(a) **PUERTO RICO - Large scale characteristics**

Although corals grow around much of Puerto Rico, physical conditions result in only localized reef formation. On the north coast, reef development is almost non-existent along the western two-thirds possibly as a result of one or more of the following factors: high rainfall; high run-off rates causing erosion and silt-laden river waters; intense wave action which removes suitable substrate for coral growth; and long shore currents moving material westward along the coast. This coast is steep, with most of the island's land area draining through it. Reef growth increases towards the east. On the wide insular shelf of the south coast, small reefs are found in abundance where rainfall is low and river influx is small, greatest development and diversity occurring in the southwest where waves and currents are strong. There are also a number of submerged reefs fringing a large proportion of the shelf edge in the south and west with high coral cover and diversity; these appear to have been emergent reefs 8000-9000 years ago which failed to keep pace with rising sea levels (Goenaga in litt. 7.3.86). Reefs on the west coast are limited to small patch reefs or offshore bank reefs and may be dying due to increased sediment influx, water turbidity and lack of strong wave action (Almy and Carrión-Torres, 1963; Kaye, 1959). Goenaga and Cintrón (1979) provide an inventory of mainland Puerto Rican coral reefs and the following is a brief summary of their findings.

On the basis of topographical, ecological and socioeconomic characteristics, Puerto Rico's coastal perimeter can be divided into eight coastal sectors -- north, northeast, southeast, south, southwest, west, northwest, and offshore islands. These are used in the following descriptions of habitat distributions. Two sectors standout as particularly rich in natural systems of importance to fishery production -- the southwest and the northeast.

NORTH COAST: Rio Grande de Arecibo (Arecibo) to Boca de Cangrejos (Carolina)

Setting. The San Juan Metropolitan Area, in the eastern part of the north coast sector, is the largest of the Island's urban areas and a major port. Topography in the north coast sector is practically level with extensive karst hillocks toward the interior. The fertility of these level lands has favored the intensive cultivation of sugar cane (32 tons to the acre) and pineapple (15.5 tons to the acre).

Coastal Features. The north coast sector contains the rivers with the greatest volume of flow on the island and the largest system of subterranean aquifers. This system of aquifers has attracted a major concentration of pharmaceutical and chemical plants to the area. Geologic formations off the north coast, from San Juan to Manatí, have encouraged interest in petroleum exploration, and discussions of possible exploration have been held between private firms and the government.

Two major non-mangrove wetlands along the north coast, Caño Tiburones and Laguna Tortuguero, are susceptible to tidal flooding and are populated principally by freshwater biological communities. Laguna Tortuguero is the only natural freshwater lagoon in the Island. It possesses a wide variety of plant species (600), of which 35 are endemic and unique to the lagoon. Faunal diversity is also remarkable. In studies by the Puerto Rico Department of Natural Resources, 18 molluscan genera, 21 species of fish, and 39 species of birds were identified. Because of its biological diversity and

recreational potential, Laguna Tortuguero is one of a number of areas requiring special management attention to insure that its values are preserved and protected.

With its exposure to heavy wave action, the north coast is highly susceptible to natural erosion, a condition aggravated in several locations by man-made activities. Wave action on the coastline has resulted in the creation of numerous tombolos and lunate bays. However, most of the north coast beaches consist of thin deposits of sand covering a rocky lower foreshore. During the winter storm period, these sands may move offshore temporarily as part of the natural erosion cycle.

Coral Reefs. There is little reef development on the north coast except for patchy coral growth and narrow linear "reefs" consisting of coral communities covering fossil sand dunes formed during lower sea levels. North of Isla Verde and in several other places these ridges are exposed as small rocky islets. There are several minor coral assemblages at Arecibo and submerged patch reefs off Camuy and Puerto de Tortuguero. An extensive but highly stressed reef fringes the shore at Dorado. The reef flat (1-3 m deep) has abundant gorgonians, and the predominant corals are *Diploria strigosa* and *D. clivosa*. The reef front has many dead corals overgrown by algae and other corals; seaward of this reef are small patch reefs at 25 m with abundant fish life. East of San Juan, there is a poorly developed and heavily stressed discontinuous chain of rock reefs trending in an east-west direction and extending 1.5 km off shore. These consist of a thin coral veneer over a shallow platform which, in some cases, such as Isla Piedra, east of San Juan, and Isla Cancora, rise above the water (Kaye, 1959). Patch reefs are found off Punta Las Marías which are typically mound-like and rise to within a couple of meters of the surface. The tops are covered with head corals bordered by *A. palmata*; the lower slopes are covered with gorgonians.

NORTHEAST COAST: Boca de Cangrejos (Carolina) to Rio Demajagua (Ceiba)

Setting. This coastal sector includes the Island's most extensive mangroves (approximately 4,850 acres), and various salt water lagoons (approximately 941 acres). Together with the mangroves that surround them; these lagoons are nursery areas for sport and commercial fish. The wide insular shelf toward the east favors the proliferation of coral reefs that culminate in a chain of small islands (La Cordillera) ending in Culebra and Culebrita.

Coral and rock reefs protect these coasts, causing tranquil waters and creating conditions favorable to the formation of abundant sandy beaches that border 78 percent (45.8 kilometers) of the coastline. The extensive insular shelf, and the presence of reefs and mangroves, support an abundant marine life, making this portion of the coast very attractive for aquatic recreational activity.

Topography is predominantly level from Boca de Cangrejos to Punta Percha in Luquillo. East of Punta Percha, extensions of the Sierra de Luquillo come down to the coastline creating hills and valleys.

The rain forest of the Caribbean National Forest locally called El Yunque and the chain of small islands known as La Cordillera augment the attraction of this area for tourism. This potential has generated enormous pressure for the construction of tourist complexes and summer residences on

the coast. The growth of the nearby San Juan metropolitan area is, nevertheless, the factor that continues to generate the largest demand for level land in this area. High population density and concentration of economic activities could have major adverse effects on the integrity and quality of the ecological systems of the northeast.

Reefs. A well developed reef system used to lie in clear waters north-west of Boca de Cangrejos with extensive coral growth from the surface to 10 m depth. This has been virtually destroyed by sedimentation due to extensive dredging and organic pollution from sewage treatment plants in Torrecilla Lagoon. Currently, almost no living coral is found deeper than 1.5 m. The reefs in the region of Punta Vacia Talega are described in detail in Goenaga and Cintrón (1979). Stony corals are present on rock reefs and beach rock platforms as encrusting forms and are most abundant along the northern side of the inner reef. *Millepora complanata* is the most abundant species near the surface, and *Diploria* and *Isophyllia* are common in deeper areas. Soft corals are present in sheltered areas. Scattered patch reefs breaking the surface are found between Punta Iglesias and Punta San Agustin, east of Punta Vacia Talega; although these do not form a continuous barrier, they provide an effective wave energy absorbing structure. Water quality is characterized by high levels of suspended particles and low visibility, and reef patches adjacent to the shore are dead, probably as a result of siltation. Water quality and coral health improves offshore but corals are only present in depths of 1-3 m on the outermost reefs.

Reef development improves east of the easternmost major river, Espíritu Santo. Fringing reefs, about 0.5 km wide, border the north and west sides of Punta Miquillo and the north and east sides of Punta Picua. Both headlands were probably once sand cays, but are now connected to the mainland by a broad marsh and narrow sand tombolos. The reefs have poor coral development, especially at Punto Miquillo where there may be damage from the dredging of a channel parallel to the shoreline.

Punta Percha, to the west, forming part of the same system, has similar reefs but slightly higher living coral cover. Ensenada Comezón, between Punta Miquillo and Punta Picua, has numerous patch reefs, more than 2 m high, which lack distinct zonation. Algae are dominant and the surrounding waters are generally very turbid but a number of corals occur. Two large, roughly circular (300-500 m diameter) patch reefs occur off the mouth of Río Mameyes, each with an exposed shoal of coarse sand. Coral diversity is low, probably due to siltation from the river.

To the east is a complex of barrier, fringing and patch reefs which are responsible for the formation of Luquillo Beach at Punta Percha. The fringing reefs surrounding the northern and eastern end of the beach have deteriorated on the seaward edge where growth is limited to the upper 3 m. East of Luquillo, water transparency increases gradually and the reefs have slightly higher living coral cover. East of Río Juan Martín, there is a series of patch and fringing reefs with low coral diversity, which have been described by Torres (1973). Siltation appears to be the main factor limiting coral growth. West of Cabeza Chiquita to Cabo San Juan, there is a fringing reef system, also in a poor state of health.

Conditions on the shallow platform east of Puerto Rico are ideal for coral development. The best reef development on the north-east coast is the fringing reef system around the La Cordillera islets and

the islets of Isla Ramos, Isleta Marina and Cayo Ahogado between the mainland and La Cordillera. These have reefs on their eastern shores, the degree of reef development apparently related to distance from the mouth of Río Fajardo. The islands are susceptible to occasional drastic wave erosion (Goenaga and Cintrón, 1979). The reefs at Cordillera, Culebra and Vieques are upstream of east coast river discharges and generally still have high coral diversity and cover (see separate accounts).

On the mainland, nearshore waters are affected by persistent high levels of turbidity. An extensive, but dying, fringing reef is found from north-east Cabo San Juan to the north end of Punta Sardinera, protecting the entrance to Bahía Las Croabas. There are no coral reefs from Playa Sardinera to Punta Barrancas, presumably because of the influence of Rio Fajardo although narrow reefs project eastward about 450 m from Punta Barrancas and Mata Redonda. Between these two headlands, there is a shallow but small reef in the north of Bahía Demajagua (McKenzie and Benton, 1972).

La Cordillera (18E22'N, 65E32'W) is a shallow, narrow submarine ridge approximately 18 miles (29 km) long, trending east-southeast and supporting a number of islets with high quality fringing reefs. The islets, especially Icacos, the westernmost and largest, are composed of oolitic eolianite, deposited and partially submerged some time previous to the development of the reefs (Kaye, 1959). Most of the islands are high and vegetated. On Icacos, rock reef fringes two thirds of the north shore (Goenaga and Cintrón, 1979); in the north-west the beaches consist of loose, white, calcite sand whereas in the south-east they are formed of consolidated beach rock. Island vegetation changes from low scrub in the north-west to sea grapes and white mangrove in the southeast (Almy and Carrión-Torres, 1963). The Palominos complex and Cayo Largo are situated on the same platform, south of the main line of La Cordillera reefs. Palominos, the top of a submerged hill, has ridges which continue south and east as large submerged banks. Palominitos was formed by wave-deposited sand and coral fragments on the reef platform and has a maximum altitude of less than 3 m (Goenaga and Cintrón, 1979). The waters in this area are affected by severe storms, tsunamis and water spouts, and the region is seismically active (Anon., 1982). The tidal range in Bahía de Fajardo is 034 m (Velazco-Dominguez et al., 1985).

Fringing reefs surround most of the islands in this area. Many of the reefs around Icacos and Palominitos have a similar formation which is probably typical of the northeast coast (Pressick, 1970). Reefs along the east, north and northeast sides of Cayo Icacos are most well known (Almy and Carrión-Torres, 1963). In the north, corals cover less than 50% of the available surface area (McKenzie and Benton, 1972), and very little growth is observed behind the northwest reef (Aliny and Carrión-Torres, 1963). The southwestern shore is more protected and has higher coral cover, particularly to the north and south where the currents pass round the ends of the island. Almy and Carrión-Torres (1963) discussed general aspects of the reefs on this coastline and listed 21 coral species collected from the reef.

The zonation of a 420 m long reef in the southeast, between Icacos and Audry Rock is described by Pressick (1970). The shore zone extends in a gradual slope to about 1.6 m, and scattered living corals are found at about 20 m from the shore line. The lagoon extends out about 195 m from the shore zone. The sandy slope has patches of coral, with *Thalassia testudinum* gradually becoming

more abundant. *Manicina areolata* is common among the seagrass. The bottom of the lagoon is sandy with sparsely scattered *Acropora cervicornis* and *A. palmata*. Gorgonians are abundant. The rear zone (seaward slope of the lagoon) rises sharply to form the reef flat and has a rich coral covering including massive colonies of *Montastrea annularis, Diploria* and *Porites asteroides*. The reef flat is about 50 m wide and is generally exposed at low tide. *A. palmate* and *Millepora complanata* predominate, and *Astrangia solitaria* forms attractive tiny red colonies throughout the zone. At the edge of the reef flat there is a 3 m drop-off with massive heads of *Montastrea annularis* and abundant *Agaricia agaricites*. This zone gives way to an *Acropora palmate* zone. Colonies of this species spread to diameters of 3-5 m and are interspersed with small, scattered *Diploria* heads. *A. Diploria* zone extends down to depths greater than 4 m.

The south coast reef on Palominitos is described in Goenaga and Cintrón (1979). The reef crest and *A. palmata* zones intermix and are dominated by *A. palmata*. *Millepora complanata* is common as well as *D. clivosa, Favia fragum, Dichocoenia stokesii, A. cervicornis* and *P. asteroides*. Coral cover is high although many colonies are broken. The mixed zone descends to about 6 m and is dominated by gorgonians and *M. annularis*; *P. porites* and *A. cervicornis* are also common. This zone is very diverse and has a small spur and groove system of about 2.5 m in relief. At 6 m, large colonies of *A. palmata* are abundant. The steep reef slope is dominated by *Agaricia agaricites* and has several other species in abundance.

Cayo Largo is a relatively untouched reef and needs further study (Goenaga and Cintrón, 1979). The reef crest has abundant *A. palmata* with occasional colonies of *M. complanata*. In the *Palmata* zone, cover is slightly reduced. It gives way abruptly to the mixed zone which is an area of medium relief with high coral diversity; *M. annularis, A. palmata, P. porites and M. complanata* are common. The reef slope is dominated by *A. cervicornis* on the upper slope and gorgonians at greater depths; *P. porites* is also very common. The reef flat is dominated by *P. porites* and there is a notable absence of *Diadema* and other urchins. The reef terminates eastwards with a bare sand "halo" about 8 m wide, after which there is a healthy *Thalassia* bed.

The area is inhabited by spiny lobster, octopus, helmet shells, and a variety of reef fish. Numerous Queen Conch *S. gigas* occur in the *Thalassia* bed adjacent to Cayo Largo (Goenaga and Cintrón, 1979).

