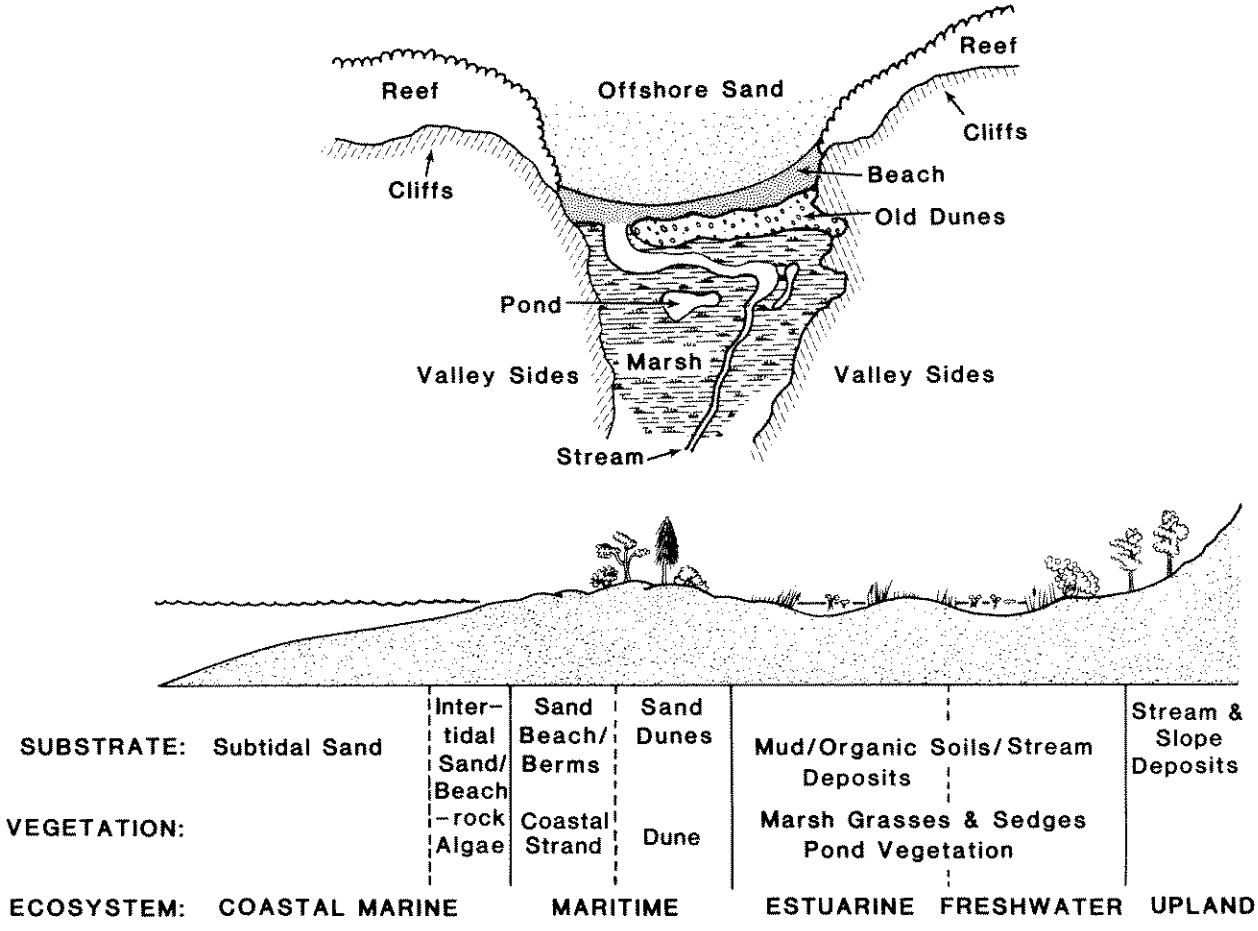
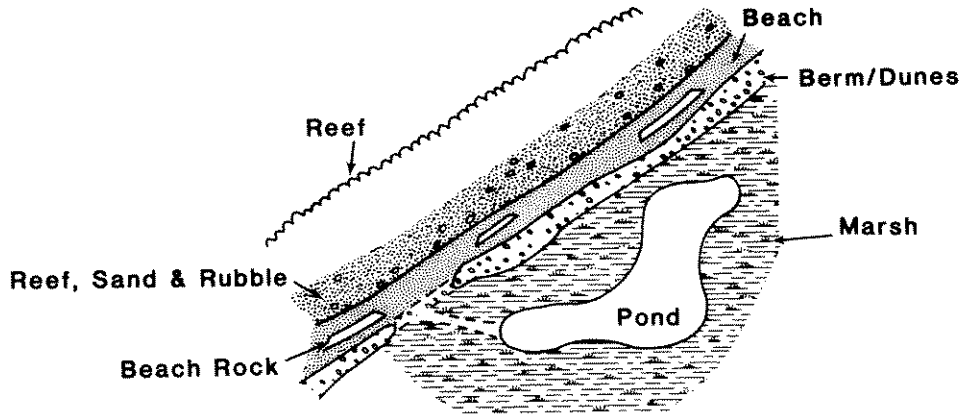


Figure 4. General schematic of coastal bay barrier ecosystems in Hawaii and American Samoa.



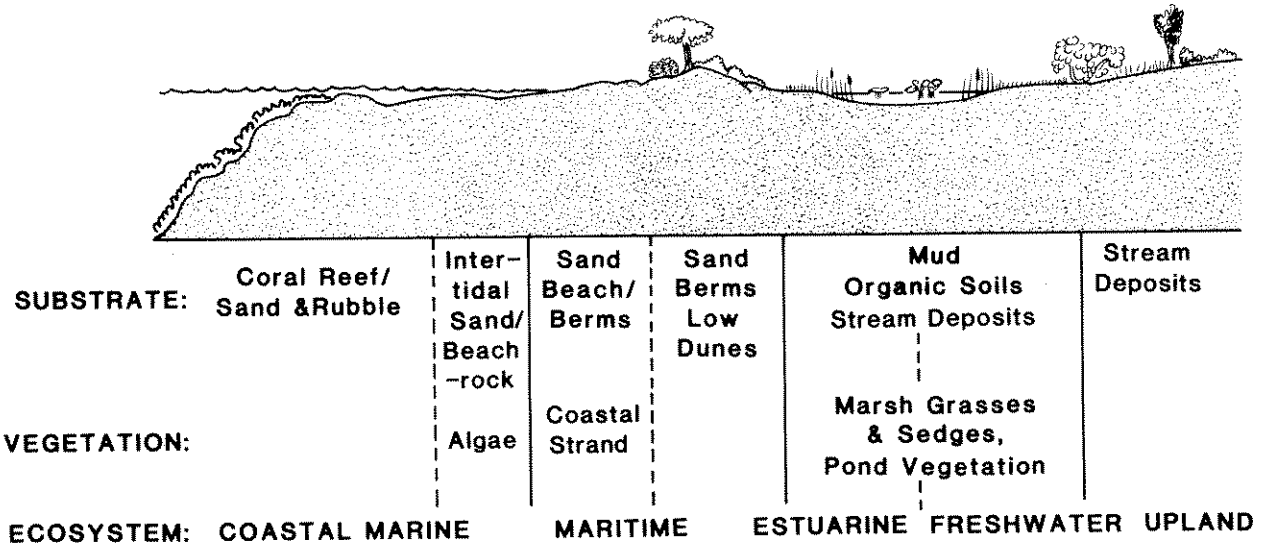


Figure 5. General schematic of coastal barrier beach ecosystems in Hawaii and American Samoa.

