Jobos Bay Estuarine Profile

A NATIONAL ESTUARINE RESEARCH RESERVE

Revised June 2008 by Angel Dieppa, Research Coordinator

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JOBOS BAY ESTUARINE PROFILE:
A NATIONAL ESTUARINE RESEARCH RESERVE (2002)
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Carmen Gonzalez, Reserve Manager
Aguirre, Puerto Rico
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PREFACE

This Site Profile has been prepared to introduce both the general public and the scientific community to Jobos Bay National Estuarine Rsearch Reserve (JBNERR). It contains information on the characteristics of the Jobos Bay estuary that will permit comparison with other estuaries on a regional and national basis.

The document contains information on a wide array of subjects including the geography, geology, environmental setting, ecology and biology, hydrology, historical and cultural resources, and environmental stressors of JBNERR. Maps, figures, and table containing data pertinent to those subjects are included. For readers wishing to pursue research on the reserve in greater depth they can refer to the literature section in the appendices.

Estuaries are unique ecosystems. Because they occur throughout the world, in different biographic regions, they vary greatly in origin, size, and spatial configuration, as well as in their biological, physical and chemical characteristics.

The designation of Jobos Bay by the National Oceanic and Atmospheric Administration, as a component of the National Estuarine Research Reserve System, recognizes Jobos Bay as a regional example of a tropical estuarine area. The Jobos Bay Reserve serves as a living laboratory for research, education and development of management practices.

Jobos Bay is located in the southeast coast of Puerto Rico, the smallest island of the Greater Antilles. Located between the U.S. Virgin Islands and the Dominican Republic, Puerto Rico has a land area of approximately 9,000 square kilometers, 75 percent of which consists of a series of mountain ranges. These mountains, which divide Puerto Rico along an east-west axis, descend into coastal plains.

The north coastal plain is quite wide and is laced with numerous rivers flowing from the Cordillera Central. With the prevailing winds from the northeat, this area is subject to high rainfall due to orographic factors. The south coastal plain, considerably narrower, and drier than the north coast, has fewer and smaller rivers that are characterized by intermittent flows.

Jobos Bay is a semi-enclosed water body on Puerto Rico's south coast between the municipalities of Guayama and Salinas. The estuarine area is subject to surface water inflows primally from the alluvial coastal riverine systems.

The entire Bay, which contains mangrove islands and coral reefs, is within the boundaries of the Reserve. Other ecosystems within the Reserve include mangrove forest, lagoons, salt flats, dry forest, and seagrass beds. These ecosystems provide the habitat for a great diversity of flora and fauna including several rare and endangered species. It is this wealth of biological diversity, which makes Jobos Bay an excellent example of a tropical estuarine system ideally suited to research and education, as well as to the development and implementation of management practices that contribute to informed and environmentally sound decision-making.

CHAPTER 1. INTRODUCTION AND SUMMARY

by Ralph M. Field

This chapter is intended to introduce both the scientific community and the general public to the Jobos Bay National Estuarine Research Reserve (JBNERR). It highlights the physical and biological characteristics of the Reserve, as well as outlining the Reserve's program within context of the national system of estuarine research reserves. For the general reader, the information contained in this introductory chapter may be sufficient. For those wishing greater depth of scientific information and research findings it is recommended that the full text, together with appendices and references, be examined.

Geographical Setting

Puerto Rico is the eastern-most island of the Greater Antilles and is located between the U.S. Virgin Islands and the Dominican Republic. The island has a total area of approximately 9,000 square kilometers, of which 75 percent is mountainous. A central mountain range, the Cordillera Central, largely of volcanic origin, divides the island along an east-west axis. A section of the range oriented to the southeast, is known as the Sierra de Cayey. The coast is characterized by an interrupted band of alluvial plains, with small limestone hill clusters on the north coast known as "mogotes". The south coastal plain is narrower than the northern plain, with shorter and smaller rivers, and with an irregular insular shelf that extends three to eight kilometers seaward.

The island's location, climate, and geographic features have created a coastal environment that supports extensive coral reef systems, mangrove forests, seagrass beds, and estuaries. The island also shelters several rare and endangered plant and animal species, as well as a variety of species of tropical fish. (See Figures 1 and 2).