SOUTHEAST COAST: Rio Demajagua (Ceiba) to Rio Grande de Patillas (Patillas)

Setting. The southeastern coastline is an alternation of rocky headlands, partly shaped by marine erosion, and valleys of alluvial material that, as a result of wave action and marine deposition, form broad beach plains. North of Punta Lima the coastline consists of mangroves, rocky headlands, and a few small beach plains and pocket beaches. This end of the island is bordered by an insular shelf, with abundant coral and marine organisms, that extends eastward to the neighboring Virgin Islands.

Average annual rainfall is high, with a range of 55 to 80 inches. Rivers and streams are abundant and meander through narrow V-shaped valleys. The most dramatic example of these is the Maunabo

Valley situated between the Cuchilla de Panduras and the Sierra de Guardarraya, which reaches to the water's edge. These two formations and their forested landscapes harbor an important wildlife habitat. Cultivation of sugar cane is the predominant land use; extensive irrigation canals are common.

Roosevelt Roads, the largest military base in Puerto Rico (25 percent of all military holdings on the Island) is located along this coastal stretch. At Yabucoa, a large man-made harbor serves the Sun Oil Company refinery and related industries.

Reefs. Isla Pineros off Medio Mundo, Ceiba, has moderate coral growth on its north and east coasts. Cabeza de Perro, an islet to the south, was used by the U.S. Navy for bombing practice and lacks marine benthic life. South to Punta Lima, the coast is mainly bordered by *Thalassia* sea grass beds with occasional small fringing and patch reefs. Most of the latter lie on a 6-7 m deep platform, many patch reefs not reaching intertidal level. Some probably lie on sand or mud formations, judging from their location at the edge of tidal swamps (Kaye, 1959).

South-west of Punta Lima, turbidity increases due to sediment-laden rivers and creeks. Several islets such as Cayo Santiago and Cayo Batata have coral growth in shallow waters and south facing areas open to the sea, with surprisingly dense 90% living *A. palmata* stands intermingled with gorgonian and head corals close to the surface. Submerged shoals with sparse coral growth occur occasionally off Humacao, as at Bajo Parse which has numerous gorgonians, small head corals and extensive patches of the encrusting sponge *Anthosigmella varians*. Further south, there is little coral growth in Yabucoa Bay (apart from an annular reef in the southern part of the bay with a few living corals) presumably because of river outflow (Díaz-Piferrer, 1969; Seiglie, 1969). About 5.5 nautical miles (10.2 km) east of Yabucoa Bay, La Conga reef is probably part of the submerged barrier reef bordering most of the southern shelf of Puerto Rico.

At Maunabo, the insular shelf is only 1 km wide; the associated high energy wave conditions and reversing tides flush Sergeant Reef, south-east of Punta Tuna, clean of river sediments (see separate account). A fringing reef extends almost continuously for four miles (6.4 km) between Cabo Mala Pascua to Puerto Patillas; this is exposed at low tide and protects a low sandy apron at the foot of the Sierra de Guardarraya. Arrecife Guayama, lying 0.6-0.9 km off Punta Figueras and nearly 5 km in length, is well developed but is now affected by siltation; the *A. palmata* zone has low coral cover and many dead colonies.

SERGEANT REEF

Southeast coast, 03 km southeast of Punta Tuna. 1.08 km long; 0.1 km wide at widest point.

Reef. The reef flat has abundant *A. cervicornis* thickets. Further seaward there is an area of reduced *A. palmata* growth with high encrusting algal cover; this zone gives way to one of dense *Porites* growth, with patches larger than 100 sq. m in some places, alternating with *A. palmata*colonies. Seaward of this is a zone of dense 100% *A. palmata*, which thins out with depth until gorgonians predominate (Goenaga and Cintrón, 1979).

The reefs protects the shoreline in the vicinity of Punta Tuna from the southeast swell (Goenaga and Cintrón, 1979).

SOUTH COAST: Rio Grande de Patillas (Patillas) to Rio Tallaboa (Peñuelas)

The arid south coast sector is a low lying alluvial plain except for a short stretch between Tallaboa and Punta Cuchara where the mountains extend to a coastline shaped by wave erosion and fringing reefs. The rest of the coastline is either beach plain or mangrove. Ponce, located in the western part of this sector, is the second largest metropolitan area -- and second largest port city -- on the island (San Juan is the largest). To reduce chronic unemployment, the Puerto Rico Economic Development Administration has proposed the establishment of heavy industries in the area, especially oil and pharmaceutical related industries. However, the water needed to serve such industrial development would have to be imported. Preliminary studies have been made to divert the waters of the Rio Manatí by means of a reservoir yielding 228,000 acre-feet per year to the south coast region.

Reefs. Off Arroyo, are the Corona and Algarrobo patch reefs which appear relatively healthy and little affected by siltation. Arrecife Las Mareas, south of Las Mareas, Guayama, is almost devoid of living coral.

Southwest of Punta Pozuelo, a fringing barrier reef, Cayos Caribes, extends for about 2.5 km forming an arc with Cayos de Barca and Cayos de Pájaros and protecting the entrance of Bahía de Jobos. Living coral cover is moderate and increases westward. On the lee side of the reefs are a number of narrow sand cays fringed by mangrove vegetation. The Ponce basin contains very turbid water, with a bottom of silt and clay. About 2.5 km south of Ponce, reefs are found at Baja Tasmanian, on a two-tiered platform, the northern level 6-12 m deep, and the southern level 18-24 m deep. *A. cervicornis* is particularly abundant at the lower level with large shingle-like growths of various massive corals at the shelf edge (Beach, 1975). Numerous offshore cays with healthy coral cover occur off Salinas, Santa Isabel and Ponce (see separate accounts for Bahía de Jobos and Caja de Muertos).

Bahia de Jobos is an area on the south coast, in the municipalities of Salinas and Guayama, including Cayos de Pájaros (17E55' N, 66E15' W), Cayo Morrillitos (17E55' N, 66El5' W), 66E17' W), Cayos de Ratones (17E56', 66E17'W - not to be confused with Cayo Ratones described in separate account), Arrecife Media Luna, Cayo Alfeñique, Cayos de Caracoles, Cayo Cabuzazos and Cayos de Barca.

The surrounding land is largely flat with a few hills rising only to 50 m. The climate is and characterized by short periods of heavy rain which may produce flash floods, most of which discharge into the sea. Annual rainfall averages 1086 mm. Temperatures range from 22 to 31EC with an annual average of 26.5EC. The dry season extends from January to April and the wet season from June to November. The area includes a wide variety of habitats such as estuaries, mangroves, salt marshes, coral reefs and sea grass beds and has been described by Beach (1975) and Diaz et al. (1983).

Szmant-Froelich (1973) studied the zonation and ecology of the Bahia de Jobos reefs and found 13 coral species. Profiles for some of these areas are given in Goenaga and Cintrón (1979). Cayos de

Pájaros has a *M. complanata* dominated reef crest fragmented into buttresses about 3 m high, a well developed *A. palmata* zone and a mixed zone and slope typical of other reefs in the area. Cayo Morrillos has a very wide *M. complanata* reef crest with 2 m high buttresses and much coralline algae; the *A. palmate* zone and slope was similar to Cayos de Pájaros.

On Cayos de Ratones, *A. palmata* is common on the *M. complanata* dominated reef crest. Seaward of this, there is an abrupt slope leading to a bare sand area with scattered isolated small head corals. Beyond this, depth increases rapidly to an area where mounds topped with *M. complanata* are found. The *A. palmata* zone is found at greater depth followed by a mixed zone with gorgonians dominant on the upper part and massive corals dominant near the reef base. *Mycetophyllia* and *Oculina* are also common.

Cayo Alfeñique is crescent-shaped with the same three zones, although these are less well defined on the east side of the reef and the *A. palmata* zone was not nearly as well developed as on other nearby reefs. A spur and groove system is found east of the reef slope, with north-south orientation (parallel to the reef crest). Gorgonians dominated the spurs and bare sand was found on the bottoms of the channels. The lagoon had sparse *Thalassia* and dead *Porites*.

On Cayo Cabuzazos, small *D. clivosa* and *D. strigosa* formed an important component of the *M. complanata*-dominated reef crest. Calcareous algae and Palithoa were common. Beyond the *A. palmata* zone the mixed zone consisted of *A. cervicornis*, gorgonians and other corals. The reef slope was dominated by *A. agaricites* and gorgonians, with other corals and sponges. The reef flat was a well developed *Porites* biotope, with a *Thalassia* bed mixed with *Porites* on the shoreward side.

More recent studies have shown that the reefs have significantly changed since 1973. Diaz et al. (1983) describe the current status of reefs at Arrecife Las Mareas-Guayama, Cayos Caribe, Cayos de Barca, Cayos de Pájaros, Cayo Morrillos, Cayos Ratones, Punta Colchones and Punta Puerca, and Cayo Media Luna. Szmant-Froelich (1973) found that reef diversity increased towards the east, but currently reef diversity is highest in the west at Cayos de Pájaros and Cayo Morrillos; these changes are probably due to hurricane damage.

Bahía de Jobos is an important wetland site with the second largest mangrove swamp in the country, brackish lagoons and saline lagoons and is one of the best areas in Puerto Rico for migratory shorebirds (Diaz et al., 1983; Scott and Carbonell, 1986). All the cays, except Media Luna, have mangroves in various stages of development (Goenaga and Cintrón, 1979). Bahia de Jobos is the most important area in Puerto Rico for the Caribbean Manatee *T. manatus* and is a feeding area for the Hawksbill Turtle *E. imbricata* and Green Turtle *C. mydas* (Groombridge, 1982; Scott and Carbonell, 1986). The fish fauna has been well documented, over 260 species having been recorded in the bay and among the cays, including many commercially important species (Diaz et al. 1983). The rich invertebrate fauna includes large populations of spiny lobsters *Panulirus sp.* and the molluscs *Crassostrea rhizophorae, Isognomon alatus* and *Brachiodontes exustus* (Scott and Carbonell, 1986). Diaz et al. (1983) describe the mammal, bird, reptile and amphibian faunas.

Scott and Carbonell (1986) list threats to the wetland area, many of which may also affect the reefs. A large petrochemical development encircles the mangrove swamp and the entire area is under consideration for industrial expansion (U.S. Dept of Commerce, 1978). Industrial development and poorly sorted fill used at El Tuque, west of Ponce, contribute to turbidity in the water, and Diaz et al. (1983) document a number of dredging activities which have caused sedimentation. The area is potentially threatened by thermal discharge from the Aguirre power plant; Szmant-Froelich (1973) discussed the possible effects of this but suggested that waste chemicals and increased productivity would do greater damage.

SOUTHWEST COAST: Rio Tallaboa (Peñuelas) to Punta Guaniquilla (Cabo Rojo)

The topography of this area is generally hilly with the exception of level areas near Tallaboa, Guayanilla, Guanica, Pole Ojea, and Boquerón. Precipitation is low -- 35 inches annually -- which gives rise to the xerophytic (desert-type) vegetation that abounds along the coast. The absence of alluvium and the relatively wide extension of the insular shelf along the southwest coast have permitted the pro-liferation of coral reefs and bioluminescent waters -- natural systems sustaining a food chain that contributes to the southwest's fisheries resources, which are abundant compared to those of the rest of the Island.

The dry forest of Guanica (9,582 acres); the mangroves of La Parguera, Boquerón, and Pitahaya (1,681 acres); the reefs of Margarita and Turromote; the beaches of Caña Gorda, Bahia de la Ballena, El Combate, Caleta Salina, Punta Ventana, and Boquerón; the bird reserves of the Cabo Rojo National Wildlife Refuge and the Commonwealth's Boqueron Bird Refuge (970 acres) are examples of the natural wealth of the southwestern coast.

The level interior lands of the southwest include fertile agricultural areas appropriate for mech-anized agriculture. To maximize this agricultural potential, among the richest in Puerto Rico, the Lajas irrigation system has been established, to compensate for the scarcity of rainfall. Residential land demand in the southwest will continue to be relatively small. On the other hand, the scenic attractions of the sector have generated a specialized demand for land for condo-hotels, summer and weekend residences, and other tourist activities. Since these tourist-related activities are generally located on the very border of the littoral, they could threaten biological systems of the region.

The maritime conditions produced by the protection given by offshore islands and in some instances, by the island of Puerto Rico itself, and the presence of natural ports in the southwest has offered opportunities for the establishment of heavy industries that require port facilities, such as petrochemical complexes. Today, for example, a petrochemical complex in Tallaboa occupies 1,649 acres, and additional heavy industrial sites have been proposed from time to time. Because of the unique biological systems of the southwest and the opportunities that they represent for recreation and tourism, proposals for industrial development create important land- and water-use conflicts. It is consequently important to provide for balanced land-use patterns whenever possible. The recreational potential that this area offers is probably the greatest on the Island. The bioluminescent

bay of La Parguera, the Dry Forest of Guanica, and the 16 kilometers of sandy beaches are outstanding features.

In summary, scarcity of water limits the potential for urban development in the southwest. Other characteristics, however, offer important opportunities for tourism and recreation and with irrigation, for agriculture. The morphology of the coast and the navigability of its waters likewise favor the development of industrial port complexes.

Reefs. Off Tallaboa and Bahía de Guayanilla, living coral cover is neglible, due to industrial development, although some isolated heads of *A. palmata* and *M. complanata* still survive on the seaward side. Over the last four years, coral cover has declined from 10-20 % to less than l %. A few areas of high coral cover and diversity still occur, for example, on the walls of the Guayanilla submarine canyon (Goenaga in litt., 7.3.86). The reef off Punta Verraco, on the west of Guayanilla Bay, has an extensive *Thalassia* and *Syringodium* bed on its reef flat. Stony coral cover on the shallow front reef is very reduced but the deeper fore-reef has an extensive and quite healthy community of soft corals and gorgonians. An extensive submerged reef extends from Punta Vaquero to Punta Ventana, where it breaks the surface first as a fringing reef and later as a barrier reef protecting Playa Tamarindo, Bahía de la Ballena and Playa de Cana Gorda just west of Guánica. This reef is almost totally devoid of living coral and has huge carpets of the fast-growing colonial anemones *Zoanthus* and *Palythoa* lying over the dead coral framework. Quinn (1972) has described surge channels on the south-west coast.