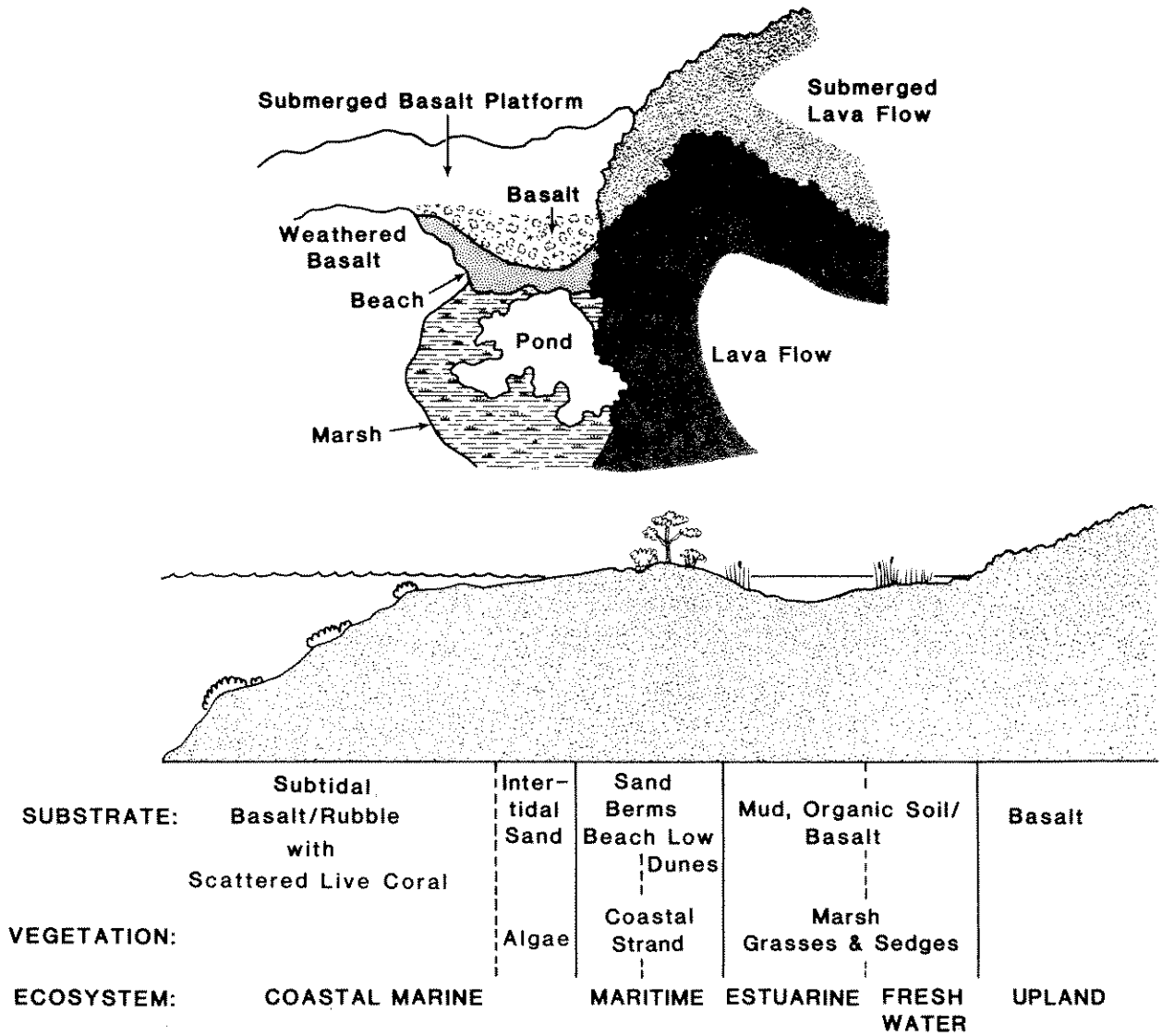


Figure 6. General schematic of coastal beach barrier/fish pond ecosystems in Hawaii and American Samoa.

Hawaii is 2,000 mi from other major land areas in any direction. The colonization of this isolated archipelago by limited numbers of plants and animals resulted in the evolution of many species which are only found there. This is especially true of the terrestrial and freshwater aquatic organisms. However, many Hawaiian habitats are becoming increasingly dominated by non-native plant and animal species that were introduced accidentally or intentionally. Although American Samoa has fewer endemic plants and animals, they may face a similar future. Federally listed endangered and threatened animal species and sensitive bird species and their associated coastal barrier ecosystems are shown in Table 5. Additional State of Hawaii listed endangered or threatened animal species are shown in Table 6. Plant species which are federally listed as endangered or threatened, or proposed for listing, and their associated coastal barrier ecosystems are shown in Table 7. The number of candidate plant species for Federal listing is shown in Table 8, and candidate invertebrate species are shown in Table 9.

Coastal Marine Ecosystem

Three major coastal marine habitats are associated with coastal barriers in Hawaii. These are coral reefs, sandy deposits, and submerged basalt platforms and slopes. Coral reefs are important to coastal barriers in Hawaii because they provide beach-forming sediments and shoreline protection. Coral reefs in Hawaii are not as spectacularly developed or biologically diverse as reefs further south and west in the Pacific (only 14 genera and subgenera of corals occur in Hawaii; Maragos 1975).

On Hawaii's reef platforms, the upper reef flat surface consists predominantly of sand, coral rubble, and coralline and fleshy benthic algae; there are few live coral or fish. Live corals are not abundant components of reef flats presumably because of high or fluctuating water temperatures, heavy surf, and fluctuating salinities (Maragos 1975). Only one species of seagrass is found in Hawaii, and extensive seagrass beds do not occur. Flourishing live coral communities, often dominated by Porites species (particularly Porites compressa) with abundant invertebrates and large, diverse fish assemblages, are found on reef slopes, especially on protected and leeward coasts.

Reef-building corals contain symbiotic algae which allow the coral colony to use solar energy to more rapidly construct its calcium carbonate skeleton, the major part of the reef framework. Coralline algae, the second major contributors to the reef framework, also harness solar energy to photosynthesize and lay down layers of calcium carbonate. Corals grow best in shallow, warm, clear waters. Freshwater runoff, with its increased turbidity and decreased salinity and temperature, inhibits coral growth, although the runoff may also add nutrients to the system. Excessive sedimentation on reefs is detrimental to corals through direct smothering, decreased light penetration, and covering of hard substrate which juvenile corals need to settle and start new colonies.

Most reef organisms, including corals, other invertebrates (e.g., sea urchins, clams, sea snails, sea cucumbers), and reef fish, have larval stages. In these stages, the tiny, drifting animals feed on smaller plankton and, in turn, are eaten by many reef organisms, including filter-feeding invertebrates. Reef fish include both herbivores and carnivores in a diverse

Table 5. Federally listed endangered or threatened animal species, and sensitive bird species of coastal barrier ecosystems in Hawaii and American Samoa.[a]

	Coastal marine	Maritime	Estuarine	Fresh-water	Upland
HAWAII					
FISHES (0)					
None					
REPTILES AND AMPHIBIANS (4)					
Turtle, green sea	x	x			
Turtle, leatherback sea	x				
Turtle, loggerhead sea	x				
Turtle, olive (Pacific) Ridley	x				
INVERTEBRATES (1)					
Snail, Oahu tree					x
BIRDS (30)					
Akepa, Hawaii (honeycreeper)					x
Akepa, Maui (honeycreeper)					x
Akialoa, Kauai (honeycreeper)					x
Akiapolaau					x
Coot, Hawaiian (= Alae keokeo)			x	x	
Creeper, Hawaii					x
Creeper, Molokai (= Kakawahie)					x
Creeper, Oahu (= alauwahio)					x
Crow, Hawaiian ('alala)					x
Duck, Hawaiian (koloa)			x	x	x
Duck, Laysan		x	x		
Finch, Laysan (honeycreeper)		x			x
Finch, Nihoa (honeycreeper)		x			x
Gallinule, Hawaiian (moorhen)			x	x	
Goose, Hawaiian (nene)					x
Hawk, Hawaiian (Io)					x
Honeycreeper, crested (= 'akohekohe)					x
Millerbird, Nihoa (old world warbler)		x			x
Nukupu'u (honeycreeper)					x

(continued)

Table 5. Continued.

	Coastal marine	Maritime	Estuarine	Fresh-water	Upland
'O'o, Kauai (= 'O'o 'A'a) (honeyeater)					x
'O'u (honeycreeper)					x
Palila (honeycreeper)					x
Parrotbill, Maui (honeycreeper)					x
Petrel, Hawaiian dark-rumped	x				x
Petrel, sooty storm[a]	x	x			x
Po'ouli (honeycreeper)					x
Shearwater, Newell's (Townsend's, formerly Manx) (= 'A'o)	x				x
Stilt, Hawaiian (= Ae'o)			x	x	
Thrush, large Kauai					x
Thrush, Molokai (= oloma'o)					x
Thrush, small Kauai (= puaiohi)					x
MAMMALS (9)					
Bat, Hawaiian hoary			x		x
Seal, Hawaiian monk	x	x			
Whale, blue	x				
Whale, finback	x				
Whale, gray	x				
Whale, humpback	x				
Whale, right	x				
Whale, Sei	x				
Whale, sperm	x				
AMERICAN SAMOA					
REPTILES AND AMPHIBIANS (2)					
Turtle, green sea	x	x			
Turtle, hawksbill	x				
BIRDS (4)					
Duck, Australian gray[a]	x	x	x		
Shrikebill, Fiji[a]				x	x
Dove, friendly quail[a]				x	x
Dove, many-colored fruit[a]				x	x

(continued)

Table 5. Concluded.