Jobos Bay National Estuarine Research Reserve (JOBNERR) lies along the south-central coast, east of Ponce, between the municipalities of Salinas and Maunabo The entire Reserve covers an area of ca. 11 km^2 (2,800 acres), while Jobos Bay has a total surface area of 11 km^2 and reaches depths of 8-10m.The Reserve is composed of two major areas:

- Mar Negro, a mangrove-wetlands forest complex, located on the land side at the mouth of Jobos Bay, and;
- Cayos Caribe, a linear formation of 15 tear-shaped, reef fringed, mangrove islands extending westward from the southern tip of the mouth of Jobos Bay (Figure 3).

Jobos Bay is a well-protected natural harbor that extends eastward from the two areas of the Reserve guarding its entrance. Further protection from offshore winds and waves is provided by Cayos de Barca (not part of JOBNERR), located south of Mar Negro and west of Cayos Caribe.

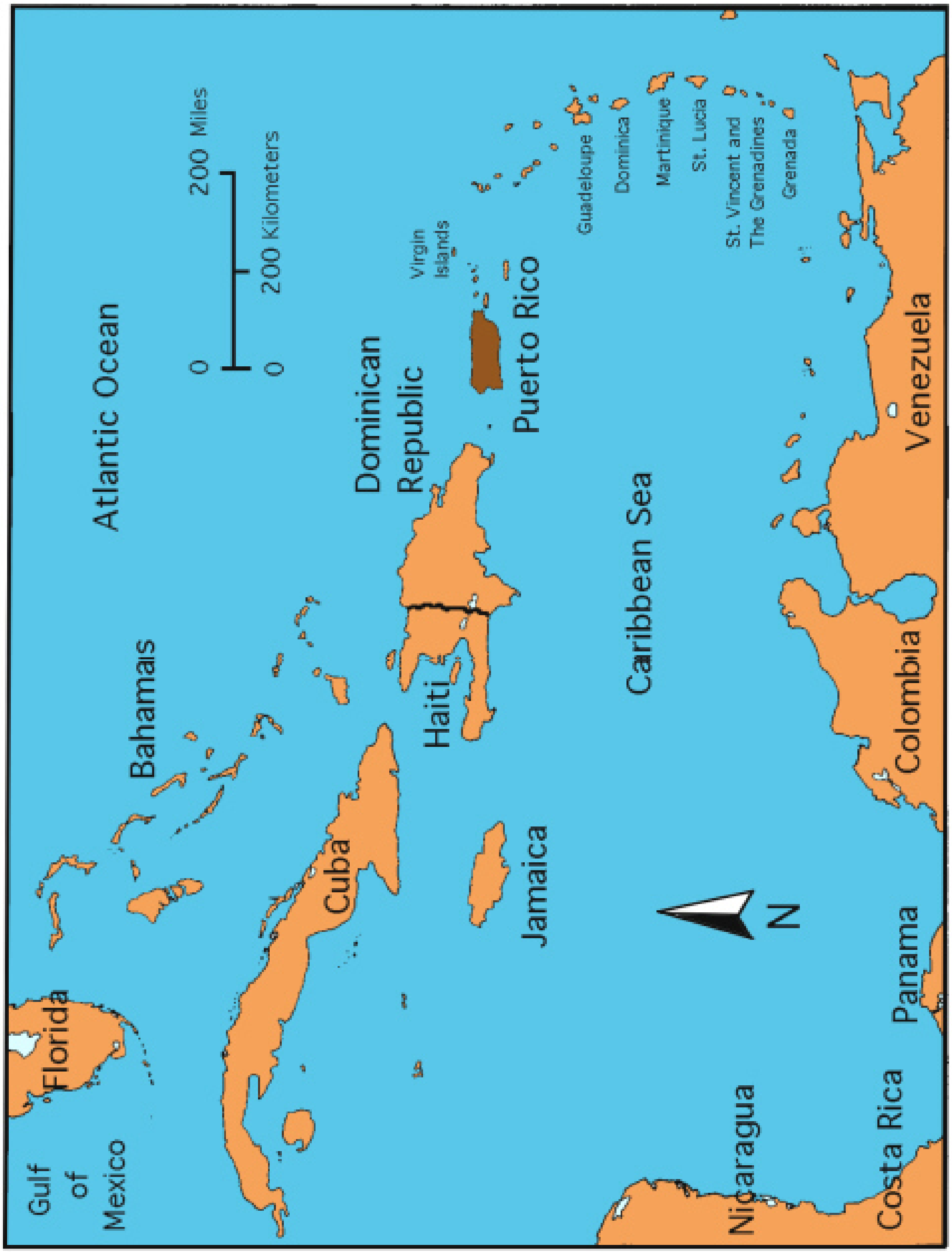


Figure 1. Site location

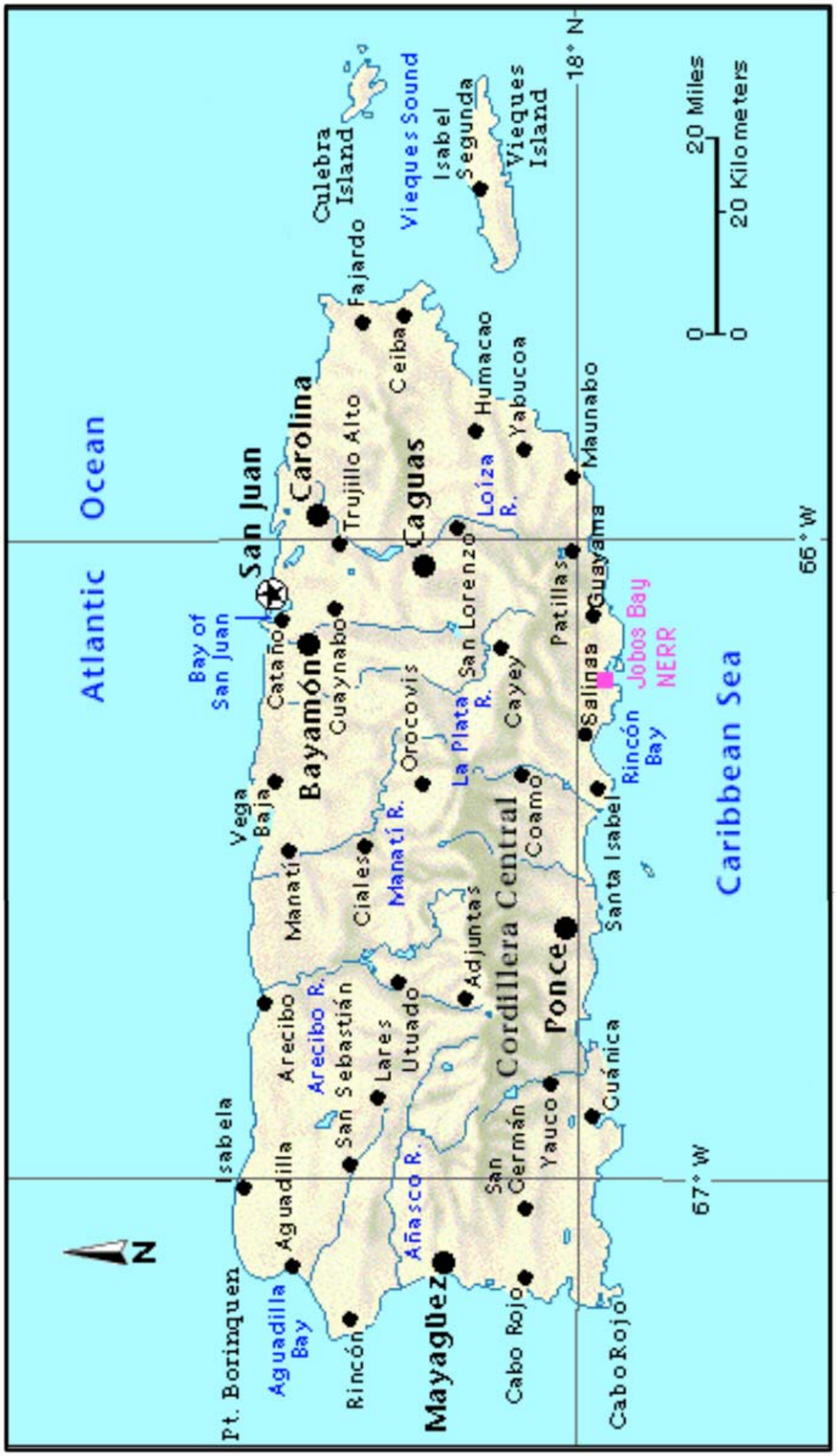


Figure 2. JBNERR site

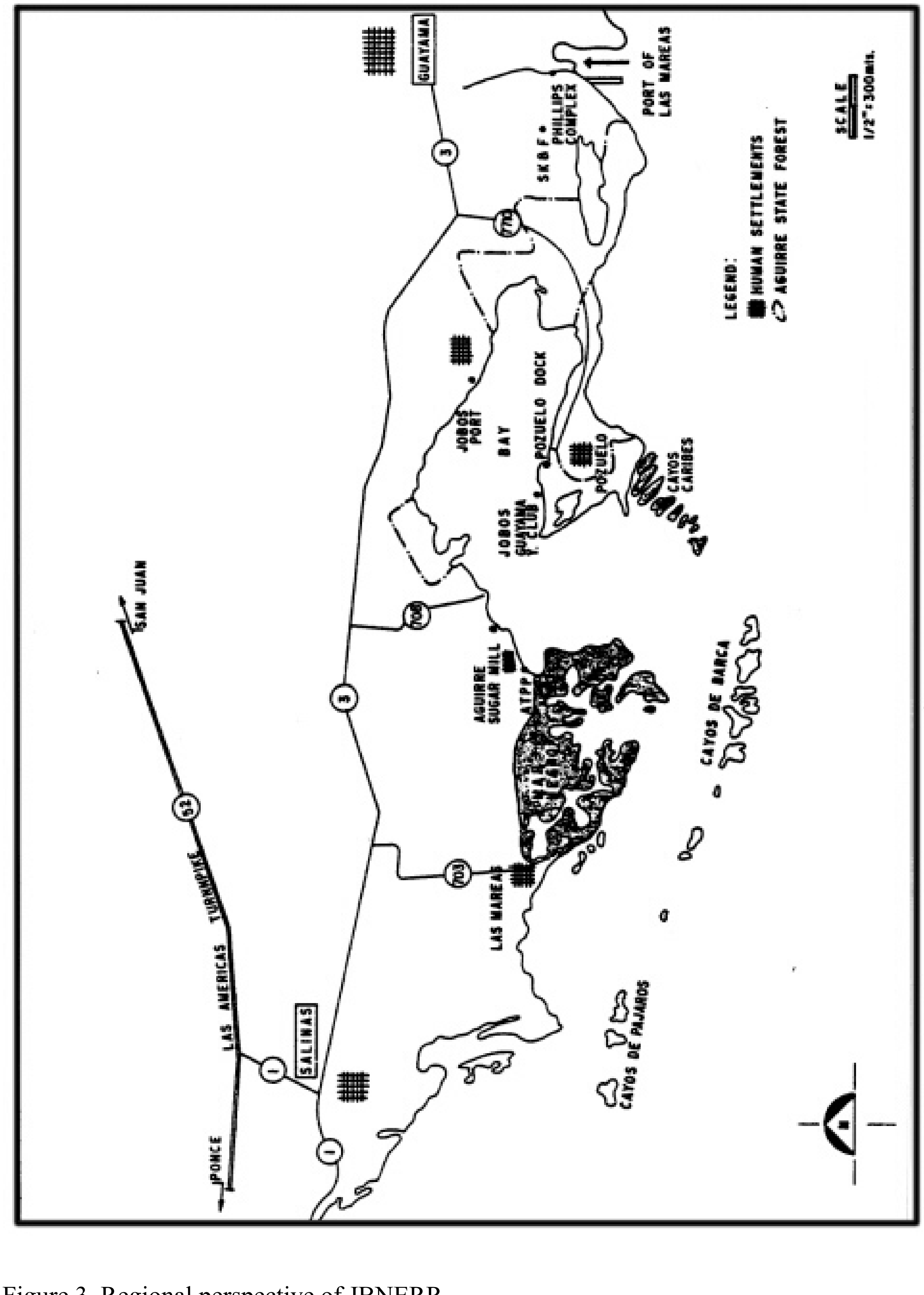


Figure 3. Regional perspective of JBNERR

Estuary Characterization

Estuaries are scattered along the shores of all the oceans and vary widely in origin, type and size. Jobos Bay can be classified as a coastal plain estuary formed approximately 18,000 years ago when sea levels rose as a result of the melting of glacial ice at the end of the last ice age. During this process the sea entered lowlands and river mouths forming drowned river valleys or coastal plain estuaries. Water covered the lowest plains as evidenced by the large amount of shell deposits found in the upland adjacent to Jobos Bay, and the coral reef fossils found in the hills immediately to the northwest boundary of the Bay.