West of Punta Jorobado, reefs become more prolific and complex, due to limited rainfall, minimal soil run-off and low wave action, and are described in the account for La Parguera (Goenaga and Cintrón, 1979). Around Cabo Rojo, the reefs are small and often do not break water although coral growth is fairly abundant. In the small bay west of Cabo Rojo lighthouse, patches of coral alternate with *Thalassia* grass beds, and are described in Almy and Carrión-Torres (1963). Bajo Gallardo is a well developed, relatively untouched reef about 13 km west of Punta Aguila, Cabo Rojo, with luxuriant *A. palmata* growth and abundant fish life. Roca Ola, a patch reef in Bahía Sucia, Cabo Rojo, has large colonies (more than 3 m diameter) of *M. annularis* (Goenaga in litt., 73,96).

The Caja de Muertos complex on the south coast includes Caja de Muertos (17E55'-17E54'N, 66E33'W, 8.5 km off the coast and west of Santa Isabel), Cayo Berberia (17E55'N, 66E27'Wg 5.5 km to the north-east) and Cayo Morrillitos at the tip of Caja de Muertos. Villamil et al. (1980) gave a detailed description of the area, including climate (data from Santa Isabel airport), geology and physico-chemical characteristics of the water. Aspects of marine geology are described by Beach and Trumbull (1980) and sedimentation by Beach (1975). Both cays are vegetated. Villamil et al. (1980) mapped the marine communities of the area; seagrass beds cover 1110 ha and coral reefs cover 519 ha, a variety of other types making up the remaining area.

Cayo Berberia had an extensive (3 km) fringing reef on the eastern and southern shores. Coral development reached a maximum on the southern shore where the *A. palmata* zone reached 95% cover prior to Hurricanes David and Frederick. The reef was described in more detail by Villamil et al. (1980) who considered it to be richer and more diverse than the reef at Caja de Muertos. The reef

crest was a low relief zone which, with the exception of some *M. complanata* and small *A. agaricites* and *F. fragum* colonies, was devoid of coral growth and dominated by alga(;, with much coral rubble. The *A. palmata* zone now appears as a low relief barren platform with sand filled depressions and only a few small colonies of *A. palmata* and other hermatypic corals. *P. astreoides* is the most abundant species and coral cover is 11.6%. Beyond this zone, the reef slopes down to a depth of 12 m at an average angle of 35E. Coral cover and diversity increase considerably on the fore-reef slope. The dominant coral is *M. annularis* and coral cover averages 21.7% (Ferrer Hansen, in litt. 12.5.86). South-east of Berberia is a small submerged reef called Las Cervezas which had extensive *A. palmata* coverage and dense gorgoruan stands. Fish life was especially abundant.

On Caja de Muertos, greatest reef development is found on the northeastern shore. This reef is particularly noticeable for its complex high relief lagoon which supported a variety of benthic and nektonic fauna (Goenaga and Cintrón, 1979). It was described by Canals et al. (1980) and Villamils et al. (1980). Four zones were identified: a) a lagoonal zone, b) a reef crest, dominated by Millepora spp. and zoanthids, c) an *A. palmate* dominated zone and d) a fore-reef (4-7 m deep), where gorgonians and octocorals predominate. Twenty six species of coral were recorded. Coral cover was highest (34-37%) on the fore-reef and only 2-11% in the *A. palmata* zone.

Villamil et al. (1980) gave a detailed description of noteworthy flora and vegetation of the cays. Mangroves are found on the two major cays and there is a large expanse of seagrass. Villamill et al. (1980) provide species lists for echinodertns, crustaceans, molluscs and fish (69 species). The reef at Cayo Berberia has a higher diversity of fish than that at Caja de Muertos. Juvenile spiny lobsters *P. argus* and the queen conch *S. gigas* have been recorded. Large numbers of marine turtles may nest on the beaches of Caja de Muertos, although not recorded in Bacon et al. (1984), and the area is visited by the Caribbean Manatee *Trichechus manatus*.

Disturbance or Deficiencies: Hurricanes David and Frederick caused greater damage at Caja de Muertos than at Cayo Berberia and affected the *A. palmata* zone, resulting in increased algal cover in this area. Caja de Muertos reefs appear to be more intensively fished than those around Cayo Berberia (Villamil et al. 1980).

Recommendations: The proposed boundaries of the reserve and recommendations for its management are given in Villamil et al. (1980). It is suggested that the mangroves on Caja de Muertos should be made a restricted zone; zones for recreational activities should be established; collection of marine organisms should be prohibited. Anchoring should be limited to certain sites, spearfishing prohibited, and an underwater trail established. It is not known whether any of these recommendations have been carried out.

CAYO RATONES PROPOSED PROTECTED AREA

Geographical Location. South coast, about 1.1 naut. mi. (2.03km) south of Ponce; 17E57'N, 66E40'W.

Physical Features. One of the numerous mangrove islets fringed by coral reefs which lie off Ponce (other islets include Isla de Frio, Isla de Cardona, and Cayo Cardona). Waters are moderately

siltladen (Goenaga and Cintrón, 1979). Tidal range at Ponce is 0.18 m (Velazco-Dominguez et al. 1985)

Reef. A fringing reef borders the south coast of the island. Its zonation was described by Goenaga and Cintrón (1979). The reef crest was dominated by *M. complanata*, with occasional colonies of *A. palmata* and abundant *Palythoa.* In the *A. palmata* zone living cover increased seaward; many dead colonies were found shoreward. Large buttresses, about 3 m in relief were topped with *A. palmata*, scattered gorgonians and *M. annularis* colonies. *A. palmata* cover decreased towards the mixed zone which was dominated by gorgonians, for a width of about 100 m. *M. annularis, M. cavernosa* and *Siderastrea* were also common, as well as dead *A. cervicornis* colonies. On the reef flat *Thalassia* and *Syringodium* were found but the *P. porites* biotope was not well developed. Ferrer Hansen (in litt., 12.5.86) reports that the fore-reef is now dominated by *M. cavernosa* and that the encrusting gorgonian *Erythropodium caribaeorum* is the most dominant species.

Mangroves grow on the reef flat (Goenaga and Cintrón, 1979). The Caribbean manatee *T. manatus*, hawksbill turtle *E. imbricata* and leatherback turtle *D. coriacea* may occur in this area.

Disturbance or Deficiencies: The reef at Cayo Ratones is considered to be deteriorating as evidenced by the abundance of *E. caribaeorum*. This is probably due to the high sedimentation rates and turbidity which have been recorded in this area, possibly because Cayo Ratones lies 2.6. naut. n-d. (4.8 km) downstream of a sewage treatment plant and 4.6 naut. mi. (8.5 km) downstream of the industrial harbour at Ponce (Ferrer Hansen in litt., 12.5.86; Acevedo, in prep.).

LA PARGUERA

Geographical Location. Southwest coast, 28 km south east of Mayagüez; 17E58' N, 67E 04'W; the area includes the following islands and cays: Cayo San Cristóbal, Cayo Laurel, Cayo Media Luna, Cayo Mario, Cayo Enrique, Cayo Turrumote, Cayo Corral, Isla la Gata, Cayo Caracoles, Cayo Majimo and Cayo Caballo and Ahogado. Bahia Fosforescente, a mangrove-bordered bay on the mainland is situated to the east of La Parguera, and Isla Magueyes is situated just south of the town.

Area, Depth, Altitude: Wetland area covers 400 ha.

Physical Features. The coast forms a broad landward indentation at the fishing village of La Parguera and is fringed with mangroves, intertidal mudflats, natural salt flats and shallow saline lagoons. The insular shelf is about five miles (8 km) wide at this point, and supports two elongated reef systems aligned approximately east-west. Goenaga and Cintrón (1979) discuss their possible origin. The outer line of reefs (Turrumote, Media Luna and Laurel) is situated about 3 km offshore, each reef facing the incoming waves from the east-southeast. The inner reefs (Enrique, La Gata complex, Caracoles, Majimo) are closer (1 km) to shore, forming an arc which is convex to the south. Most of the reefs are small but they increase in length westwards, and Arrecife Margarita reaches a length of two miles (3.2 km). They are considered to be poorly formed barrier or ribbon reefs. Channels between the reefs are 50-70 ft (15.2-21.3 m) in depth and have sandy bottoms. Between the inner

reef line and shore are small patch reefs; their rapid growth combined with the spread of mangroves is causing the shelf in this part to become shallower.

Hydrographic conditions in the waters off La Parguera are described by Coker and Gonzales (1960) and summarized by Almy and Carrión-Torres (1963). The climate is semi-arid with an average rainfall of 30 in. (762 mm) and an annual evaporation rate of 80 in. (2030 mm). Salinity averages 35.4 ppt and surface temperatures range from 25.5 to 32.0EC. The temperature-salinity characteristics are indicative of a mild hydrographic climate (Glynn, 1973). Winds are from the south-east or east-southeast and tend to freshen in the forenoon. Currents are from east to west and flow parallel to the coast. A continuous surface current flow over the reef, and a maximum daily tidal range of only 40 cm prevents marked temperature and salinity differences. A detailed description of this area is given by U.S. Dept of Commerce (1984).

Reef Structure and Corals. The majority of the larger reefs typically have a broad (up to 50 m wide) shallow reef flat. Of the outer reefs, Cayo Turrumote has the greatest variety of species although it is comparatively short. It is formed from large coral boulders thrown up by waves to an average height of about 1 m, but reaching 2-3 m on the eastern end. The exposed part of the reef has maximum dimensions of 100 x 1000 ft (30 x 300 m) and is topped with white mangroves. Seaward of the exposed part, the shallow fore-reef flat is covered with a *P. porites* pavement, scattered with *M. complanata, A. palmata* and *A. prolifera*. The pavement is unusually narrow, about 60 ft (183 m) wide, and at a depth of 2 ft (0.6 m) gives way to a dense growth of *A. palmata* in the surf zone. At 5-10 ft (1.5-3 m) *M. complanata* is found intermixed with *A. palmata,* with large massive boulders of *M. annularis*. Beyond 30 ft (9.1 m), coral density decreases although diversity increases. Coarse sand patches occur among the gorgonian patches.

On the shoreward side of Cayo Turrumote, an open lagoon extends to a steep slope along the north edge of the reef. *P. porites, F. fragum* and *S. radians* floor the shallow parts of the lagoon and give way to sand and widely spaced coral colonies in water deeper than 2 ft (0.6 m). At the north edge of the reef, the gently sloping lagoon floor drops from 15 ft (4.6 m) to a sand covered bank at 35 ft (10.7 m) depth. *A. palmata* is abundant along the edge of the drop-off and a variety of corals are found on the slope (Almy and Carrión-Torres, 1963). A buttress zone of very high relief, "The Pinnacles", so-called because of the large colonies of *M. annularis* which have grown in pyramid-like form (Nash pers. obs., 1983), has an abundant fish fauna (Goenaga and Cintrón, 1979).

Cayo Laurel is described by Glynn (1973). The reef flat has a high population density of *P. furcata,* usually oriented in patches parallel to the longitudinal axis of the reef. Six zones were identified down to 3 m depth. The shoaling seaward slope, with no spur and groove structure, is dominated by *A. palmata* and gives way to a rigid framework of *M. complanata* which forms a sill on the seaward edge of the reef flat. This has abundant dead coral colonies and is often exposed at extreme low water. On the leeward side, *P. furcata* and coral rubble predominate, the former appearing in dense stands in depths of 1.5 m. The deep edge of this *P. furcata* belt grades abruptly into a smooth sandy bottom, beyond which *Thalassia testudinum* is abundant.

The other outer reefs are similar, built of coral boulders with *P. porites* dominating the fore-reef flat and parts of the lagoon, and abundant *A. palmata* in the surf zone. A steep slope usually borders the seaward edge of each reef, beginning at 15-20 ft (4.6-6.1 m) and dropping to a trough at 65 ft (20 m) which tends to be particularly well developed along the fronts and east ends of the longer reefs. Where the trough is less evident on long reefs, a buttress formation may be present. There seems to be a slight variation in the faunal assemblages of each reef (Almy and Carrión-Torres, 1963).

Cayo Enrique is the best known of the inner reefs and is described by Aliny and Carrión-Torres (1963), Armstrong (1981) and Morelock et al. (1977). It is located 1.5 km south of La Parguera and is approximately 1.4 km long and 0.4 km wide at its widest point, aligned almost parallel to the shore (Armstrong, 1981), but oriented to the incoming waves and currents. It forms an apron reef with a shallow (0.5-3 m) area of sand deposition leeward of the reef flat. *T. testudinum* areas occur at both ends of the sandy lagoon and on the reef flat, and patch reefs are found in the middle and western parts of the lagoon. The reef flat is composed mainly of living *Thalassia, Zoanthus, Porites* and occasionally *Halimeda clumps* (Armstrong, 1981). The reef crest is dominated by *M. complanata,* and the zoanthid *Palythoa caribbea* is found encrusting dead corals near the reef crest.

At the eastern end, the fore-reef of Cayo Enrique is relatively broad and gradually slopes to a depth of 20 m. It gets narrower and steeper towards the west. The reef lacks a spur and groove formation but has a well defined coral zonation. *A. palmata* occurs seaward of the crest to a depth of 3 m followed by *A. cervicornis* to 5 m. A zone of massive corals occurs from 5 to 15 m and is composed mainly of *Montastrea, Diploria* and *Agaricia*. The lagoon patch reefs are dominated by *M. annularis* in addition to numerous sponges and gorgonians. Other corals present include *A. cervicornis, S. siderea* and *D. labyrinthiformis*. Dead coral heads covered with algae are common in this area (Armstrong, 1981).

The reef flat at La Gata reef complex has been divided into seven zones: a) a latticework of *M. complanata* and encrusting calcareous red algae; b) a pool with dead coral debris; c) an emergent reef flat; d) a mixed *Thalassia* - coral rubble zone; e) sand; f) massive clumps of the alga *Acanthophora spicifera*, and g) a sandy leeward lagoon (Glynn, 1968).

Goenaga and Cintrón (1979) give brief descriptions of reef zonation at San Cristóbal, Cayo Enrique, Cayo Laurel, Turrumote, Isla La Gata, Margarita, Las Pelotas, Cayo Ahogado, Cayo Media Luna, La Conserva, and Collado. San Cristóbal, a small reef 4-5 km south-west of La Parguera, has a high relief *A. palmata* zone with an abundant fish fauna. Cayo Laurel is a large, well-developed reef. Cayo Caballo Ahogado is situated shoreward of Cayo Enrique and is described briefly by Almy and Carrión-Torres (1963) and Morelock et al. (1977).