	Coastal marine	Maritime	Estuarine	Fresh-water	Upland
MAMMALS (2)					
Whale, humpback	x				
Whale, sperm	x				

[a]Sensitive bird species are those species, subspecies, or populations that could become Federally listed as endangered or threatened without active management or removal of threats.

Table 6. State of Hawaii listed endangered or threatened animal species (which are not federally listed), the major island for which they are listed, and their associated coastal barrier ecosystems.

Birds	Island listed	Coastal marine	Maritime	Estuarine	Fresh-water	Upland
Band-rumped (Hawaiian) storm petrel	Kauai	x				x
Hawaiian owl	Hawaii, Maui, Molokai					x
Fairy Tern	Oahu, Lanai	x	x			
Maui amakihi	Maui, Molokai					x
Oahu iiwi	Molokai, Oahu					x

Table 7. Plant species federally listed, or proposed for listing, as endangered or threatened in coastal ecosystems in Hawaii and American Samoa.

	Coastal marine	Maritime	Estuarine	Fresh-water	Upland
HAWAII					
Taxa listed as endangered:					
Vicia menziesii Spreng.					x
Haplostachys haplostachya var. angustifolia (Sherff) St. John					x
Stenogyne angustifolia Gray var. angustifolia					x
Lipochaeta venosa Sherff					x
Kokia cookei Deg.					x
Euphorbia skottsbergii var. kalaeloana Sherff		x			
Panicum carteri Hosaka		x			
Bidens cuneata Sherff					x
Schiedea adamantis St. John					x
Gouania hillebrandii Oliver					x
Kokia drynarioides (Seem.) Lewt.					x
Gardenia brighamii Mann					x
Taxa proposed for listing:					
Achyranthes splendens var. rotundata Hbd.		x			
Argyroxiphium sandwichense var. sandwicense (DC.) Hbd.					x
Santalum freycinetianum var. lanaiense Rock					x
Hibiscadelphus distans Bishop and Herbst					x
Abutilon menziesii Seem.		x			
Scaevola coriacea Nutt.		x			
Menzoneuron kavaiense (Mann) Hbd.					x
AMERICAN SAMOA					
None listed, none proposed					

Table 8. Number of candidates for Federal listing as endangered and threatened plants in Hawaii (U.S. Department of the Interior 1985).

Official listing category[a]	Significance of category	Number of taxa listed
1	Total taxa considered appropriate for listing as endangered or threatened.	423
1*	Category 1 taxa which are possibly extinct.	132
1**	Category 1 taxa believed to be extinct in the wild, but which occur as cultivated plants.	1
2	Taxa possibly appropriate for listing as endangered or threatened, but for which sufficient information is not available.	192
3	Taxa no longer being considered for listing as endangered or threatened	
3A	Taxa for which there is evidence of extinction.	46
3B	Taxa which do not quality as species.	135
3C	Taxa which are more abundant or less threatened than considered before.	75

[a]Categories follow those used in U.S. Department of the Interior (1985).

Table 9. Number of candidates for Federal listing as endangered and threatened invertebrates in Hawaii (U.S. Department of the Interior 1984).

	Official listing category[a]		
	2	3A	3C
Amphipods (Crustaceans, Order Amphipoda)	1		
Spiders (Arachnids, Order Pseudoscorpiones)	1		
Rockhoppers and bristletails (Insects, Order Archeognatha)	2		
Dragonflies and damselflies (Insects, Order Odonata)	12	1	
Grasshoppers, crickets, and katydids (Insects, Order Orthoptera)	7	1	
Zorapterans (Insects, Order Zoraptera)	1		
True Bugs (Insects, Order Hemiptera)	23	1	
Cicadas and allies (Insects, Order Homoptera)	15		
Lacewings and allies (Insects, Order Neuroptera)	6		
Beetles (Insects, Order Coleoptera)	16		
Flies (Insects, Order Diptera)	1	3	
Butterflies and moths (Insects, Order Leptidoptera)	20	20	1
Ants, bees, and wasps (Insects, Order Hymenoptera)	53	17	
Snails (Mollusks, Class Gastropoda)	2	1	

[a]See Table 8 for definitions.

assemblage. Reef organisms, which spend their adult lives around the reef, are also preyed upon by oceanic fish, which remove reef biomass to the offshore ecosystem.

Shifting marine sand deposits often extend offshore from coastal barriers (Figure 4). Sand bottom subtidal communities are generally dominated by mollusks, including cones (Conus spp.), mitres (Terebra spp.), and pen clams (Pinna spp.; Maragos 1975). Patches of subtidal algae become established on stable sand deposits. Some coastal barriers on the west side of the island of Hawaii have shallow basalt platforms and slopes of recent lava flows just offshore (Figure 6). These wave-and surge-exposed habitats are usually sparsely occupied by sturdy corals (especially Pocillopora meandrina), algae, and a limited assemblage of reef fish (Nolan and Cheney 1981; ORCA, Ltd. et al. 1981). In protected areas, well-developed coral communities may become established on the lava. Coral communities are destroyed where lava flows enter the sea, and take decades to recover (Grigg and Maragos 1974).

Adult green sea turtles (Chelonia mydas) feed and rest in coastal waters around the major Hawaiian islands (Balazs 1980). Other threatened or endangered sea turtles (leatherback, loggerhead, and olive Ridley) occur in Hawaiian waters. Many of the world's endangered whales (blue, finback, gray, humpback, right, sei, and sperm) also are found offshore from Hawaii. The endangered Hawaiian monk seal is established in the Northwestern Hawaiian Islands National Wildlife Refuge, but does not occur around the main islands.

Maritime Ecosystem

The maritime ecosystem in Hawaii, between the high-tide line and the inland aquatic habitat, occupies a narrow zone relative to the other ecosystems. The maritime environment is characterized by salt spray, constant wind, low rainfall, intense sunlight, high evaporation, high temperatures, and shifting sands (Tabata 1980). Exposed beaches are inhabited by decapod, amphipod, and isopod crustaceans, mollusks (Terebra spp.), and polychaete worms (Maragos 1975). Richmond and Mueller-Dombois (1972) recognized thirteen coastal ecosystem classes based on dominant plant species and landform. The distribution of the ecosystems is broadly related to rainfall and drought patterns. The zonation of maritime plants in the coastal strand is controlled by exposure to wind and surf, and by soil and water salinity.

Bay mouth barrier systems, such as Lumahai Valley and Waimea Bay, may have seasonally shifting sands. Vegetation in these areas is restricted to stable sand berms or ridges behind the active beach. The vegetation helps to trap sand and stabilize these areas. Some bay barriers, such as Waimanu Bay and Waipio Bay, have a narrow band of low, older, vegetated dunes behind the beach. Dune vegetation generally consists of Hawaiian coastal strand plants, such as Scaevola, Messerschmidia, and Ipomea (Moberly and Chamberlain 1964). Among the native coastal flora, a number of species are indigenous and relatively common in certain localities (Tabata 1980). However, of the 12 federally listed endangered plants in Hawaii, 2 occur in the maritime ecosystem; and of the 7 plants proposed for listing as endangered, 3 are found in maritime sites (Table 7).

Well-developed dunes are found behind the barrier beach at Kahuku on the northernmost shore of Oahu. Other barrier beaches such as those on Maui and those fronting former fish ponds on the west coast of Hawaii, have narrow beaches with low backshore berms and coastal strand vegetation. Protected bay mouth coastal barrier units usually have wide, low-profile beach berm systems, often with introduced plants (Nolan and Cheney 1981). True maritime forests do not occur in Hawaii, although some beaches have stands of introduced Casuarina pines behind the beach berms. The vegetation of strand and dune areas is host to a number of small lizards, but little is known of the other terrestrial animals which inhabit these areas. Various seabirds and shorebirds make use of the coastal dune and strand vegetation for roosting and nesting. Green sea turtles formerly nested on many sandy beaches throughout the archipelago. There is still major nesting in the uninhabited Northwestern Hawaiian Islands; however, a nest is rarely reported from a beach in the inhabited main islands.

Estuarine Ecosystem

In Hawaii, most aquatic habitats that fit the U.S. Fish and Wildlife Service definition of estuaries (Cowardin et al. 1979) are associated with streams. Most of these estuaries occur on Kauai and Oahu; very few are found on Hawaii. Using broad definitions of an estuary, Cox and Gordon (1970) identified as many as 50 estuaries in the State.