The main differences between the inner and outer reefs are the extensive red mangroves *R. mangle* on the former, mainly on the east and west ends, and the well developed mud flats and *Thalassia* beds in the lagoons (Almy and Carrión-Torres, 1963). The patch reefs north of the inner line of reefs, have mangrove thickets in various stages of development and a restricted coral fauna compared with the other reefs. *P. porites* is abundant in shallow areas and there is a poorly developed *A. palmata* zone on the seaward side. *P. porites* is the main constituent of the coral assemblages fringing the coastline

and also around the non-coral island Isla Magueyes. Almy and Carrión-Torres (1963) and Armstrong (198) provide a checklists of coral species found in the La Parguera area which has the greatest recorded number (54) in Puerto Rico. The productivity of the reefs is described in Odum et al. (1959); Rogers (1979a and 1983) studied productivity and sedimentation on San Cristóbal Reef.

Mangroves *R. mangle*, *L. racemosa* and *A. nitida* are found on the cays and along the shoreline throughout the area (Almy and Carrión-Torres, 1963; Armstrong, 1981; Glynn et al. 1964; Odum et al. 1959). The importance of the area as a wetland is described by Scott and Carbonell (1986). The Caribbean manatee *T. manatus*, the green turtle *C. mydas*, the hawksbill turtle *E. imbricate* and the leatherback turtle *D. coriacea* are found within the La Parguera area. The haemulid (grunt) fishery is described by Appeldoorn and Lindeman (1985). The area is a popular recreation site; Cayo Enrique is visited frequently by pleasure boats that stay up to 3-4 days anchored in the calm, sandy lagoon (Armstrong, 1981). La Parguera is being used increasingly as a weekend resort by families from further inland and increasing numbers of "casetas", houses on stilts, built over the waters bordering the mangroves (Nash pers. obs., 1983). The iguanas resident on Isla Magueyes are a popular tourist attraction with special boat trips to the island to "feed the iguanas" and Bahia Fosforescente is a further attraction.

Disturbance or Deficiencies: Hurricanes are the main destructive agents. The effects of Hurricane Edith in 1963 were documented by Glynn et al. (1964). Although extensive coral destruction on the outer reefs was observed, Cayo Enrique and other inner reefs suffered only 10 to 50% Acropora destruction, and there was slight damage to the mangroves. The topography of many of the outer cayos was considerably altered. Hurricane Beulah had a major impact in 1969. Hurricane David in 1979 passed 160 km to the south of Ponce and caused significant damage with boulder rampart accumulation on the reef flat at Cayo Enrique. The impact of this hurricane is described by Goenaga (1982a).

Changes on Cayo Enrique from 1936 to 1979 were studied using aerial photo-analysis (Armstrong, 1981). A two-fold increase in lagoonal seagrass areas occurred over this period. Mangrove areas increased fifteen times between 1936 and 1978 but an area of 1560 sq. m was destroyed by Hurricane David. Mass destruction of reef biota was recorded in 1965 as a result of extreme midday low tides. The impact was felt most strongly by echinoids and is discussed by Glynn (1968).

Increased deforestation inland on the La Parguera limestone hills, proposed resort development, domestic waste discharge and proximity to major industrial areas give cause for concern (Goenaga and Cintrón, 1979; Rogers, 1979b). Oil pollution, in the form of tar balls, was observed on the boulder ramparts at Cayo Enrique in 1979 and 1980. If this continues it could represent a major source of pollution. The effects of collecting by local fishermen and anchoring of pleasure boats are considered negligible at present by Armstrong (1981) but Appeldoorn and Lindeman (1985) consider the grunt fishery to be heavily over-exploited.

WEST COAST: Punta Guaniquilla (Cabo Rojo) to Rio Culebrinas (Aguada)

The west coast, like the southeast, is characterized by valleys defined by mountain chains that come down to the coastline. This stretch of the coast receives the largest amount of rainfall---from 65 to 90 inches annually. The abundance of water makes the principal valleys of the area---Añasco, Culebrinas and Guanajibo – of great agricultural value.

In the southern portion of this sector, beach plains predominate. However, north of Punta Guanajibo, there is a variety of coastal characteristics: rocky shorelines, mangrove stands, and fringing reefs. Mayaguez, located midway between Punta Guaniquilla and Rio Culebrinas, is the Island's third largest urbanized area -- and the third largest port city -- (after San Juan and Ponce).

Añasco, north of Mayaguez, is potentially an area of great agricultural importance because of highly productive soils. The Planning Board has proposed the area for agricultural uses. In addition, it is potentially an excellent site for a port and for heavy industry. The site has a good approach to the sea and favorable upland features. Development north of Añasco would be limited by topographical conditions, but there is ample land to the south.

Nickel deposits with an estimated gross value of $1.65 billion are located in Barrio Guanajibo, south of Mayaguez. Mining activities could affect some 1,850 cuerdas over a 25-year period.

Reefs. Between Cabo Rojo and Mayagüez, there is high water turbidity near shore, unusually slight wave action and heavy land drainage. The broad bank that lies immediately offshore minimizes wave action, limiting water circulation and the removal of land drainage pollution. The coral patches and assemblages generally have few stony corals, often covered by mats of macro-algae, but there are spectacular, dense stands of gorgonians (Kolehmainen, 1974). Bahía de Boquerón is very turbid, its reefs surrounded by mud, but nevertheless there is a dense covering of corals, particularly gorgonians.

Reefs to the north include Escollo Negro and Arrecife Tourmaline (see separate account), Las Coronas, Escollo Rodríguez, Cayo Fanduco, Manchas Interiores, Manchas Exteriores, Arrecife Peregrina and Gallardo. Las Coronas is a shallow (2-4 m) sand shoal colonized principally by large-sized gorgonians and occasional massive corals, extending east to Cayo Fanduco. Manchas Interiores, Manchas Exteriores and Arrecife Peregrina have low relief spur and groove systems sloping more or less abruptly westward giving way to a dense black coral dominated fauna. Encrusting coral growth with large pillar corals and gorgonians dominate the shallow depths. Escollo Rodríguez, situated about 1.6 km west of Cayo Corazones, consists of a series of elongated patch reefs which lack the distinct zonation found in the other reefs. There is abundant fish life but the reefs appear to be affected by siltation from the Guanajibo River (Morelock et al.1983; Schneidermann and Morelock, 1973).

A study of reef fish was carried out on a 25 sq. km reef tract about 9.5 km off the coast on the west coast from an underwater habitat (Parish, 1982; Parish and Zimmerman, 1977). This area consisted of a shallow bank, 3-6 m deep with a steeply sloping face of living coral on the seaward side to 16.5 m depth. The reef has a variety of living hexacorals and octocorals growing on an open porous structural framework of dead coral with a diverse assemblage of other sessile invertebrates and low, encrusting filamentous algae.

North of Arrecife Peregrina to Punta Higuero, the insular shelf is less than 1 km wide and has well developed reefs at its outer edge where the bottom slopes steeply. Stony corals, unusual gorgonians and black corals are abundant at depths of 15-40 m but water transparency is quite variable, being influenced by river discharge. Poorly developed fringing reefs, consisting mainly of partially dead *A. palmata* and scattered gorgonians occur on the north side of the Rincón Peninsula from Punta Higuero to Punta del Boquerón.

Arrecife Tourmaline and El Negro (Escollo Negro) (18E5'-18E10'n, 67E17'-67El9'W)lie off the west coast approximately 10 km west of Punta Ostiones and are two of the offshore reef areas on the west coast north of Boquerón. Currents flow mainly north-south or south-north, the northerly flow predominating (Loya, 1976). Visibility at El Negro is poor according to Loya (1976) although Goenaga and Cintrón (1979) mention high water transparency. East and West Reefs rise vertically on Escollo Negro from an average depth of 20 m to about 7 m; West Reef is a flat patch reef.

Escollo Negro is characterized by a low relief spur and groove system with high living coral cover and diverse encrusting coral growth. The system diminishes shorewards and gorgonian cover increases (Goenaga and Cintrón, 1979). East Reef has a reef flat at 6-8 m depth dominated by *A. cervicornis* which provides 45% coverage, *M. annularis* accounting for 28%. The upper fore-reef is at 9-17 m depth and the lower fore-reef at 18-20 m depth. At greatest depths, *M. cavernosa* is the main reef builder. At West Reef, the four commonest species, *M. cavernosa, S. radians, S. siderea* and *D. strigosa*, cover 73%. At East Reef, the four commonest species, *M. cavernosa, M. annularis, Agaricia agaricites* and *S. siderea* cover 62%. Twenty-one coral species have been recorded at El Negro (Loya, 1976).

Disturbance or Deficiencies: Turbidity and sedimentation produced by resuspension of local fine calcareous sediments during heavy, long-period ground swells originating in the Atlantic Ocean mainly during winter months are the most important factors affecting reef growth in this area (Cintrón et al., 1973; Kolehmainen, 1974; Loya, 1976). Terrigenous suspended sediments and domestic pollution from Rio Guanajibo and the presence of seston and plankton in the water column also affect turbidity. *M. cavernosa* is the dominant coral in areas most seriously affected by sedimentation, *S. siderea* suffering high mortalities.

NORTHWEST COAST; Rio Culebrinas (Aguada) to Rio Grande de Arecibo (Arecibo)

This sector -- the tableland of the northwest -- is characterized by a hilly interior and rocky cliffs along the coast. These cliffs, some as much as 300 feet high, are a tourist attraction because of their dramatic scenic beauty. Nevertheless, since the coastline is exposed to direct wave action of the sea, the potential for aquatic recreation is limited. The sand dunes on the coastline are an important resource, and submarine sand deposits off the coast of Isabela are important potential resources. The limestone bluffs of the northwest coast have been shaped by wave erosion. Along much of the coast, the bluffs extend several hundred meters or more back from the shoreline, with beach plain between the bluffs and the water. In the Jobos Beach area in Isabela, an extensive system of sand dunes exists. These pose a major coastal issue because of extensive mining which threatens the resource. East of Isabela, beaches are generally narrow, consisting of thin layers of sand over a rocky shoreline.

Despite numerous rocky headlands that separate these beaches, adjacent sand dunes supply most of the beach sands by landward erosion and littoral migration.

Borinquen Airport, the former Ramey Air Force Base now being leased by the Commonwealth, has the longest runway in the Caribbean. In addition, it has extensive aviation infrastructure, more than 1,000 housing units, and recreational facilities, including an 18-hole golf course, pools, and beaches. These facilities suggest the potential for commercial passenger and air cargo services, tourism, and related industries. Major steps towards the realization of this potential are currently being taken.

Reefs. North of Punta del Boquerón, only scattered, undeveloped coral growth occurs. There is an underwater cave system off Bajura, Isabela, with dense coral growth, especially *Agaricia*, on the outer walls and ledges.

THE OFFSHORE ISLANDS: including Culebra, Vieques, Mona, and others

The principal offshore islands of Puerto Rico are Vieques (33,970 cuerdas), Culebra (7,180 cuerdas), and Mona (13,900 cuerdas). The topography of the first two is similar, characterized by small hills. Rainfall on these islands is light. Vegetation is the same as that of the semi-arid South coast of Puerto Rico. Portions of the coasts are bordered by mangroves, and some of the bays are bioluminescent. The clarity of coastal waters contributes to the presence of coral reefs in the near-shore waters. These waters also provide favorable conditions for marine life and recreational boating. Economic activity on Vieques and Culebra is limited. The small population is supported by subsistence agriculture and fishing, limited industry and tourism, and civilian employment generated by the Marine Corps base on Vieques.

Mona is predominantly a limestone tableland surrounded by cliffs interrupted sporadically by bands of beach. Low rainfall and the extreme porosity of its soils result in a vegetation typified by dry coastal forest. The island is uninhabited; its flora and fauna include a large number of endemic species. The principal value of this island is as a natural reserve.

The other small islands, the majority of coral origin, are uninhabited and reflect natural conditions similar to the islands previously described. The many fringing islands of the south coast of Puerto Rico are also very important in numerous coastal processes.

THE ISLAND OF CULEBRA

Setting. The island of Culebra lies approximately 17 miles east of Puerto Rico, 12 miles west of St. Thomas,, and 9 miles north of the island of Vieques. Its total , including surrounding keys,, is 7,700 acres, It is characterized by irregular topography with hills of low elevation, the tallest being Monte Resaca; with an elevation of 650 feet.

Due to Culebra' s small size and low elevation, it does not force precipitation from the trade winds to any great degree. This accounts for the island's limited rainfall. As a result, the climate of Culebra is slightly xeric; mean annual rain-fall is only 36 inches, varying from 16 inches in the drought year

of 1967, to as high as 59 inches in 1942. There are no permanent fresh water streams on Culebra. Such conditions are favorable for a profuse coral growth in the surrounding clear littoral waters where sedimentation is reduced to a minimum.

Due to its long and intricate shoreline, Culebra presents a series of bays, peninsulas, and bars, some of which end in abrupt cliffs, sandy shores, or mangrove forests. The principal harbor is Ensenada Honda, which is considered one of the most secure hurricane harbors in the Leeward Islands.

Turtlegrass beds: Turtlegrass beds are found around most of the islands, in waters shallower than 30 feet, usually interspersed with stretches of sandy bottom, or coral reefs. The north and northwest sides of the islands are the exceptions because of heavy surf action caused by swells from the Atlantic Ocean.

Mangrove shores: Mangrove forests cover much of the shoreline in Ensenada Honda, and to varying degrees, the southeastern coasts of the islands . Most of the animals encrusted on mangrove roots are flat tree oysters and, to a lesser extent, edible mangrove oysters. Important mangroves are also present behind the following beaches: Flamenco, Resaca, Brava, and Larga.

Reefs. There is no information readily available for the reefs of Culebra and Culebrita Islands. The shallow-water sublittoral benthos is described by Cerame-Vivas et al. (1971); communities of P. furcata are found along the southeast coast of Culebra (Glynn, 1973) and Ensenada Honda is described by Cintrón et al. (1974).

Ensenada Honda on Culebra has been described by Cintron et al. (1974). Communities of Porites furcata are found along the southeast coast (Glynn, 1973) and are extensive off Puerto del Manglar off the eastern coast (Goenaga, 1983). These corals form extensive monotypic stands that extend from the leeward reef through the reef crest and into the reef front. This is quite uncommon in other reefs where large, monotypic stands of this coral are restricted to the leeward reef sections.