Coastal barrier estuarine habitats in Hawaii include shallow, brackish, and tidally influenced stream mouths, their periodically flooded marsh and grass lands, and associated small ponds (Figure 4). Ponds and marshes behind barrier beaches (Figure 5) form estuaries. Former fish ponds, which have open, partially obstructed, or sporadic connections with the sea are also considered estuarine (Figure 6). Thus, nearly all the aquatic habitats associated with coastal barriers in Hawaii include estuarine components which merge into freshwater ecosystems further inland. Estuaries are generally highly productive ecosystems because high concentrations of organic nutrients are trapped within them by physical and biological processes. Much of this productivity contributes to the large amount of organic detritus in estuaries. This material supports large populations of detritivores, which, in turn, are fed upon by higher animals. A variety of waterbirds share the resources of estuaries by feeding on the plants, invertebrates and fish.

The vegetation of estuaries in Hawaii (Elliott and Hall 1977) is heavily influenced by exotic species, such as the water hyacinth (Eichornia crassipes), which is found in pond waters. Pond edges and wetter areas are often occupied by sedges and bulrushes, such as endemic Cladium and Scirpus, and Cyperus (which has both indigenous and exotic species). Marshlands are dominated by indigenous grasses, such as Bacopa and Sesuvium, and introduced species, such as Paspalum and Brachiaria mutica (California grass). Mudflats are often covered by introduced pickleweed (Batis maritima). The edges of the estuaries are often lined by indigenous hau trees (Hibiscus tiliaceus), but introduced mangrove (Rhizophora mangle) is beginning to spread in some wetlands. Taro (Colocasiaes culenta) was introduced prehistorically. It was formerly grown in many Hawaiian stream wetlands, and is currently cultivated in other wetlands associated with coastal barriers.

Faunal diversity in Hawaiian estuaries is relatively low compared to continental situations; however, many of the organisms are endemic (Maragos 1975). Most estuarine species in Hawaii are adapted to a wide range of salinity and are derived from marine rather than freshwater ancestors (Maragos 1975). Estuaries harbor native species of fish, prawns, and mollusks, and serve as nurseries for many inshore marine fish. Introduced animals such as Tilapia, mosquitofish, frogs, and crayfish are also found in estuarine ecosystems. Some of these exotic species may depress populations of native species by predation, competition, and alteration of the habitat.

Estuaries in Hawaii play an important role in providing feeding grounds and nesting habitat for resident and migratory waterbirds. Wetlands are particularly important for the endemic waterbirds which are federally listed as endangered: the Hawaiian stilt (Himantopus himantopus knudseni), Hawaiian coot (Fulica americana alai), Hawaiian gallinule (Gallinula chloropus sandvicensis), and the Hawaiian duck (Anas wyvilliana) (Ahuimanu Productions 1977). The black-crowned night-heron (Nycticorax nycticorax hoactli) is not federally listed as endangered, but it is protected by migratory bird treaties and State regulations. The estuarine habitats used by endangered birds must not only supply their feeding and nesting requirements, but must also provide sufficient isolation from human disturbance and protection from introduced predators such as cats, dogs, rats, and mongooses.

Freshwater Ecosystem

A number of the wetlands behind coastal barrier beaches are spring-fed, have no surface connection to the ocean, and may be considered as freshwater systems. The flora and fauna of these marshes and ponds is similar to the inland portions of estuaries, which are also freshwater environments (Maragos 1975).

Streams are Hawaii's principal freshwater habitat. Three types of streams are found in Hawaii: (1) ephemeral streams, which carry water only during and immediately after rain, (2) intermittent streams, which carry water part of the year but are dry the rest of the year, and (3) perennial streams, which flow throughout the year. Approximately 336 perennial streams have been identified in the five major Hawaiian islands (Timbol and Maciolek 1978). These are subdivided into continuous streams of year-round discharge and interrupted streams with perennial upper courses but seasonal ocean discharge (Maragos 1975).

The native fauna of Hawaii's streams are limited in diversity and are particularly adapted to the rocky, precipitous, rapidly flowing nature of the streams. All native species of stream macrofauna are diadromous (having marine larval development) as a result of their recent evolution from oceanic ancestors and partial adaptation to freshwater life. Each year these animals release large numbers of planktonic larvae into nearshore waters (Maciolek 1971). Hawaii's native freshwater fauna include five fish species, all of which are gobies. Some of these were important in traditional Hawaiian diet and culture (Titcomb 1972). Four of them, Awaous stamineus, Eleotris sandwicensis, Sicyopterus stimpsoni, and Lentipes concolor, are endemic, and one, Stenogobius genivittatus, is indigenous. Other native freshwater

macrofauna include two mollusks, Neritina granosa (endemic) and a Melanoides (=Melania) sp. (indigenous), and two endemic crustaceans, Atyoida bisulcata and Macrobrachium grandimanus (Parrish et al. 1978; Timbol and Maciolek 1978). In addition to the native animals of freshwater ecosystems, at least 27 introduced aquatic species, most of which are successful competitors or predators, have become established in Hawaii's streams (Parrish et al. 1978).

Upland Ecosystem

Inland watershed boundaries for coastal drainage basins generally extend to the highest central ridges of each island. Therefore, nearly all the land area in Hawaii is within the coastal zone and is interrelated both physically and ecologically (Maragos 1975).

The upland portions of coastal barriers generally contain disturbed forests dominated by introduced flora and fauna. However, in remote areas and at higher elevations, native forests containing many of Hawaii's endangered plants (Table 7) may still be found. These forests are home to Hawaii's rare and endangered native forest birds (Tables 5 and 6). The only federally listed endangered invertebrates in Hawaii are the approximately 40 species of Oahu tree snails (Achatinella spp.), which are found in upland forests. There are 160 species of other invertebrates that are Category 2 candidates for Federal listing as endangered or threatened (Table 9); 47 of these may already be extinct. These candidate species may occur in maritime, estuarine, freshwater, and/or upland ecosystems; their distribution is only partially compiled for Hawaii.

FISH AND WILDLIFE VALUES OF INDIVIDUAL ISLANDS

Hawaii

Kauai Island. The coastal barriers of Kauai consist primarily of bay barriers with estuarine wetlands fed by continuous or interrupted streams (AECOS, Inc. 1982; Manoa Mapworks 1983). The relatively undisturbed lower Wainiha and Lumahai Streams are among the few that still have an abundance of native freshwater gobies (Timbol and Environmental Impact Study Corp. 1977; Wilson Okamoto and Associates, Inc. 1981). One species (Awaous stamineus) migrates downstream to spawn, where it is an important fishery resource. Two native freshwater gobies, are abundant and three are less abundant in the Hanalei River (Timbol and Environmental Impact Study Corp. 1977). Fishes inhabiting the estuarine streams of northeastern Kauai include flagtails (Kuhliidae), mullet (Mugilidae) and introduced Tilapia (AECOS, Inc. 1982).

The estuaries at Wainiha and Lumahai Streams are considered primary waterbird habitat, providing nesting and/or feeding for all the endangered Hawaiian waterbirds (Ahuimanu Productions 1977). Nearby Hanalei Valley, is also a primary waterbird area. A National Wildlife Refuge has been established in the wetlands inland from these coastal barriers to secure the habitat for the endangered Hawaiian waterbirds which feed and nest there (Ahuimanu Productions 1977). The streams and estuaries of the coastal barriers along northeast Kauai provide cover and feeding habitat for all the endangered native

waterbirds (Ahuimanu Productions 1977). Most of the coastal barrier sites on Kauai are also used by migratory waterfowl and shorebirds (Ahuimanu Productions 1977).

Niihau Island. The coastal barrier units of Niihau consist of barrier beach and dune systems which separate what are essentially coastal lagoons from the ocean (Cox and Gordon 1970). The dunes are well-developed and vegetated on the Kaununui and Leahi barriers. Much of the coastal plain surrounding the lakes and lagoons is used for cattle grazing. The lagoons themselves are fringed with introduced pickleweed (Batis maritima) and contain mullet that die off when the lagoons seasonally dry up (U.S. Fish and Wildlife Service, n.d.). The lagoon wetlands provide habitat for the Hawaiian stilt, Hawaiian coot, Hawaiian duck, and other duck species. Niihau's wetlands support one-fifth to one-sixth of the entire Hawaiian stilt population and are believed to provide seasonal habitat for many of the stilts from Kauai (U.S. Fish and Wildlife Service, n.d.).

Oahu Island. A variety of coastal barrier types are found on Oahu and they support various fish and wildlife resources. The lower estuarine reaches of Waimea Stream contain Tilapia, mullet, and milkfish (Chanos chanos) (AECOS, Inc. 1979a, 1981). The wetland, which forms when the stream is seasonally impounded behind the bay barrier, provides marginal endangered waterbird habitat (Ahuimanu Productions 1977). The wetlands at Kahuku are identified as primary habitat for endangered Hawaiian waterbirds (U.S. Fish and Wildlife Service 1978). Portions of these wetlands have been set aside as a National Wildlife Refuge (Ahuimanu Productions 1977). These wetlands are used by numerous migratory waterbirds and the Laysan albatross. The dunes along the shore at Kahuku contain some native Hawaiian strand vegetation which is not common along most of Oahu's highly altered shoreline. Endangered green sea turtles are thought to nest occasionally on the beach at Kahuku, probably the only site on Oahu where this occurs.

The extensive estuary of Kahana ranked high in a survey conducted to select a National Estuarine Sanctuary (Ahuimanu Productions 1977) because it is one of the least disturbed natural estuaries in Hawaii. However, it is of limited significance (and rated secondary) as waterbird habitat (U.S. Fish and Wildlife Service 1978). The estuary's macrofauna includes the native prawn and native fishes (Maciolek 1972; Timbol 1972). Introduced mangroves are encroaching along the lower shores of Kahana estuary and around the fish ponds at Nuupia (Ahuimanu Productions 1977; Elliott and Hall 1977). The interconnected ponds at Nuupia contain both exotic and native fishes characteristic of waters with variable salinity (AECOS, Inc. 1979a, 1981). Macroinvertebrates at Nuupia include the introduced oyster (Crassostrea virginica) and assorted crustaceans (grapsid and portunid crabs and shrimp) (AECOS, Inc. 1979a). The ponds provide nesting and feeding habitat for the Hawaiian stilt, black-crowned night-heron, and Hawaiian duck (Ahuimanu Productions 1977), and have been rated as primary Hawaiian waterbird habitat (U.S. Fish and Wildlife Service 1978). Migratory waterfowl and shorebirds also make use of the aquatic habitats associated with coastal barriers on Oahu (Ahuimanu Productions 1977).

Maui Island. Ponds associated with the coastal wetlands located behind the barrier beaches on Maui's north-central shore contain Tilapia and mosquitofish. An abundant variety of small invertebrates (shrimp, snails, aquatic insects) are found on the bottoms of these ponds and on their vegetation. Bullfrogs occur around pond edges (AECOS, Inc. 1979b, 1979c). Kanaha Pond is primary nesting and feeding habitat for Hawaiian waterbirds. It is of critical value for the Hawaiian stilt and is also important for the Hawaiian coot and the black-crowned night-heron (Ahuimanu Productions 1977). Kanaha Pond is the most valuable single habitat for wintering waterbirds in Hawaii and is also used by some of the less common species of migratory shorebirds (Ahuimanu Productions 1977).

The shallow waters and mudflats of Kealia Pond provide valuable habitat for resident and migratory waterbirds. The pond has been designated as primary habitat for Hawaiian waterbirds, especially the endangered Hawaiian stilt and coot and the black-crowned night-heron (U.S. Fish and Wildlife Service 1978). The Hawaiian owl is also apparently a regular inhabitant (Ahuimanu Productions 1977). The pond contains native macrofauna such as milkfish (Chanos chanos), mullet (Mugil sp.), and prawn (Macrobrachium grandimanus), but it is dominated by introduced species, especially Tilapia and the Malaysian prawn, the latter of which has spread from nearby aquaculture facilities (AECOS, Inc. 1979b, 1979c). During low-water periods, the fauna concentrate in the reduced pond, providing an important feeding ground for the waterbirds.

Hawaii Island. Coastal barrier habitats on the island of Hawaii can be separated into two groups: (1) those associated with the drowned river valley and bay mouth barrier systems on the east coast of Kohala peninsula, and (2) the aquatic habitats enclosed by beach barriers on the west side of the island, which were converted into fish ponds by the ancient Hawaiians. Pololu, Waimanu, and Waipio Valleys have aquatic fauna typical of stream and estuary ecosystems in Hawaii, including mullet, gobies, milkfish and other native Hawaiian fishes. Exotic mosquitofish and Tilapia occur in the streams and in wetland ponds. Frogs and toads occur around pond edges. Melanoides and other freshwater snails, native shrimp and prawns, and introduced prawns are also found in the streams and ponds of these areas (Ahuimanu Productions 1977). The wetlands of these three coastal barriers have been identified as habitats of secondary importance for Hawaiian waterbirds (U.S. Fish and Wildlife Service 1978). The endangered Hawaiian coot and duck and the black-crowned night-heron are all known to use these habitats for feeding and nesting (Ahuimanu Productions 1977).

The beach barrier/fish ponds on the west coast of Hawaii Island are divided into those with surface connections to the sea and those without such connections. This western coastal region has no perennial streams and very little rainfall; the wetlands permit pockets of high productivity to persist in otherwise barren areas. Common fish in these aquatic habitats include the introduced Tilapia and mosquitofish, as well as mullet, barracuda, flagtails, and other small fish species (Brock and Brock 1974; Maciolek and Brock 1974; Madden and Paulsen 1977).

Wainanalii Pond, with its open connection to marine waters, has varying salinities. The sea anemone Aiptasia, the rock oyster Isognomon costellatum,

the mussel Brachidontes, and the hoof shell Hipponix are all common in this pond (Kay et al. 1977). The coastal barrier wetlands at Aimakapa and Opae Ula have been identified as primary waterbird habitat (U.S. Fish and Wildlife Service 1978). They are especially critical nesting and feeding locations for the endangered Hawaiian stilt and coot, and also provide feeding grounds for the black-crowned night-heron. Both areas are also major migratory waterfowl and shorebird habitat during winter months (Ahuimanu Productions 1977).

American Samoa

Tutuila Island. The northern and eastern shores of Pala Lagoon are bordered by 84 acres of mangrove, the largest mangrove area in American Samoa. The mangrove forest consists mainly of Bruguiera gymnorhiza, but also contains Xylocarpus moluccensis, which is relatively rare on Tutuila (Whistler 1976). The mangrove crab (Scylla serrata) is found in abundance, and the Australian grey duck (Anas supercilliosa pelewensis), a resident waterbird, also uses the mangrove habitat (AECOS and Aquatic Farms 1980). The lagoon is considered an important nursery and spawning ground for fish and invertebrates, and the threatened green sea turtle (Chelonia mydas) is reported in small numbers (AECOS and Aquatic Farms 1980). Diverse benthic communities of seagrasses (including one found only rarely on Tutuila), algae, corals, other invertebrates, and fishes occur in various assemblages throughout the lagoon (Helfrich et al. 1975; AECOS and Aquatic Farms 1980; Aquatic Farms and AECOS, n.d.). An uncommon shrub, Sophora tomentosa, occurs on the barrier spit at Coconut Point. The fringing reefs outside Pala Lagoon support a flourishing reef community, except where human disturbance, especially dredging, has occurred.

HUMAN ACTIVITIES AFFECTING BARRIERS

Because the entire land mass of each island in Hawaii and American Samoa is within the coastal zone, human activities throughout the islands have the potential of affecting coastal barriers. Human activities that alter coastal barrier processes are especially likely to result in many direct and indirect effects on coastal ecosystems (AECOS, Inc. 1979a, 1979b, 1982; AECOS and Aquatic Farms 1980; Nolan and Cheney 1981). The discussion of human activities affecting coastal barriers will be based on the ecosystems previously described.

Coastal Marine Ecosystem

Coral reefs and their diverse biological communities are subject to many forms of use, degradation, and destruction. Some nonconsumptive, recreational uses of reefs can be benign, but they also have the potential to degrade reef habitats. Potentially destructive activities include board and body surfing, wading (in which live coral may be trampled), outrigger canoeing, SCUBA diving and snorkeling (when it includes collecting souvenir corals), and boating. Some of these activities, especially boating, require substantial shore facilities. In addition, boats may cause water pollution from engine, bilge, and toilet discharges, and may damage corals when travelling through shallow waters and during anchoring.