THE ISLAND OF VIEQUES

Located 18 km east of Puerto Rico (18E06' N, 65E 24' W). The special area is situated on the southern coast of the island between Punta Negra and Punta Jalova. The seaward boundary is delineated by the 50 m isobath, which is the edge of the island's coral shelf and is situated 2.6-4.5 km from shore (Anon., 1982).

The island of Vieques is approximately 9 miles southeast of Puerto Rico. It cover approximately 6,844 Hectares (33,000(Total) - 26,156 (Excluded Federal lands)).

Setting. There are no permanent fresh water streams on Vieques Island, and precipitation is minimal. Almost 3/4 of the island belongs to the Navy (approximately 26,156 of the 33,000 cuerdas). These portions of the island constitute excluded Federal land. Other lands include 1,900 cuerdas belonging to the Commonwealth Land Authority for agricultural uses; 1,200 cuerdas reserved by Fomento for

future industrial uses, 700 cuerdas belonging to the Social Programs Administration; 2,500 cuerdas in private lands for farming purposes, and 600 cuerdas for urban uses.

Vegetation in Vieques is similar to that of the semi-arid region of southwest Puerto Rico. The coast is fringed by mangrove wetlands and bays that exhibit the phenomenon of bioluminescence, such as Puerto Mosquito, Bahia Tapon, Puerto Ferro, and Puerto del Manglar. Many coral reefs are found in Vieques, and the broad insular shelf provides favorable conditions for proliferation of marine life. The most important natural areas in Vieques include its beaches, like Sun Bay, which has complete facilities; and mangrove systems like the ones in Laguna Kiana, Ensenada Honda, Bahia Tapon, Bahia Mosquito, Playa Grande, Bahia Ferro and Bahia Chiva, all of which are of great importance for Puerto Rico's wildlife.

The most important coral reefs bordering the coastal waters near Vieques are Ensenada, Cana Honda, Punta Vaca, Isabel Segunda, Caballo Blanco, Mosquito and Corona. These corals are of varied shapes and colors, and several species of fish are associated with them.

The eastern part of the island (within the Navy Base and therefore excluded Federal lands), exhibits numerous swamps and the adjacent hills of Mt, Pirata, as well as Kinani Lagoon, all of them natural areas of importance to Puerto Rico's wildlife.

The Vieques population, approximately 8,500 inhabitants, depends mainly on agriculture, fishing, and a modest tourist industry for subsistence. Water scarcity as well as the small amount of available land, have limited opportunities for industrial development in Vieques.

Reefs. Numerous fringing, patch and offshore bank barrier reefs are found around the coast of Vieques. Reefs on the south coast are discussed in the separate account for the proposed Vieques marine sanctuary. Those off the eastern end are well known as a result of a series of studies carried out for the U.S. Navy in 1978. The area is used as a practice range for air-dropped bombs and ships gunnery, but includes reefs at Punta Este on the eastern point, Peñasco Fosil, Punto Gato, Gato Afuera, Isla Yallis and Punta Icacos around Bahía Icacos on the north coast, Cerro Indio, Pena Roja, Bahía Salinas, Punta Salinas, Cerro Matias, and Roca Alcatraz on the south coast (Antonius and Weiner, 1982; Dodge, 1981; MacIntyre et al., 1983). Brief descriptions of these reefs are given in Antonius and Weiner (1982).

In the late 1970s, it was alleged that they were threatened by excessive run-off and sedimentation as a result of bombing and bulldozing and were being directly damaged by stray bombs and shells (Antonius, 1981; Antonius and Weiner, 1982; Dodge, 1981; Raymond, 1978; Rogers et al., 1978). Field investigations were concentrated within Bahía Icacos and Bahía Salina del Sur, the areas believed to be suffering the greatest military impact. The sediments of these two areas are described by Morelock (1978) and Raymond (1978). Raymond (1978) also carried out an ecological survey of the shallow reefs fringing the promontories on the eastern, western and northern shores of Bahia Salina del Sur. Two extensive sand beaches border the northeastern and northwestern corners. The fringing reef off the west side of the bay consists of a well-developed *A. palmata* community and banks and mounds of *P. porites* occur around two distinct promontories on the north coast

(MacIntyre et al., 1983), The fringing reef on the eastern side of the bay consists of *Montastrea, Siderastrea* and *Diploria* coral heads. Another reef juts out from the promontory and has zonation typical of shallow water Caribbean reefs: a reef crest and shallow forereef dominated by *A. palmata* and a mixed coral community at depths greater than 4 m, including *M. annularis, D. strigosa* and *S. siderea*. The seaward slope levels off at a depth of 8 m, grading into the sediment floor of the bay. The backreef, shoreward of the reef crest, is composed of large colonies of *M. annularis* on rubble and pavement. Maclntyre et al. (1983) describe the results of core drilling and give estimates of accumulation rates for this reef. Roca Alcatraz, an island 1 km south of the bay is surrounded by an *A. palmata* reef.

Reefs outside the range area include Mosquito Reef, some distance off the northwest coast and Ensenada Honda off the south coast (Dodge, 1981) which falls within the proposed marine sanctuary area (see separate account).

Physical Features: The seabed within the proposed area is a gradually sloping limestone and coral shelf, sheared off at the edge by volcanic activity. Beyond 50 m depth, the bottom plunges sharply to 900 m within the 4.8 m territorial water boundary, finally reaching a depth of 4 km, at 24 km from shore. Fine-grained sands overlay the hard coral bottom. The shoreward boundary is fringed by mangroves and sandy beaches. The clarity of the water contributes to the luxuriousness of the reefs. Several phosphorescent bays occur in the western portion of the proposed area outside Federally restricted water (Anon., 1982).

Reef Structure and Corals: No detailed information although there is a reef at Ensenada Honda. The reefs are probably similar to those of Culebra, and almost certainly similar to those at the eastern end of Vieques which have been intensively studied.

Mangroves fringe the coast. The Caribbean manatee may be found here occasionally. Green turtle *C. mydas*, Hawksbill *E. imbricata* and Leatherback *D. coriacea* Turtles nest sparsely on Vieques (Bacon et al., 1984; Groombridge, 1982).

The area's relative isolation makes it an ideal site for research, particularly into the nature and ecological relationships of phosphorescent bay habitats (Anon., 1982). Despite the intensive work carried out at the eastern end of Vieques, particularly at Bahia Salina del Sur, the reefs of this area do not seem to have been surveyed.

THE ISLANDS OF MONA AND MONITO

Geographical Location 67E57'W, 18E10'N; the islands are about 3 miles (4.8 m) apart, about 50 miles (80 km) west of Puerto Rico, half way between Puerto Rico and the Dominican Republic, in the middle of Mona Passage.

Area, Depth, Altitude Monito = 500 m x 300 m; maximum altitude 60 M;
Mona = 14,000 cuerda (5486 ha); maximum altitude 90 m.

Physical Features Both islands are surrounded by high vertical cliffs which drop to 100 ft (30 m) below sea-level and are undercut by caves at sea-level. They are the furthest offshore islands in Puerto Rico and are surrounded by clear seas with visibility up to 200 ft (60 m). The current in Mona Passage, where depths reach 500 fathoms (915 m), is generally to the south-west, but sometimes to the north-east. Winds are mainly from the north-east and south-east, and high seas often make access difficult; there are occasional hurricanes. The climate is semi-arid with a mean temperature of 79EF (26.1EC) and mean annual rainfall of 32 in. (813 mm). There is no water supply other than rain. Monito is roughly rectangular and covered with xeric scrub vegetation. Mona is a carbonate island with a very flat, gently sloping upland surface, composed mainly of pitted limestone and dolomite, with caves which contain phosphorite deposits. The upland area is bordered by a narrow coastal lowland plain around the southern edge of the island from Punta Este to Punta los Ingleses and from just west of Punta Caigo o no Caigo almost to Punta el Capitan on the west. The north has high sheer sea cliffs. Sandy beaches extend for five miles (8 km) on the south. Vegetation consists of low cacti and shrubs or is absent (Anon., undated).

The marine communities of Mona are described by Goenaga (1982b) and Cintrón and Thurston (1975). Reefs are found on the less exposed south-east, south and west sides of the islands and are considered to be in good condition. The north coast of Mona descends vertically as a wall to 90-100 ft (27-30 m) depth with abundant soft corals, fish and turtles. The south-west coast is fringed by reef. Black coral is present. A barrier reef south of Cabo Barrio Nuevo protects a shallow lagoon with coral.

The green turtle *C. mydas*, leatherback turtle *D. coriacea* and hawksbill turtle *E. imbricate* are known to nest on Mona Island (Bacon et al., 1984; Groombridge, 1982; Olson, 1985). Surrounding waters are visited by humpback whales *Megaptera novaeangliae*, pilot whales G. macrorhynchus, large fish such as tuna, shark and blue marlin. A total of 270 fish species have been recorded. Ghost and Hermit Crabs are common on the Mona beaches. There are important but potentially threatened populations of spiny lobster *P. argus*, queen conch *S. gigas* and West Indian top shell *Cittarium pica* (Pagán-Font, undated). There is a small area of mangrove. Turtlegrass is not extensive (Anon., undated).

Disturbance or Deficiencies: Although comparatively undisturbed at present, the islands are extremely vulnerable to any form of development and current visitor use is already having adverse impacts. There is no control over spearfishing which is reported to have had a deleterious effect on fish populations and oil pollution has been reported on Mona beaches (Anon., undated). A ship which was wrecked on a reef off Mona in 1985 is still there, with fuel leaking onto the reef and beach (Praded, 1986).

(b). **U.S. VIRGIN ISLANDS - Large scale characteristics**

General Description: The U.S. Virgin Islands (USVI), a territory of the U.S.A., comprises three main islands: St. Thomas and St. John (88 km east of Puerto Rico) in the north and St. Croix, 40 n. mi. (74 km) to the south, and about 90 small islands and cays. St. Thomas (8.3 sq. km) and St. John (5.2 sq. km) lie on the same submerged bank as Puerto Rico and the British Virgin Islands and the earliest

volcanic deposits of the north-west Caribbean lava flows are visible in many places (Connelly, 1966). St. Croix is the largest island (22 sq. km) and, unlike others in the Lesser Antillean chain, is primarily sedimentary in origin, and lies on a submerged bank separated from the other islands by a 4000 m deep trench. The geology of St. Croix is described by Adey et al. (1977). The islands are hilly with peaks rising to 474 m; the original forest is largely destroyed and existing forest and scrub is secondary.

The major wind and wave patterns affecting the Virgin Islands are related to westerly trade wind circulations to the north. Severe winds occur in the winter and hurricanes in the autumn. Average temperatures vary little between winter (25EC) and summer (28EC). The climate of St. Croix is described in Adey et al. (1977). Annual rainfall varies between 750 and 1250 mm, with heavy autumn and winter rains having profound effects on local marine sedimentation (Hubbard et al., 1981). Tides on St. Croix vary between diurnal and semi-diumal with a spring-tidal range of 0.24 m. Climatic conditions on St. John vary from the drier, windward (eastern) exposures to the moist mountain top.

A general description of the marine environments of the USVI is given in Island Resources Foundation (1977a). The marine environments of St. Thomas are described in two separate accounts. The ecology of Lindbergh Bay has been described by van Eepoel and Grigg (1970). No other general information has been obtained for St. Thomas. The fringing reefs on St. John are said to be poorly developed (Randall, 1963); those within the Biosphere Reserve, which covers over two thirds of the island, are described in a separate account. Outside this area, in Coral Bay, a more mature reef profile is found at Lagoon Point. Randall (1963) compared fish populations on an artificial and two natural reefs.

St. Croix has the most extensive reefs, with many miles of bank-barrier reefs, often with algal ridges, extending in an almost unbroken line from Coakley Bay on the north coast, around the eastern tip to Great Pond Bay on the south coast. There are also numerous fringing and patch reefs (Teytaud, 1980). On the north coast, the eastern shelf is up to several kilometers wide and is rimmed by emergent Holocene reefs, considered to be the best developed on the island (see separate account) (Dahl et al., 1974). The western portion is less than 0.2 km wide and is traversed by two small submarine canyons; in the Salt River and Cane Bay areas, the edge of the shelf drops precipitously into great depths and the reefs form a vertical wall supporting abundant growths of black coral (Teytaud, 1980). The south shore has a shelf up to 4 km wide (Hubbard et al., 1981). The reef zonation of the entire island has been mapped from aerial photographs for the Bureau of Land Management. The Virgin Islands National Park and Biosphere Reserve Buck Island National Monument (St. Croix)

Four recreation areas on St. Croix, administered by the Virgin Islands Government, provide similar activities to those at Buck Island and are mainly used by residents. These include the Stony Ground complex near Frederiksted in the west, with waterfront and beach access at Frederiksted; the Altona Lagoon facility in Christiansted Harbour; and Cramer Park on the east end opposite Buck Island (Anon., 1977).

A number of reef areas have been recommended for protection and are described in the following accounts:

South-eastern St. Thomas
Saba Island/Perseverance Bay (St. Thomas)
Salt River Submarine Canyon (St. Croix)
St. Croix Coral Reef Area of Particular Concern (APC)

Cane Bay, off the north coast of St. Croix, towards the west end, is also of conservation interest because of its popularity with divers and tourists and its scientific interest (Gladfelter in litt., 9.12.85). Lagoon Point on St. John has been recommended as a coral reef reserve (Björklund, 1974) but no further details are available.

ST. THOMAS

Southeastern St. Thomas
Geographical Location: South--east St. Thomas, 7 km south-east of Charlotte Amalie; 68E48'-64E54'W, l8El6'-l8El9'N. This area comprises Mangrove Lagoon, Benner, Jersey and Cowpet Bays and the waters surrounding nine offshore islands and cays: Bovoni Cay 50 acres (20 ha), Buck Island 42 acres (17 ha), Capella Island 22 acres (9 ha), Cas Cay 14 acres (6 ha), Dog Island 12 acres (5 ha), Patricia Cay 33 acres (13 ha), Rotto Cay 2 acres (1 ha), Great St. James 157 acres (64 ha) and Little St. James 69 acres (28 ha).

Mangrove Lagoon with its passages and bays forms a system 2 x 13 km in size although the average width of the lagoon is only 0.5 km; areas of offshore islands are given above; the area originally proposed as a sanctuary covers 32 sq. km.