Renewable use of coral reef resources involves removal of portions of the biotic community on a potentially sustainable yield basis. In Hawaii and American Samoa, fishing is a major reef use ingrained in the local culture. Reef fishing involves various forms and methods, including fishing from boats, trapping, gill netting, throw netting, spear fishing, shore casting, octopus hunting, and shellfish and other invertebrate harvesting (AECOS, Inc. 1979a, 1979b, 1982; AECOS and Aquatic Farms 1980; Government of American Samoa 1979; Nolan and Cheney 1981). In addition, a variety of edible seaweeds are collected for home and commercial use. Other uses that are potentially sustainable include the taking of reef organisms for scientific and medical research, and the harvest of aquarium fish, shells, and ornamental corals for personal collections or sale. The overharvest of any organism has negative impacts on that particular plant or animal population and affects the other components of the reef community as well. The removal of corals, which live very long, are slow to regenerate, and are essential to the physical reef structure, has especially deleterious effects on the entire reef community.

Consumptive uses of coral reefs mainly involve the extraction of nonrenewable reef materials, such as reef rock or sand, for use in construction or as fill. Coral reefs are also dredged to create channels and harbors. This not only directly removes reef material, but also impacts adjacent reef communities through altered current patterns and the generation of suspended sediments that reduce light penetration and smother benthic organisms. The construction of jetties and causeways across reefs (and the building of fish ponds in the past) also produces indirect effects, such as alteration of current and sedimentation patterns.

Finally, coral reefs, which require clean, clear, well-lit water, are seriously threatened by intentional and unintentional discharge of a variety of substances into nearshore waters from both point and nonpoint sources. When watersheds are disturbed, the result is often an increased runoff of terrestrial sediments onto coral reefs. Urbanization and stream channelization may also lead to significantly increased freshwater runoff. Agricultural and industrial activities may introduce pesticides, herbicides, fertilizers, sugar cane and other agricultural product wastes, miscellaneous chemicals, oil, and solid wastes into coral reef waters. Power plants and sewage treatment plants discharge thermal and municipal waste effluent, and dredge spoils may be dumped in reef areas.

Maritime Ecosystem

Accessible beaches and dunes in Hawaii are subject to intensive human use and are a major attraction for Hawaii's millions of tourists. The beaches provide recreation or access to recreation for sunbathers, surfers, fishermen, beachcombers, campers, and small boat users. Use by these groups often involves altering the natural environment with access roads, parking lots, public conveniences, concession facilities, boat ramps, and parks. Most of these uses involve conversion and construction in the backshore area, but some facilities are built right on the beaches and eventually require protection against severe or prolonged beach erosion. The construction of beachfront houses, hotels, and resorts has caused major alterations of many coastal barrier beaches, especially on Oahu. Many of these developments now require

structural shoreline protection structures or beach nourishment to prevent loss of property by erosion.

Off-road recreational vehicles have a particularly deleterious effect on maritime ecosystems. Four-wheel drive vehicles, dune buggies, and motorbikes have a major impact on the dunes, beach berms, and beaches of Hawaii, especially where native maritime vegetation still exists. Many dune areas in Hawaii are now vegetated by non-native plants which contribute to their stability but have replaced native vegetation. This invasion of introduced plants generally occurs in areas disturbed by human activities. Aggressive introduced plants (for example, Leucaena, Pluchea, and Prosopis) dominate many coastal areas (Tabata 1980). However, in Scaevola ecosystems, the native strand flora is able to persist, except under extremely disturbed conditions (Richmond and Mueller-Dombois 1972). The sand on a number of the coastal barriers has been mined in the recent past, although there is no such activity at present (Moberly and Chamberlain 1964).

Coral reefs provide calcareous sediment for coastal barrier beaches and dunes from the continuous breakdown of dead coral and other calcium carbonate producing organisms. However, the large-scale degradation or death of reef communities reduces the reef's ability to generate sediment and nourish beaches. Changes in coral reefs may also change current patterns, resulting in increased beach erosion or decreased sand deposition.

Estuarine Ecosystem

Wetlands and streams associated with coastal barriers in Hawaii are subject to a variety of human activities which alter them to different degrees (Ahuimanu Productions 1977; Elliott and Hall 1977). Uses which are potentially sustainable include small-scale, local fisheries for gobies, prawns, atyid shrimp and limpets; farming of taro (a traditional food crop grown in swampy areas); and the use of coastal estuaries for fish ponds (as practiced by the ancient Hawaiians).

A primary threat to estuarine wetlands is draining and filling for agriculture (usually sugarcane farming or cattle ranching), aquaculture, or urban uses (Ahuimanu Productions 1977). Draining and filling not only directly destroys wetlands in the developed area, but also often affects the entire estuary by changing water circulation and sedimentation patterns, and degrading water quality.

The diversion of streams for their water is another serious threat to the integrity of estuaries. In many of the watersheds which feed estuaries, streams have been diverted for agricultural or urban use. The resulting reduction in water flow can lead to increased sand bar development, separating stream and ocean waters. It can also alter the salinity characteristics of the estuary. Blocked stream mouths may prevent the recruitment of diadromous species. The stagnation of water in stream mouths reduces water quality, which can adversely affect native stream fauna.

The natural processes of estuarine filling that operate over long periods of time have been accelerated by human disturbance of watersheds and changes in

upland land-use patterns. Increased sediment loads are filling in some streams. Although marsh habitats may persist in some of these streams, water quality is often seriously degraded. In addition to sediment, other introduced substances, such as pesticides, fertilizers, and bacterial contaminants, may drain into estuarine ecosystems from upland agricultural areas.

The dynamic balance of physical and chemical characteristics which makes the estuarine ecosystem a habitat for native waterbirds, fish, crustaceans, mollusks, and wetland plants may be upset by human activities upstream that initiate far-reaching changes in ecological relationships. Slight changes in the physical characteristics of the estuary may change the competitive interactions between plants and animals. This may lead to long-term changes in floral and faunal composition; some species may be severely reduced in abundance while others may increase in numbers.

Various introduced plant species have overrun many of the native marsh grasses and sedges. Some slow-moving streams and estuaries are clogged by the exotic water hyacinth. The introduced mangrove is also spreading across some estuaries and marshes in Hawaii. Non-native vegetation has reduced the quality of estuarine ecosystems as habitat for native waterbirds and stream fish. Almost 50 nonmarine exotic animals (decapod crustaceans, mollusks, amphibians, and especially fishes) have been released in Hawaii. Thirty-six of these have become established, many of which successfully compete with or prey upon the native fauna. Of these 36 species, 27 are found in streams (Kanayama 1968).

A recent review of introduced fish in Hawaii (Maciolek 1984) lists 31 exotic, nonmarine fish. Seven of these species--Chinese catfish (Clarias fuscus), mosquitofish (Gambusia affinis), mollies (Poecilia mexicana), guppies (P. reticulata), swordtails (Xiphophorus helleri), smallmouth bass (Micropterus dolomieui), and tilapia (Tilapia mossambica)--are having major impacts on stream communities. Predation by introduced mongooses, rats, and feral cats and dogs have all contributed to the demise of the native waterbirds which inhabit estuaries.

Freshwater and Upland Ecosystems

Many of Hawaii's perennial, continuous streams have been diverted for agricultural, industrial, and domestic uses (Parrish et at. 1978; Timbol and Maciolek 1978), and have therefore become interrupted streams. Many other streams have been channelized or dammed, altering the quality of the habitat they provide and impeding upstream migration by diadromous species (Parrish et at. 1978; Timbol and Maciolek 1978). Stream water quality, physical characteristics, and biota are also negatively affected by watershed disturbance. Activities such as agriculture, road building, logging, and other developments in upland areas of the watershed result in increased erosion and siltation. These activities are often accompanied by increased pesticide, fertilizer, and bacterial runoff, which produce impacts on all the downstream ecosystems.

In American Samoa, Pala Lagoon is subject to most of the nonconsumptive, potentially renewable, and extractive uses described for coastal barriers in Hawaii. The lagoon is currently experiencing eutrophication problems and is known to have high coliform counts (Helfrich et al. 1975). An additional concern is that American Samoan coastal ecosystems in general, and Pala Lagoon in particular, are heavily utilized for subsistence activities, especially fishing (Aquatic Farms and AECOS, n.d.; Helfrich et al. 1975; Government of American Samoa 1979; AECOS and Aquatic Farms 1980).

HAWAII

The passage of the Federal Coastal Zone Management Act (P.L. 92-583) in 1972 affirmed a national interest in the effective protection and development of the coastal zone by providing assistance and support to encourage coastal States to develop programs for Coastal Zone Management (CZM). The State of Hawaii rapidly responded to the national initiative, building upon earlier planning and legislative efforts to rationally manage, protect, and develop Hawaii's unique natural resources, including those of the coastal zone (State of Hawaii 1978).

In the year following passage of the Federal Coastal Zone Management Act, Hawaii State legislation (Act 164, SLH 1973) was enacted, authorizing the State Department of Planning and Economic Development (DPED) to prepare the State's CZM Program. Two years later, passage of the Hawaii Shoreline Protection Act of 1975 (Chapter 205A, HRS) established a Special Management Area (SMA) extending inland from the shoreline vegetation line for at least 100 yards. The Act established guidelines for the management and protection of resources in the SMA's. County permission is required for any development in the SMA which exceeds $25,000 in value or significantly affects the shoreline (as determined by the Director of the County Department of Land Utilization, using established assessment and review criteria).

Between 1974 and 1976, a series of technical documents was published as part of the CZM Program development. These provided information on various subjects, such as technical considerations in developing a CZM program for Hawaii (including ecosystems, vegetation, water quality, tsunamis, historical resources, beaches, and other major issues); the amount and distribution of federally controlled land; mapping, remote sensing, and computer applications to CZM; and legal and organizational aspects of developing a CZM program.

State Coastal Zone Management

The Hawaii CZM Act of 1977 (Act 188, SLH 1977) established basic State policy to guide State agencies and county governments in all actions affecting the State's coastal zones. The Act outlines specific objectives and policies as topics of particular concern, including

(1) provision of recreational opportunities,

(2) protection and restoration of historic resources,

(3) improvement of scenic and open space areas,

(4) protection of coastal ecosystems,

(5) provision for coastal-dependent economic uses,

(6) reduction of coastal hazards, and

(7) improvement of the review process involving development activities, including permit coordination and opportunities for public participation.

These basic objectives and policies are reinforced by existing specific State and county statutes which are enforced in conformance with the CZM Act of 1977.

The Federal Coastal Zone Management Act requires an inventory and designation of Areas of Particular Concern (APC's). APC's are administered in Hawaii by various programs concerned primarily with the preservation and restoration of such areas for their conservation, recreational, ecological, or aesthetic values. As part of this administration, the legislature established the Natural Area Reserve System (NARS) under Chapter 195, HRS. The NARS was set up to protect unique geological, volcanic, and other natural sites with distinctive marine, terrestrial, floral, and faunal features from degradation due to human activities. A NARS commission recommends areas for inclusion and proposes rules regarding their use, control and protection, for action by the Board of Land and Natural Resources.

Another form of protection is available to marine ecosystems under the Marine Life Conservation District (MLCD) Program established under Chapter 190, HRS, to preserve unique areas of Hawaii's marine environment. These districts are designated by the Department of Land and Natural Resources (DLNR) and are protected by regulations prohibiting certain activities and controlling allowable uses. DLNR also designates Marine Fishery Conservation Areas in which there are gear, season, or location restrictions on certain kinds of fishing to allow stock replenishment and prevent conflicts in use.

The Shoreline Setback Law (Chapter 205-32, HRS) was passed in 1970. This legislation delineated a restricted zone 40 ft from the upper wash of waves (or 20 ft in certain small parcels) in which construction or other related activities are prohibited except by a special approval procedure. The Shoreline Setback area is considered an APC because of its importance to the economy and environment of the State. The Waimanu Estuarine Sanctuary, which was designated under Section 315 of the National CZM Act for protection and preservation, also qualifies as an APC.

State-Mandated County Programs

Hawaii has several State-mandated county regulatory programs that are related to the State CZM Program. The most important of these is prescribed by Section 205A - Part I of the Hawaii CZM Act. This program establishes the objectives, policies, and guidelines to which counties must adhere in the administration of the SMA, consistent with the Hawaii CZM Program. The

counties ensure compliance with those policies through the issuance of a development permit, as required by Section 205A-28. Certain terms and conditions may be placed upon those land and water uses determined to constitute development. County planning agencies have set up specific regulatory procedures for administering SMA permits.

Area Subject to Management

The objectives and policies of the Hawaii CZM Act in the broadest sense provide the basis for including within the coastal zone all those lands whose use may have a direct and significant impact upon coastal waters. More specifically, the CZM area for the State of Hawaii includes all coastal waters seaward to the limit of the State's jurisdiction, all land areas included within the SMA boundaries, and all remaining inland areas except those lands designated as State forest reserves. In addition, federally owned, leased, or controlled lands, of which Hawaii has a large amount, are excluded from State CZM programs, as required by Section 304(a) of the Federal CZM Act of 1972. Thus, except for State forest preserves and Federal lands, the entire land area of each island is within the coastal zone.

CZM Organizations

A variety of State and county agencies are involved in implementing and administering the objectives and policies of Hawaii's CZM Program. The Department of Planning and Economic Development (DPED) is the lead agency implementing Hawaii's CZM Program. Its responsibilities include handling fiscal and administrative matters, coordinating the organizational network, and reviewing State and county agency compliance with the program. DPED is also responsible for determining instream flow requirements, but the Division of Land and Water Development, in the Department of Land and Natural Resources (DLNR), is actually setting standards for instream water quality. The Land Use Commission (LUC), housed in DPED for administrative purposes,is responsible for classifying all lands into the four land-use districts, administering requests for district boundary changes and reclassification, and approving special use permits in agricultural and rural districts.

The Department of Land and Natural Resources (DLNR) is the State's principal agency for managing State-owned lands and regulating uses in conservation district lands. It manages water development, commercial fishing, forestry, wildlife, fish and other aquatic resources, open space, and mineral resources. The DLNR also administers the NARS and the MLCD programs, which cover these types of APC's, and prepares the State Comprehensive Outdoor Recreation Plan (SCORP).

The Department of Health (DOH) is the primary implementer of pollution controls relating to Hawaii's CZM Program through management of air and water quality, solid wastes, public health, and sewage treatment. DOH also manages the National Pollution Discharge Elimination System permit program of the Clean Water Act of 1977, and thus regulates nearshore water quality.

The Office of Environmental Quality Control (OEQC) coordinates and directs State agencies in matters concerning environmental quality and coordinates the

writing of State Environmental Impact Statements. The Department of Transportation (DOT) regulates activities in the shore waters, including boating and recreation, and maintains, regulates, and issues licenses and permits for the construction of harbors and related facilities. The Department of Agriculture carries out programs to conserve, develop, and utilize the State's agricultural resources, many aspects of which interact with CZM objectives and policies.

The University of Hawaii provides research, technical assistance, and educational programs which interrelate with the State CZM Program. These activities are conducted primarily through five components of the University: the Curriculum Research and Development Group at the College of Education, the Hawaii Institute of Marine Biology, the Environmental Center, the Water Resources Research Center, and the Sea Grant Program.

The Counties of Hawaii, Maui, Kauai, and the City and County of Honolulu have numerous responsibilities in the management of the Hawaii coastal zone. The counties determine the SMA boundaries and directly administer land and water use controls through the issuance of development permits consistent with State CZM objectives and policies. State-mandated county regulatory programs dealing with a variety of issues and important planning and zoning activities are also under county jurisdiction.

AMERICAN SAMOA

The Territory of American Samoa, which includes Tutuila and six other smaller islands, is included in the Federal Coastal Zone Management Act of 1972 (Government of American Samoa 1980). The Governor designated the Development Planning Office (DPO) as the lead agency in formulating a CZM program. The objectives and policies of the Territory's CZM Program are divided into three categories which establish priorities, guidelines, and standards to deal with coastal problems and issues:

(1) government activities, which include territorial administration and village development;

(2) development policies, which cover shoreline, fisheries and agricultural development, coastal hazards, erosion, and major facility siting; and

(3) resource policies, which address reef protection, air and water quality, marine resources, cultural and historical resources, and critical areas.

Coastal zone boundaries include virtually all land areas of American Samoa and the coastal ocean to a limit of 3 nautical miles seaward. Federally managed Rose Atoll is excluded from the coastal zone. The program is implemented by Executive Order X-80 which directs all government agencies to act consistently with the CZM program policies and incorporate them into their procedures. As lead agency, the DPO may submit rules for the Governor's promulgation as they become necessary. Other key agencies include the Department of Public Works,

the Zoning Board, the Environmental Quality Commission, the Department of Health, the Capital Improvement Program Committee, and the Governor's office. Pala Lagoon was designated as one of two APC's in American Samoa in order to enhance and restore its water quality and fish, wildlife, and recreational values (Government of American Samoa 1979).