Physical Features. This area is typical of the St. Thomas bank shelf, representing a former Pleistocene back-reef lagoon environment. The sedimentary geology and oceanography of the area is described by Hubbard (1979). Run-off caused by the steep slope of the island and the erodable nature of the soils causes sedimentary deposition within Benner Bay and Mangrove Lagoon. The latter lies in a north-east/ south-east trending fault zone of sedimentary fill at the mouth of Turpentine Run, the largest perennial stream on St. Thomas. Its mangrove-fringed islands and shallow waters contrast with the steep rocky coast of the rest of the south coast (Towle, 1985).

Bovoni, Patricia and Cas Cays, interspersed with reefs, separate Mangrove Lagoon from Jersey Bay. The uninhabited offshore islands are similar to each other in ecology and appearance, being volcanic in origin, and covered with thin stony soil. Cas and Patricia Cays have precipitous south and east windward sides but are flatter to leeward, where the headlands are dominated by cedar and mangroves (Anon., 1982; OCZM, 1981). Other islets in Jersey Bay include several groups of rocks such as Cow and Calf, the Stragglers, Welk, Dog and Fish Cay. Salt ponds are found on Great and Little St. James, Dog, Patricia and Capella Islands.

The rest of the area is dominated by fine sandy substrate with transitional seagrass beds of *Halimeda* and turtlegrass *T. testudinum*; 15 different biotic associations of calcareous algal plains, zones of rock and rubble and open ocean waters have been identified, as well as a series of shallow fore-reefs, deep reefs and back-reefs. Seaward of the reef community is the characteristic sand zone which typically separates Caribbean reefs from the deep water algal association (OCZM, 1981). Most of the offshore areas below 15 m depth are covered by a rich and diverse algal plain which is extremely productive and is frequented by a variety of crustaceans, molluscs and fish (Olsen et al. , 1978; Wells and Olsen, 1973). In the extreme eastern portion of Benner Bay there are two well-defined zones of sabellid worms.

Towle (1985) provides a detailed analysis of the area and identifies ten ecological zones or units within the lagoonal complex, all of which are bathed by the flow of water. They include the upland Tutu Valley area, the primary drainage basin of Turpentine Run, black mangrove-dominated high tidal flats, and several ponds and inner lagoons.

The climate of the area is subtropical and semi-arid, with a mean annual temperature of 79EF (26EC). Trade winds from the east are predominant from March to October and from the north-east from November to February. Periods of strong northerly winds are common from December to February. Annual rainfall averages 40 in. (1020 mm), most falling between August and December. Drainage into Mangrove Lagoon is described in Towle (1985). Tidal range averages 12 cm with a maximum of 24 cm at spring tides. Offshore currents are dominated by a branch of the Equatorial Current from the east for most of the year. The inshore area is dominated by tidal currents in the narrow passes and to the east of the St. James Islands (OCZM, 1981). Mangrove Lagoon has a salinity of about 42 ppt and is subject to periodic flooding and drying out.

Reefs. *A. palmata* dominates the shallow fore-reef along with a variety of other corals including massive formations of *Siderastrea, Montastrea* and *Diploria* and some *A. cervicornis, Agaricia* and *Millepora*. The reef communities surrounding the offshore islands and cays are variable and include several species of sponges and soft coral assemblages in the shallower waters. In deeper waters gorgonian forests are found, characterized by *Pterogorgia, Pseudopterogorgia, Eunicea, Plexaurella* and sponges.

Noteworthy Fauna and Flora The area including Jersey Bay, Mangrove Lagoon and Benner Bay with Bovoni Cay, Cas Cay and Patricia Cay, is the most extensive red mangrove *R. mangle* system remaining in the Virgin Islands. The cays of Mangrove Lagoon (Rotto Cay, Manglar Cay, Cas Cay, Patricia Cay and Bovoni Cay) support a unique and simple community of red, white and black mangroves. Sea Grape *Coccolaba uvifera*, cactus *Cephalocereus* and *Opuntia*, Saltwort *Batis maritima*, Bay Bean *lpomoea pescaprae* and Sea Spinach *Sesuvium portulacastrum* are found along the beaches of the mainland. Further inland White Frangipani *Plumeiia alba*, palms *Cocos nucifera* and *Coccothrinax alta, Agave sp.* and Casha *Acacia farnesiana* are found. The vegetation of the offshore islands is primarily mixed grasses, scrubby thorn woods and cactus, which is often extremely dense. A complete list of plant species found in the proposed sanctuary area is given in OCZM (1981).

Faunal lists for the area are given in OCZM (1981). More than 76 species of algae, 46 mollusc species, 15 sponge species, 58 echinoderm species, numerous cnidarian, annelid and crustacean species, 243 fish species, 5 marine turtle species, 100 shore bird species and three whale species have been recorded within the proposed sanctuary area. The green turtle *C. mydas*, Hawksbill *E. imbricata*, leatherback *D. coriacea*, olive ridley *Lepidochelys olivacea* and loggerhead *Caretta caretta* have been recorded (Towle et al. , 1978). They are no longer common but there are still two or three nesting sites of hawksbills on the beaches of Great St. James, Dog Island and Great Bay (Bacon et al., 1984). Turtles are often sighted at the precipitous underwater cliffs at Little St. James. The waters to the north and east of the sanctuary area serve as one of the many migrational paths for the humpback whale *M. novaengliae* as it enters the Caribbean from the Atlantic.

Over 300 species of fish have been recorded in the area (Randall, 1968), with seventy-nine species reported from Jersey Bay; Mangrove Lagoon is estimated to support more than 50,000 fish individuals. Prior to stresses from development, this area supported extensive populations of juvenile lobsters *Panulirus argus* and crabs. There is an extensive juvenile conch *S. gigas* bed between Great and Little St. James (Haines and Brownell, 1978; Sigina Environmental, 1979). Colonies of the West Indian fighting conch *S. pugilis* are found in Great Bay and in the St. James Passage.

The offshore islands are aesthetically spectacular, with windward rocky shorelines, sheer cliffs and massive boulders, and receive about 1,000 boats each year. Buck and Capella Islands, 15 minutes by boat from Charlotte Amalie, and Christmas Cove, facing Great St. James, are particularly popular, the former receiving about 6,000 visitors a year. Large numbers of recreational and charter boats are based in the area and Benner Bay and Mangrove Lagoon are used as hurricane anchorages. The St. Thomas Yacht Club is situated in Cowpet Bay and races often take place through the area. The leeward bays, coves and rocky points offer many of the finest dive sites in the USVI, including the cave formations at Cow and Calf Rocks, the ledges at Little St. James and the reefs at Buck Island, Capella Island and Nazareth Bay. There are sixteen dive sites within the proposed sanctuary which are frequented by tour operators, who make over 4,000 trips a year to them and several shipwrecks including a Royal Mail steamship on the south shore of Buck Island, a World War I freighter in West Bay, Buck Island, an unidentified wreck at Whelk Rocks and a Caribbean trading schooner.

Commercial fishing within the area involves about 50-60 fishermen. Inshore from the algal plain, the deep reefs support an important small-scale artisanal local fishery valued at 2.5 million dollars (Olsen, 1979). Landings average 1.7 million pounds (0.77 million kg) of fish and 122,000 pounds (55 340 kg) of lobster. Indian fish traps and boats generally less than 25 ft (7.6 m) in length are used. There is also a bait fishery for Harengula sp. and Anchoa sp., caught in fish traps and with hand lines. Benner Bay and Mangrove Lagoon are important fish nursery grounds (Olsen, 1979) and over 80% of the reef fish in the area are juveniles.

Disturbance or Deficiencies. Towle (1985) provides a summary of the events which have taken place since the early 1960s, when development started in earnest. The area was originally threatened by proposals to site a new airport on the southern shore of Mangrove Lagoon. Numerous environmental studies were carried out (e.g. McNulty et. al., 1968; Tabb and Michel, 1968) and the plans were eventually dropped, but an enormous increase in recreational activities created new problems. Upland

slopes and floodplains were bulldozed for residential sites, mangroves were cut and buried to create marinas, docks and sewage plants, roads and a race track. By 1980 the population of the drainage basin had reached 15,000.

Current impacts on the lagoon include: sewage pollution from anchored boats, sewage treatment plants, local septic tanks and shore establishments (the problems of sewage treatment are described in more detail in Towle (1985)); release of toxic trace metals from the municipal dump, boat yards, and local debris scattered around the lagoon margins and watershed; discharge of wastes causing high turbidity, low transparency and low oxygen content, an abundance of coliform bacteria posing a health hazard; growth of filamentous algae associated with high nutrient pollution loads; sedimentation associated with storm run-off from the watershed and shoaling of the lagoon floor with formation of a black mud blanket; disturbance of mangrove habitats by bulkheading, dumping and landfill to create dock space, berthing facilities and useable land; loss of productive inshore clam and fishing grounds and reduction in vitality of bottom biota; restriction of drainage with loss of fishing capacity and stagnation of backwaters favorable to mosquito breeding. Shoals in the Benner Bay entrance channel limit boat traffic, marine use and consequently economic viability (OCZM, 1981). Intense development in the upper drainage basin of Turpentine Run has increased the potential for flash flooding into Mangrove Lagoon (Towle, 1985). Most watershed sediment reaching the lagoon is fine-grained silt and clay which remains suspended, degrading water clarity. Changes in the drainage patterns into the bay since 1961 are described by Towle (1985).

Shoreline development is considerable in some areas. Hotels and condominiums are located at Nazareth Bay, Secret Harbour, Cowpet Bay and Cabrite Hill and there are private residences on the western side of Benner Bay and on the cliffs between Compass Point and Cowpet Bay. Commercial docks and a number of privately owned small docks are concentrated east of Mangrove Lagoon between Turpentine Run and Benner Bay. Extensive marina development has occurred in the Benner Bay area (Anon. 1982).

In the late 1960s, turtlegrass dominated Jersey and Benner Bays and the Mangrove Lagoon (McNulty et al., 1968; Tabb and Michel, 1968) but by the early 1970s, this had been largely replaced by algae and mud (Olsen and Damman,1971). The benthic jelly fish *Cassiopea* population had increased dramatically. These changes were probably caused by development in the surrounding watershed and eutrophication. Deteriorating water quality has caused the formation of a loose semiliquid sediment, covered by the spermatophyte *Halophila baillonis*, a species characteristic of stressed environments, over 90% of the inner lagoon, extending through Bovoni Passage into deeper parts of Benner Bay.

A number of dredge and fill activities took place between the 1960's and 1970s. In Mangrove Lagoon, the area between the mainland and Patricia Cay was dredged to make a small beach on the northside of Long Point. Artificial beaches were created at Cowpet using sand from Cowpet Bay, and at Secret Harbour using sand from Nazareth Bay. Some illegal small-scale dredging has taken place in and around Benner Bay.

Houseboats at Cas Cay and in the Lagoon have caused local pollution. The seagrass beds of Cas and Patricia Cays are a maze of drag lines where boats have run aground, and the bottoms of Boyd and

Delugo Bays are already littered with trash (Anon., 1982). In the 1960s the back-reef community of *Porites* extended through the entrance channels at Patricia Cays into the lagoon (McNulty et al., 1968) but the segment in the Patricia entrance is now dead. Cas Entrance reach was once filled with Porites rubble and living corals (McNulty et al., 1968) but subsequent surveys have shown it to be covered with a *Halimeda/Penicillus* community (Grigg et al., 1971), turtlegrass (Tabb and Michel, 1968) and a fine calcium carbonate sand (Olsen, 1979).

The carrying capacity of the area for boats and yachts may well have been exceeded. Buck, Capella and the St. James Islands have been affected by careless anchoring. Cabrita Point and Packet Rock were popular spearfishing grounds less than a decade ago but are now seldom visited. Spearfishing still occurs occasionally off Dog Island, Cow and Calf and Little St. James (OCZM, 1981). Increased recreational use may destroy conch and lobster habitat (Anon., 1982); the conch bed between Great and Little St. James is under heavy recreational pressures. Triton and helmet shells have been over-collected by tourists and resident shell collectors.

Management. There have been numerous, so far unsuccessful, attempts to control pollution in the lagoon and these are discussed by Towle (1985). Current attempts include proposals for a new sewage treatment plant and a solid waste incinerator/energy recovery plant, to be located at the Lagoon head shoreline on the land previously purchased by the government for the aborted jet airport. Dive guides had assumed a substantial degree of responsibility for protecting the reefs by the 1970s (Anon., 1982).

Recommendations. The area was identified as a potential marine sanctuary under the 1972 Marine Protection, Research and Sanctuaries Act (Anon., 1982), and a Draft Environmental Impact Statement was prepared (OCZM, 1981), containing detailed proposals, goals and objectives. A number of options for regulatory measures and boundaries were suggested and are discussed in Anon. (1982) and OCZM (1981). It was suggested that the Virgin Islands should promulgate specific regulations pursuant to the Virgin Islands Coastal Zone Management Act of 1978 (I2VIC #901) which should apply only within the sanctuary boundary. These should prohibit the taking or damaging of any living natural resource; permit traditional fishing methods except at designated dive areas; prohibit disturbance of cultural resources; prohibit anchoring in a manner damaging to coral; prohibit the discharge of substances except cooling waters from vessels, fish, fish parts or chumming materials and discharges from marine sanitation devices; and limit alteration of the seabed to the area outside Mangrove Lagoon to those in the public interest. The area is still on the Site Evaluation list, but has been removed from the list of Active Candidates.

Much of the Government owned land between Long Point and Turpentine Run was designated an area of particular concern under the Virgin Islands Coastal Zone Program in 1978 but this has had little impact. A management plan for the St. Thomas Mangrove Lagoon area of particular concern was produced (Teytaud, 1981) but this was considered too late to have any effect, too complex for efficient application and too removed from prevailing uses and management requirements to be accepted (Towle, 1985). A cleaning-up operation would be necessary to restore the seriously disturbed areas.

SABA ISLAND AND PERSEVERANCE BAY AREA

The southwest coast of St. Thomas (18E20'N, 64E59'W), including Perseverance Bay, Brewers Bay, a portion of South-west Road, and waters surrounding Saba Island, Dry Rock Cay, Turtledove Cay and Flat Cay. Covering approximately 14 sq. km.

Physical Features Perseverance Bay is the largest bay on the south-west coast of St. Thomas and is naturally protected from waves driven by the prevailing northeast trade winds. The mainland shores are primarily sand and cobble pocket beaches situated between rocky promontories. Below 15 m depth, algal plains predominate. In shallower depths, seagrass beds, sand and coral formations cover the bottom (Anon., 1982). Saba Island and Flat Cay are uninhabited cays 3.6 and 2 km SSW of Truman Airport runway. The area is described in detail by Rogers (1982), and the hydrology by Island Resources Foundation (1977b).