SUMMARY

The Hawaiian Islands and American Samoa are the tops of large, undersea volcanic mountains of relatively young geological age. The basalt which composes these volcanoes is subject to rapid weathering in the humid tropics and deep valleys have eroded along their flanks. Sea-level changes have left many drowned river valleys, especially in the older islands, and some fossilized sand dunes. More recent volcanic activity has punctuated parts of the shorelines with smaller volcanic cones. Coral reefs have grown along the island fringes where they protect the shore and provide beach-forming calcium carbonate sediments.

Current coastlines are built of volcanic rock, biologically derived calcareous sediments, and terrigenous sediments, all in various shapes, sizes, and states of weathering. Calcareous sand and rubble derived from coral reefs provide most of the beach material, along with stream-eroded and transported deposits of weathered basalt. These materials are redistributed along the shoreline primarily by ocean waves, coastal currents, and winds. Tsunamis and hurricanes are responsible for major coastal changes on an episodic basis.

The characteristics of coastal barriers are different for each island. Kauai, an older, deeply weathered volcano, has the largest number of coastal barriers, almost all of which are bay mouth barriers. These consist of drowned stream valleys with depositional barrier bars across the valley mouths. Streams, which perennially or seasonally breach the barrier bar, meander in the lower, sediment-filled valley floor; wetlands occur behind the beach and low dunes. The size and stability of the barrier depend upon the amount of streamflow and sediment input, the exposure of the barriers to strong wave action and currents, the supply of coral sand and rubble, and the extent of protective reefs nearby.

Coastal barriers on Maui consist of unconsolidated barrier beaches and outcrops of beachrock which protect aquatic habitats. The wetlands occupy coastal depressions behind the beaches and low dunes. These wetlands are usually spring fed, often with ponds, whose size and condition vary with seasonal water availability. The long, relatively narrow beaches are composed primarily of calcareous sand and most are protected by extensive fringing reefs. Most of the coastal barriers on the complex and diverse shores of Oahu are either bay barrier or barrier beach type and have characteristics similar to those described on Kauai and Maui.

The youngest and largest island, Hawaii, has two types of coastal barriers. Along the windward side of its northern peninsula, three deep valleys support bay barriers that are similar to those on Kauai, but lack extensive offshore reef development. On the long west coast of Hawaii, lava flows and fault

lines have created small shoreline embayments that have been blocked by sand deposition. These aquatic habitats were modified and used by ancient Hawaiians as fish ponds. The shallow ponds and marshes are sometimes spring fed. Their low, narrow beach barriers generally have little if any protective coral reef.

In American Samoa, the coastal barrier of Pala Lagoon on Tutuila Island is an anomaly. It was created by a protective barrier spit that nearly encloses a shallow, embayed portion of the fringing reef.

Coastal barriers in Hawaii and American Samoa can be divided into five component ecosystems: (1) coastal marine, (2) maritime, (3) estuarine, (4) freshwater, and (5) coastal uplands. These ecosystems are all interrelated and continue to be shaped by the upland and coastal processes which created them. They are also significantly altered, both physically and biologically, by human activities.

Coral reefs are the most conspicuous component of coastal marine ecosystems. They harbor diverse biotic assemblages of corals, other invertebrates, fish, and algae. The extent and distribution of coral reefs vary depending upon island age, exposure to direct wave and wind action, and the presence of inhibiting factors such as low salinity and heavy sediment loads in the water. Complex ecological relationships have developed among the diverse flora and fauna. This results in a high level of interdependence among organisms of many sizes, with diverse feeding and habitat requirements. The threatened green sea turtle feeds and rests in marine waters adjacent to some coastal barriers in Hawaii and American Samoa, and other protected marine turtles or mammals may be occasional visitors.

The characteristics of the maritime ecosystems in Hawaii and American Samoa are determined by the presence and size of the adjacent coral reefs because most beaches and dunes are built of calcareous, reef-derived sediments. Beach waves and stream discharge rates are also important controlling factors. Backshore dunes are generally of limited extent, except where Pleistocene dune deposits occur. Maritime ecosystems occupy harsh environments characterized by salt spray, constant wind, low rainfall, intense sunlight, high evaporation, high temperatures, and shifting sands. Beach sands are stabilized in dunes by vegetation adapted to these conditions. These plants trap sand and their roots anchor the dune surface against wind erosion. Dune vegetation consists predominantly of introduced coastal strand species although some native plants are still abundant.

The regional distribution of maritime vegetation is related to rainfall patterns. The zonation of strand plants from seaward to landward is controlled by exposure to wind and surf, and by soil and water salinity. Few animals permanently inhabit these areas. Various crustaceans are found in the intertidal beach, and small lizards occur in the strand and dune vegetation. Sea- and shorebirds roost and nest in these areas in places where human disturbance is minimal.

Estuarine ecosystems in Hawaii and American Samoa consist of lower stream valleys and associated marshes, grasslands and ponds behind barrier bars, and

marshes and ponds occurring in coastal depressions landward of barrier beaches, including some that were formerly used as fish ponds by ancient Hawaiians. The vegetation of estuarine ecosystems has become heavily influenced by exotic plant species. Introduced water hyacinth often covers pond waters, non-native sedges, bulrushes and other grasses occupy the wetlands, mudflats are covered with pickleweed, and introduced mangroves have begun to spread in some estuaries. Taro cultivation was formerly practiced in many Hawaiian wetlands and the plant still occurs in some of the aquatic habitats associated with coastal barriers.

Although the diversity of fauna in Hawaiian estuaries is relatively limited, much of it is endemic, including native species of fish, prawns, and mollusks. Estuarine ecosystems are also nurseries for many reef fish. Many estuaries have been invaded by exotic animals such as Tilapia, mosquitofish, crayfish, and frogs, which may depress populations of native species by predation, competition, and alteration of the habitat. Estuarine wetlands in Hawaii are especially important in providing feeding and nesting grounds for indigenous waterbirds, particularly the endangered and endemic Hawaiian stilt, Hawaiian gallinule, Hawaiian coot, and Hawaiian duck. Most of the aquatic habitats associated with coastal barriers have been identified as critical primary or secondary habitats for these birds, and some are parts of existing or proposed National Wildlife Refuges. In addition, many migratory waterfowl and waterbirds use estuarine wetlands during winter months.

Freshwater ecosystems are found in the inland portion of the stream-estuarine continuum and in barrier-protected wetlands that have limited saltwater influence. Streams in Hawaii are ephemeral, intermittent, or perennial. Intermittent and perennial streams support various complements of native fauna that are adapted to their rocky, precipitous beds and greatly fluctuating flows. Many stream species have marine larval stages and must migrate to complete their life cycles. In addition to native freshwater fauna, many introduced species have become successful competitors or predators in Hawaii's streams.

Upland ecosystems in Hawaii and American Samoa extend to the inland boundaries of coastal watersheds and thus include nearly the entire land mass of each island. Upland watersheds, especially in Hawaii, are often dominated by exotic flora and fauna. Consequently, many rare and endangered plants and animals, particularly birds, are found only in pockets of undisturbed upland habitat.

Coastal barrier ecosystems are affected by a wide variety of human activities. Some of these cause direct physical and biological alterations. They may also produce more subtle effects by influencing the processes which maintain ecosystems. Coral reefs are used for fishing and for a wide range of nonconsumptive recreational activities, all of which have important cultural and community values in Hawaii and American Samoa. Reefs are also altered by mining for building materials (such as sand and rubble), construction activities, and dredging. The diverse biota of coral reefs are vulnerable to overharvest and to introduced pollutants such as silt, oil, pesticides, and sewage.

Estuarine and freshwater ecosystems are altered by dredging, filling, and stream channelization or diversion for agricultural or urban uses. Upstream activities can introduce silt, pesticides, fertilizers, and sewage to these coastal wetlands. Introduced plant and animal species are outcompeting the native biota of many Hawaiian streams and estuaries. Some wetlands and streams still support fisheries and taro cultivation.

The State of Hawaii and the Territory of American Samoa both responded to the passage of the Federal Coastal Zone Management Act of 1972 by developing coastal zone management programs. In Hawaii, this was preceded by legislation dealing with land use, shoreline setbacks, and shoreline protection. Hawaii's Department of Planning and Economic Development is the lead CZM agency. It is assisted by the Land Use Commission, the Department of Land and Natural Resources, other State agencies, and county governments, the latter of which administer the Special Management Areas along Hawaii's coastline.

In American Samoa, the Development Planning Office is the lead CZM agency and formulates the Territory's CZM objectives and policies. Numerous agencies assist the Development Planning Office with the CZM program and a number of APC's have been designated.

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