Reefs. Extensive fringing reefs are found in western and eastern Perseverance Bay, central and western Brewers Bay and along the eastern shores of Saba Island and Flat Cay (Anon., 1982). Perseverance Bay has a submerged barrier reef. Brewers Bay has submerged barrier reefs in the western and central portions, the smaller western reef being separated from the central one by a distinct sand channel. *P. porites* and *M. annularis* are abundant; *Agaricia* sp. is abundant at Perseverance and Brewers West, and *Millepora* is abundant at Perseverance and Flat Cay (Rogers, 1982; Rogers et al., 1983).

Seagrass beds intermixed with algae cover much of the sandy substrate of Perseverance and Brewers Bays. Mangroves are found around salt ponds on the mainland shore. Perseverance Bay Pond is briefly described in Scott and Carbonell (1986). Fighting conch *S. pugilis* are found on the algal plains. 136 fish species have been recorded (Anon., 1982).

Disturbance or Deficiencies. Hurricanes occur on average once every 23 years, damaging corals and causing surge water levels 1.5-3.7 m above normal. Rogers et al. (1983) describe damage at Brewers West, Brewers Middle, Perseverance Bay and Flat Cay due to Hurricanes David and Frederic in 1979 and Allen in 1980. There was a significant decrease in live coral cover and water quality and recovery will not be complete for several years. Water quality within the area is generally good but high concentrations of heavy metals have been recorded in salt ponds near Perseverance Bay and turbidity in Perseverance Bay has been increased by dredging operations in Brewers Bay and following hurricane disturbance of the bottom. The runway of Harry S. Truman Airport was extended into South-west Road, south of Brewers Bay, and appears to have modified the water circulation here although there was no severe damage to reefs and seagrass beds (Rogers, 1982). Sediment plumes moved by wave-generated longshore currents have been observed to transport sediment from Brewers Bay into Perseverance Bay where the net circulation appears to move in a counter-clockwise direction. Convergent littoral currents within Perseverance Bay cause the accumulation of unsightly refuse and debris along the shore (Anon., 1982).

ST. JOHN AREA

Virgin Islands National Park And Biosphere Reserve
Covers two thirds of the island and surrounding waters of St. John; 18E21'N, 64E44'W. The reserve includes 3644 ha land and 2286 ha sea; total area: 6127 ha; altitude 0-389 m.

The Park includes steep, verdant hillsides, rising from rocky shores which are interspersed with coral sand beaches, numerous bays and cays, and is described by Robinson and Henle (1978). There are clear, warm waters, fringing reefs, seagrass beds, mangroves and natural salt ponds. At Leinster Bay there is a mangrove swamp and reef flat. Along the north shore beaches, west of Mary Point, there are shallow fringing reefs adjacent to the major headlands and deeper, sloping fringing reefs of scattered coral heads. There is also a system of extensive patch reefs rising to within 5-20 ft (1.5-6 m) of the surface. Cinnamon Bay has a large beach and a small offshore cay; fringing reefs surround the headlands and cay and there are offshore patch reefs. Within Trunk Bay there are several large reefs, mostly fringing the headlands, and an offshore cay. Along much of the southern and eastern shores, water depth increases more rapidly off shore and much of the shallow-water coral growth consists of scattered colonies on hard rock, with few significant offshore patch reefs (Hoffman et al., 1974). Temperatures remain fairly constant around 26EC, and rainfall averages about 1000 mm per year (IUCN, 1982).

Reef Structure and Corals The shallowest fringing reefs, at eastern Cinnamon Bay, Windswept Beach and Denis Bay, are typically barren on their upper, wave-washed surfaces, which are occasionally exposed by extreme low tides. The emergent reef crests support encrusting sponges, zooanthids, the sea urchin *Echinometra sp.*, seaweeds and encrusting *Millepora sp.* Seaward of the reef crest, *A. palmata* stands, oriented in the direction of incoming waves, are interspersed with encrusting *Diploria* spp. and *Millepora* sp. The protected reef face is steep or overhung.. with *Agaricia* sp. and *Cladocora* sp. *Montastrea spp*. dominate the base of the reef (Robinson and Henle, 1978).

Various stages of reef development are apparent, from eastern Cinnamon Bay, where development is minimal, to Annaberg and Mary Creek where the reef extends seaward over 100 m, producing a broad, shallow back-reef supporting a dense growth of the alga *Halimeda* sp. and isolated patches of *P. porites*. Mary Creek has dense growths of seagrass *Thalassia* sp. Offshore patch reefs, such as Johnson's Reef off Trunk Bay, are similar to the fringing reefs (Robinson and Henle, 1978). A low lying, shallow patch reef in the eastern part of Greater Lameshur Bay was surveyed in the course of a study of fish diversity (Risk, 1972). Corals present included *M. annularis, M. alcicornis, P. furcata*, and *A. agaricites*.

Disturbance or Deficiencies. IUCN (1982) describes some of the problems occurring within the terrestrial part of the Reserve. Centuries of intensive plantation agriculture stripped St. John of its original vegetation although gradual regrowth has brought back some forest. There are road cuts and residential development within the authorized Park boundaries and private development of land is causing heavy soil erosion. The marine environment has remained relatively undisturbed, but there is some visitor impact on the reefs of Trunk Bay, poaching of turtle eggs, coral collecting and boats anchoring on reefs. The underwater trail at Trunk Bay has been badly damaged by tourists, usually

collecting coral mementos. There has been noticeable damage in some areas from trampling, diving or swimming (Rogers, 1985). The reefs off Windswept Bay are regularly damaged by charter boats running aground (Boulon, R. pers. comm. to Nash, S., 1983).

ST. CROIX

St. Croix Coral Reef. Located mainly along the northeast and southeast coasts of St. Croix; 17E45N, 64E33'W.

The mainland shore consists largely of segments of sandy beach interspersed with low and steep rocky areas. Coral reef formations are distributed throughout the area with numerous reefs fringing the shore (Anon., 1982). Seagrass beds are found in shallow lagoon areas in association with patch reefs. Sediments of the insular shelf are described by Hubbard et al. (1981).

The east end of St. Croix is fairly dry with an annual rainfall of 30 in. (760 mm), much of this concentrated in the rainy season from June to December. Occasional very heavy rains may reduce salinity below 35 ppt near shore where intermittent streams enter the lagoons. In the vicinity of the reefs and ridges, salinities probably only rarely go below 34 ppt. Offshore sea temperatures range from 25EC in February to 28EC in July; lagoonal temperatures behind the reef are in the range 23-30EC. Easterly trade winds are very constant. Water clarity is usually largely dependent on wave action and the resulting suspension of fine carbonate sediment. In rough weather visibility is about 4-6 m; in calm weather visibility may reach 15-20 m. Visibility is poorest in the summer when plankton density is at its highest. The tidal pattern is diurnal with a range of 30-35 cm during spring tides and 10-15 cm during neap tides when a semi-diurnal pattern may occur (Adey, 1975). Tropical storms or hurricanes occasionally pass to the south during the autumn and tsunamis have been recorded (Anon., 1982; Rogers et al., 1979).

Reefs. The shallow coral reef and algal ridge systems on the eastern shelf of St. Croix are described and mapped by Adey (1975). Bank barrier reefs on the landward edge of the insular shelf parallel the northeastern and southeastern coasts for over 5 km (Dahl et al., 1974). The insular shelf is relatively shallow (10-15 m) at its western ends both in the western Buck Island Channel on the north and along the south shore from Krause Lagoon west. Further east on the south coast, around Grassy Point, the shelf lies at about 15-18 m under the reef and 20 m outside. To the north, off Boiler Point, a shallow shelf in the bay slopes to about 20 m just off shore and has given rise to a triple-reef complex. At East Point, outside the reef, the shelf is about 24 m deep.

The reefs on the inner shelf extending eastward to East Point, from Pull Point in the north and Long Reef in the south, show a general pattern of decreasing maturity. Reef flats are relatively broad to the west, becoming narrower towards the east; they are fragmented off Boiler Bay in the north and Grapetree Bay in the south, and are virtually absent from Isaac Point around East Point to Lamb Point (Adey, 1975; Adey and Burke, 1976). In many places they have become so shallow that coral growth is less prolific now than it used to be. West of the southern ship channels, there are a few reefs which are generally poorly developed with narrow or patchy reef flats. Abundance of live *A.*

palmata decreases from east to west; in the east shallow reefs are dominated by impressive living and dead stands (Adey et al., 1981).

The reef flats are generally dominated by *A. palmata*, a large part of the pavement surface being constructed of dead branches coated with crustose coralline algae. The outer edge or crest of the flat tends to have a high proportion of *M. complanata*. The back-flat sections, as they deepen into the lagoon (2-6 m), frequently have abundant Montastrea annularis, Diploria spp., P. porites and the small form of *A. cervicornis*.

The *A. palmata* forereef extends to about 13 m depth at East Point, the lower boundary gradually rising to the west probably because of decreasing light due to turbidity and lessened wave action. Further west on the north shore (on the Teague Bay Reef, on the south side of Buck Island Channel and on the western parts of the South Shore), the lower depth limit is 5-8 m (Adey, 1975). The bank barrier off Teague Bay has about 5 m relief off the shoreward edge and is approximately 90 m wide. It is dominated by *A. palmata* but an indistinct zonation is found around the inner edge of the reef where the base is characterized by *M. annularis*, the edge by *A. palmata* and large mounds of *P. porites* (up to 2.5 m high and 4.5 m wide) and the top by *A. palmata, Diploria* and *Millepora*. The seaward slope drops off to 14 m depth (Dahl et al., 1974). The reef at Teague Bay and Knight Bay is described in several publications including Gladfelter (1979) and Ogden and Ehrlich (1977). Candlelight Reef, at the end of the northern bank reef forming the seaward margin of Coakley Bay, is a large patch reef, slightly separated from the main reef by a boat channel. The reef flat is partly algal turf. The reef, which supports sparsely vegetated Sand Cay, is dominated by A. palmata, with small amounts of *Porites, Montastrea* and *Diploria* present (Gerhard, 1981). Long Reef, in Christiansted Harbour on the north coast, was surveyed in 1972 (Teytaud, 1980).

Several patch reefs northeast of Buck Island, rising from a sandy shelf at a depth of about 10-12 m, appear to be anastomosing thickets of massive *A. palmata* from top to bottom (Adey, 1975). A deep patch reef directly east of Buck Island consists of mainly *A. palmata* and has a relief of 8-9 m. It is covered with large heads of *M. annularis, Diploria* sp., *M. cavernosa* and surrounded by a great abundance of alcyonarians (Dahl et al., 1974). Reefs immediately around Buck Island are described in a separate account.

In the relatively quiet Buck Island Channel, an irregular band of *P. porites* often extends from the base of the *A. palmata* forereef to the sand channel floor at a depth of 10-12 m. Further east and on the south shore, this zone is usually occupied by *A. cervicornis*. The A cervicornis band can be extensive or may consist only of scattered patches. From the lower end of the *A. palmata* fore-reef to the sandy shelf, the dominant coral is usually *M. annularis*, with interspersed *Diploria* spp., *A. cervicornis* and *A. palmata*. Occasionally a marked spur and groove pattern occurs in the lower fore-reef. The lower boundary of the deeper fore-reef is sometimes marked by an abrupt drop of 1-2 m to the sediment interface. A flat sandy shelf is found directly below the *Montastrea-Diploria* deep forereef which generally extends almost to the reef margin (Adey, 1975).

Between East Point and Lang Bank the sand band is narrow and the shelf beyond is coated with a pavement or hard ground. The dominant coral here is *M. meandrites* although *M. cavernosa, S.*

siderea, D. strigosa, D. stokesii and *Zoanthus* spp. also occur. Approximately 75% of the surface is coral-bare pavement with abundant sponges and gorgonians (Adey, 1975). Lang Bank is the best example of an inactive reef, the predominant reef type of St. Croix. It is situated at the eastern shelf edge at 9-18 m depth and is ideally located for active barrier reef growth. However, an interlocking reef framework is lacking, and the bank is largely a rubble-covered carbonate pavement with abundant alcyonarians, sponges and large sand patches with only scattered coral heads and very little *A. palmata* (Adey et al., 1977; Dahl et al., 1974).

Isaac Reef on the eastern tip, extending from Cudejarre Point to Isaac Point, is a relatively young reef with narrow reef flats. The crest is broken by numerous channels, there is high living A. palmata cover and the reef breaks the surface in a discontinuous fashion. Off Robin Bay, on the southeast coast a strongly developed mature reef, with a nearly continuous crest and a moderately deep reef flat, blocks most of the shore from Rod Bay to Great Pond Bay. It has a wide and relatively shallow back-reef. Living A. palmata is an important constituent but there is only 20% cover. Further west off Halfpenny Bay there is a continuous reef with a broad and shallow reef flat, and few living acroporids (Adey et al., 1981).

A reef (known in some publications as Long Reef) forms a barrier between the sea and Krause Lagoon, opposite the Hess Refinery on the south coast. Two channels have been cut across the reef to provide access to the lagoon. The waters is relatively turbid. The reef appears to consist of a rather loose aggregation of coral fragments, although this may be a result of blasting in the channel (Adey, 1975). Further west, Channel Reef is the remains of a reef between the Hess Refinery and the Martin Marietta Bauxite plant channels, and Airport Reef is a patch-like structure lying west of the ship channels (Adey et al., 1981). The back-reef areas of Airport Reef do not correspond to the normal pattern but appear to be a series of relatively young, elongate patches.

Off open shores, the reefs develop algal ridges at the surface (Adey, 1975). *Lithophyllum congestum, Porolithon pachydermum* and several Neogoniolithon species are the primary algal ridge builders. All of the known algal ridges occur east of Canegarden Bay on the south coast. The westernmost ridge is on the south shore at Vagthus Point but most of the ridges lie east of Great Pond Bay. Small ridges are found on the north side of Buck Island, on the south shore outside Spring Bay and at East End Bay. Algal cup reefs are found around Cottongarden Point. These have pronounced rims and overhand , with a relief of about 2 m. Their upper surfaces are covered by fleshy algae including *Sargassum* ssp. and a few flat colonies of *P. astreoides* (Dahl et al., 1974). The main ridges, however, are found off the South Shore at Fancy Mountain, Robin Point, Isaac Bay, and at Boiler Bay at the eastern end.

The algal ridges at Fancy Mountain are relatively low and are degenerating as a result of wave-blocking by the *A. palmata* ridge forming on the outside. The algal ridge complex off Robin Point lies on a south-westerly projection of the reef system. It is open to the easterly sea and almost perpendicular to the wave direction and is generally the roughest and most active of the ridges. In the outer line, there are small individual boilers or cup reefs, 2-3 m in diameter, with well-developed raised rims and marked central depressions. Others are up to 30 m in diameter, with highly raised rims on the seaward margins only. The relatively deep (1 m) central basins in this case often have

large *Diploria* heads. Such structures are formed by fused individual boilers. Robin Ridge lies landward and north-west of the actively growing *A. palmata* reef. The waters immediately around these high algal ridges are often relatively deep (3-6 m), and in addition to rubble and sand patches in some of the channels, the pavements often support a community of scattered but large *Diploria* spp., *Millepora* and *M. annularis*.

Beach Algal Ridge, between Grassy and Grapetree Points, is the longest (over 0.5 km), straightest, and probably the oldest Holocene ridge. It is being blocked by an off-lying reef system which has already developed a reef flat in the eastern part. Isaac Algal Ridge off Isaac Point is one of the smallest, but being quite exposed it has high rims. The developing A. palmata reef here is still relatively deep (3-4 m). The Boiler Bay Algal Ridge is described in detail by Adey (1975). The surfaces of the boilers are infested with *Echinometra*, their burrows occupying about 30%. Crustose corallines occupy about 30% of the remaining surface, interspersed with algal-bored, dead coralline peysonnelid crusts, *Homotrema* and the crusts or filamentous bases of abundant fleshy-leaf algae. The latter are described by Conner and Adey (1975).

Marine algae of this area are described by Adey et al. (1981). Fish communities have been studied at a number of sites by Gladfelter and Gladfelter (1978), Gladfelter et al. (1980) and Ogden and Ehrlich (1977). The halos formed around West Indian patch reefs by the echinoid *Diadema antillarum* have been studied at Knight Bay (Ogden et al., 1973), 1 km west of Cottongarden Bay. Hawksbill *E. imbricata*, Green *C. mydas* and leatherback *D. coriacea* turtles nest at a number of sites in this area (Bacon et al., 1984). Scott and Carbonell (1986) describe several important wetland sites including Altona Lagoon, Southgate Pond (4 km north-east of Christiansted), Coakley Bay Pond and Great Pond.

The 4,000 year old eastern and southeastern bank barrier reef of St. Croix is one of the best developed reef systems in the tropical Atlantic Caribbean area and is the most extensive reef on the Puerto Rican-Virgin Islands shelf (Adey et al., 1981). It has long been of considerable scientific interest, partly because it is relatively untouched but also because the many subtypes of reef which exist in the one complex serve as a baseline for comparison with others throughout the Caribbean. The south shore reefs are particularly interesting as all of the reef geographical and ecological successional stages, young to old, are present.

The *Meandrina* hard ground off East Point is in need of extended study because of its possible importance to shelf-building in the Antilles (Adey, 1975).

BUCK ISLAND REEF NATIONAL MONUMENT

Geographical Location. Area: 71 ha terrestrial 4,285 ha marine.

Buck Island (17E 45'N, 64E45'W) is a small cay located 6 mi. (10 km) north-east of Christiansted, St. Croix, 2 km off the eastern shore covered with vegetation, with beaches on the south and west shores. A bank barrier reef surrounds the east and north of the island, 12 m high in places along its outer perimeter. The enclosed lagoon is up to 100 m wide with an average depth of 3 m (Anon.,

1977). The water is extremely clear, since there is no freshwater run-off (Randall and Schroeder, 1962) and horizontal visibility often exceeds 100 ft (30 m) (Gladfelter et al., 1977).

Reefs. The reef extends from the middle of the southern coast where it joins the shore, around the eastern tip of the island and along the north shore. To the north-east, it breaks up into large patch reefs. It lies approximately 200 ft (60 m) from the southern shoreline, where the lagoon has clear water, a clean sandy bottom and a patch reef system. At the eastern tip of the island and along the north shore, the lagoon has many patch reefs reaching the surface. There are several small passages through the reef that can be negotiated by boat, the largest of which is near the western end of the reef on the southern shore (Anon., 1977).

The barrier reef in the Underwater Trail area has complex back-reef topography, with 2-3 m vertical relief of crevices and caves within the reef structure. Although separated from the shore by a narrow sandy belt, it can be considered a form of fringing reef (Dahl et al., 1974). The front of the reef comprises a solid stand of *A. palmata* and *A. cervicornis*, which shelves off steeply from the surface to the bottom at 35 ft (11 m) where sand alternates with coral patches. On the lagoon side the reef is composed mainly of *Millepora* and *Diploria* with some *Montastrea, Agaricia and Isophyllia*. The reef off the northwest end at West End is different, having a broad area of patch reefs in 10-30 ft (3-9 m) of water with rich coral growth (Anon., 1977). There is a barren pavement area with scattered eroded dead coral heads with little algal cover. Gladfelter and Gladfelter (1980) provide a map of the principle reef zones.

The distribution, abundance and standing crop of marine benthic algae are described by Stanhope (1980). Ninety-three of the 250 species known from St. Croix waters, were recorded within the Monument. The gorgonian fauna is poor, with only a few colonies and less than half a dozen species. Sea anemones, including *Stoichactus, Palythoa* and *Zoanthus* are abundant (Anon., 1977; Adey et al., 1977). *S. gigas*, the whelk *Cittarium pica*, the spiny lobster *Panulirus argus*, moray eels and many fish such as the foureye butterfly fish *Chaetodon capistratus*, smooth trunkfish *Lactophrys triqueter*, porkfish *Anisotremus virginicus*, french angelfish *Pomacanthus paru*, queen angelfish *Holancanthus ciliaris* and blue angelfish *H. bermudensis* are found. Larger fish include sharks, snappers, barracudas and tarpon. Dolphin occur in these waters.

The island has hawksbill *E. imbricata*, leatherback *D. coriacea* and green turtle *C. mydas* nesting sites (Bacon et al, 1984).

Disturbance or Deficiencies. The reefs are subject to storm damage. Hurricane David and Tropical Storm Frederick passed Buck Island in 1979 and Rogers et al. (1979) describe the damage to the reefs from hurricane-generated waves. The effect of these storms on the beaches was monitored at West End (Gladfelter and Gladfelter, 1980). *Diadema antillarum* used to be a conspicuous member of the fauna, particularly on the flat, barren pavement area off the north-west coast of the island. Sizable populations were found on all parts of the living reef in the 1970s (Gladfelter, 1980a), which appeared to be stable although long term monitoring of this species was recommended. The high densities may have resulted from decades of over-exploitation of reef fish (prior to the establishment of the National Monument), including species which prey on urchins (Gladfelter, 1980a). However,

more recently, St. Croix has been affected by the mass mortality of *Diadema* which occurred throughout much of the Caribbean (Carpenter, 1985).

Oil, sludge, litter and debris discharged from tankers, cruise ships and other watercraft, as well as that drifting in from islands further east, deposit pollutants within Monument waters. Oil slicks have caused damage along rocky shores and sandy beaches. increased visitor use is potentially threatening the underwater trail area and congestion at the moorings has caused problems, with some coral damage from anchors and pollution caused by boat cleaning (Anon., 1977; IUCN, 1982). St. Croix fishermen used to take turtles and bird eggs, and the marine resources of the surrounding waters are considerably over-exploited (Schell, 19?).

In the past, the island was extensively grazed by goats, but these have been eliminated. The original forest was felled and repeatedly burned to provide pasture, but vegetation has regenerated.

SALT RIVER SUBMARINE CANYON

Geographical Location. 17E47' N, 64E 45' W; north coast, St. Croix. The 8 sq. km. area includes the Salt River Estuary and shoreward portion of the Salt River Submarine Canyon.

Physical Features. There is virtually no shelf outside the mouth of the estuary. The canyon floor shelves gently northward from the apex for about 200 m, at which point it drops precipitously to 3500 m through cemented, carbonate sand terraces towards the deep Virgin Islands basin which lies between St. Croix and St. Thomas. The west wall is very steep, with overhanging cliffs cut by sediment-filled tributaries. The east wall is more gradually sloping with a cobble-border substrate (Olsen and Wood, 1980). An algal/coral reef forms a bar across the mouth of the estuary (Anon., 1982). The area is described in Adey et al. (1977); sediments are described by Gerhard (1978). Water within the estuary flows only intermittently seawards and the waters in the inner portions of the estuary are poorly mixed. Salinities in the southern portion may reach 38 ppt during extended periods of low rainfall. The tidal range is about 0.3 m.

Reefs. *Siderastrea* corals occur along the southern shoreline of the estuary (Anon., 1982). Other reefs are briefly described in Adey et al. (1977) and Rogers et al. (1984). The upper lip of the canyon has a dense covering of hard coral and gorgonian fans (Adey et al. 1977). The east wall has a raised flange of *A. palmata* extending along its margin. The west wall is composed of carbonate rocks of coral reef origin, with overhanging cliffs cut by sediment filled tributaries. Dead coral is common at 9 m depth. Highest living coral cover occurs at a depth of 18 m and is about 6-24% on the east wall and 5-24% on the west wall. At 9 and 18 m depths, the dominant corals are *A. agaricites*, *M. decactis* and *M. cavernosa. A. lamarcki* is the most abundant species at 27 m and 37 m depths on both walls (Rogers et al. 1984). There is abundant black coral (Teytaud, 1980).

The estuary is lined by white, black and red mangroves and is described in Anon. (1982) and Scott and Carbonell (1986). Seagrasses occur over much of the shallow bottom. Juvenile fish are common in the estuary and sharks are reported to occur quite frequently in the central portion (Anon., 1982; Scott and Carbonell, 1986).

Several sponges in the genus *Verongia*, and the gorgonian *Iciligorgia schrammi* occur in the canyon but are unknown or rare elsewhere on St. Croix. Hawksbill *E. imbricata* and green *C. mydas* Turtles nest at Salt River (Bacon et al., 1984).

Disturbances and Deficiencies. The reefs of the USVI have suffered a variety of forms of natural damage. The impact of Hurricanes David and Frederick was studied on Buck Island and the south shore reefs of St. Croix by Rogers et al. (1979) and on St. Thomas by Rogers et al. (1983). Tropical Storm Klaus caused damage in 1984 (Rogers, 1985). Implications of the *Diadema* die-off on St. Croix are described by Carpenter (1985). High *Diadema* mortalities were also observed at St. Thomas and St. John (Lessios et al., 1984), and are probably due to a water-borne pathogen which caused Caribbean-wide mortality of this species. Outbreaks of white band and black band disease have been reported (Rogers, 1985).

Dahl et al. (1974) found the reefs to be healthy and suggested that this was because there was little need to exploit them for food. Adey et al. (1981) also reported that, in spite of the explosive population growth on St. Croix since the beginning of the 1960s, most of the reef system had remained largely unaffected. However, human activities have had an increasingly serious impact. For example, poor management and erosion control practices in many upland watersheds on St. Croix have resulted in large quantities of sediments being discharged into coastal waters. During periods of high rainfall, plumes of sediment are often visible in the nearshore waters (Teytaud, 1980). Similar problems occur on St. John and St. Thomas, where abnormally high rainfall in April 1983 created extensive run-off, and calm seas reduced circulation in the bays, compounding the problem. On St. Croix industrial development and pollution has been extensive on the south shore (see separate account) and north shore around Christiansted. The Tereco Corporation (1973), Weston (1974) and Howard et al. (1975) provide environmental impact statements dealing with the reefs in the area off the Hovic oil refinery and the proposed VIRCO oil refinery.

Dubois and Towle (1985) describe problems resulting from dredging and sand removal. There has been a long history of mining for marine sand in the USVI, over one million cu. yds (0.76 million cu. m) having been dredged from the bottom of Lindbergh Bay on the south-west of St. Thomas for airport construction in 1935. Turbidity is still a problem, compounded by siltation from soil erosion resulting from construction work on hillsides (van Eepoel et al., 1971). Between 1961 and 1981, over 2.2 million cu. yds (1.7 million cu. m) of aggregate were extracted for local construction activity from Christiansted Harbor on St. Croix (Hubbard et al., 1981); over 200 000 cu. yds (152 920 cu. m) of sand were taken from each of eight other bays (Brewers, Water, Crown, Cruz, Great Cruz, Vessup, Long and Turns) during the 1960s and early 1970s.

Dubois and Towle (1985) summarize the events which took place at Water Bay on the north-east shore of St. Thomas, an area dominated by seagrass flats interspersed with small patch reefs. More detailed accounts of this area are given in van Eepoel (1969), Grigg and van Eepoel (1970 and 1972), Insular Environments (1975) and in an Island Resources resurvey of 1983. Dredging for a resort development project took place until hotel guests complained that swimming and snorkeling conditions had declined. Renewed dredging later on led to the disappearance of the beach at Sugar Bay, reef die-off and a reduction in seagrass density. Grigg and van Eepoel (1970) estimated that

approximately 90% of the undredged corals on the south-east shore and 20-25% on the north shore were killed through sand extraction. Despite legislation and monitoring programs, the Bay is still considered to be damaged, the beach has not recovered and the dredge pits act as sources of continuing turbidity. Other studies on the problems of dredging for sand include Anon (1971) and Grigg (1970).

Traditional artisanal fisheries for turtles, conch, baitfish, shellfish and fish potting have drastically declined (Koester, 1985; Damman and Sylvester, 1976; Dubois, 1985). On St. John, demand for fish is consistently greater than supply, much of the local demand now being met by fishermen from the British Virgin Islands and St. Thomas. The limited supply is attributed to a variety of possible factors such as adverse environmental change, curtailment of several traditional fishing methods, increasing numbers of tourists and fewer fishermen. Local people generally consider the decline to be due to over-exploitation and environmental misuse associated with tourism. Tourism has certainly increased the demand for conch and lobster. The increase in shipping, pleasure boats and motorboats may also have had an impact (Koester, 1985). Rogers (1985) reports the reefs of the USVI to be under stress from a variety of additional factors including visitor impact, boat groundings, coral collection and sewage pollution.