Physical Environment of Jobos Bay Estuary

The 2,393 acre Aguirre State Forest (total area, 2,393 acres) borders the north shore and the east end of the Bay. Jobos Bay is the second largest estuary in Puerto Rico, covering an area of approximately eight square kilometers but with three times as much shoreline as any other estuarine zone on the Island. It is a shallow embayment with maximum depths of around 10 meters. Tides at Jobos are mixed, but chiefly diurnal, showing a mean of 13.7 cm, ranging from 17.0 cm to 36.0 cm (Lugo *et al.*, 1987). Lowest tides occur early in the year, while the highest water levels occur around October (Figure 4), a period that coincides with higher rainfall water storage in the mangrove forest**.** Figure 5 shows the exposure of shallow substrata during low tides. The tide dynamic of Jobos Bay conforms to the USFWS criteria (1979) of an intertidal estuarine system dominated by aquatic beds and coral reefs.

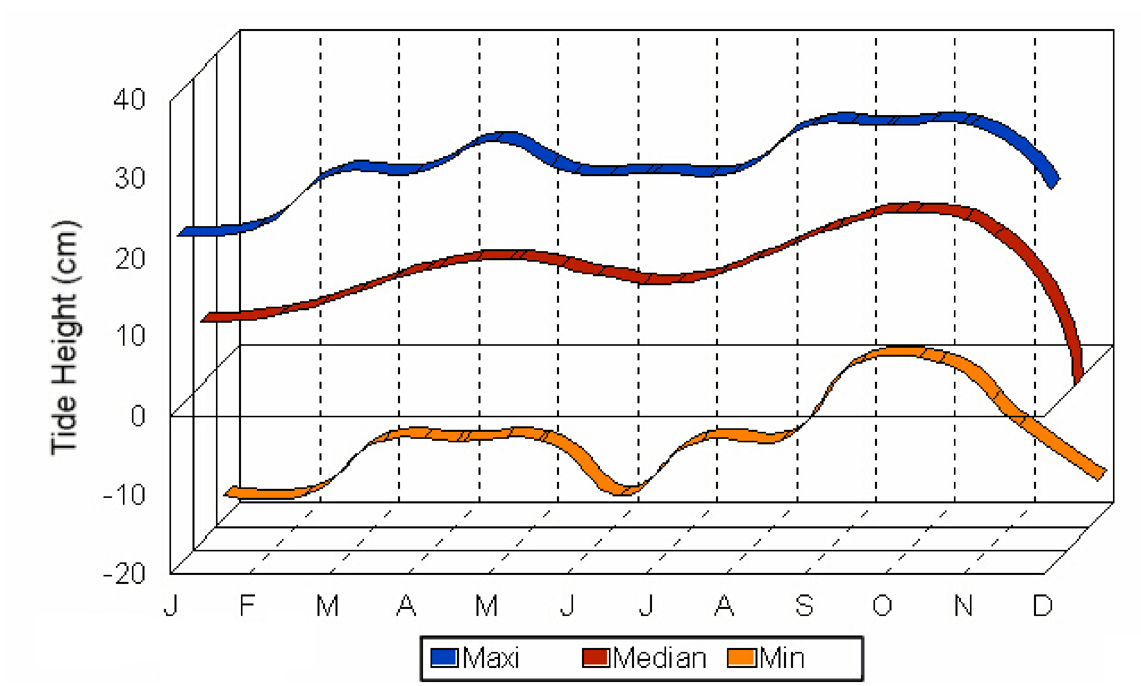


Figure 4. Temporal variation of tides in Jobos Bay

Figure 5. Exposition of substrata during low tides at Cayos Caribe.

Historical Background

Prior to its designation in 1981, a large part of the present Reserve area was owned by the Aguirre Corporation, and was known as the Lugo Viñas farm. During the early 1970's, the area was considered a potential site for an oil transhipment port, in response to the world-wide energy crisis resulting from the oil embargo imposed by the Organization of Petroleum Exporting Counties (OPEC).

With the lifting of the oil embargo, pressure for constructing a major crude oil terminus abated. Due to the environmental policies and regulations that were adopted following enactment of the Puerto Rico Environmental Policy Act, the creation of the Puerto Rico Department of Natural Resources, and the passage of the Federal Clean Water Act, interest in developing the Lugo Viñas farm for industrial purposes also declined dramatically.

By 1980, the Aguirre Corporation ceased operations and was in process of liquidation. That year, the Corporation contacted the Sanctuary Programs Division of OCRM/NOAA, proposing to sell the Lugo Viñas farm. Based on the provision of Section 315 of the Coastal Zone Management Act (CZMA). NOAA advised the Aguirre Corporation to re-direct its offer to the Puerto Rico Department of Natural Resources.

The Commonwealth of Puerto Rico had previously shown interest in the National Estuarine Research Reserve System. In 1975, staff from NOAA's Office of Ocean and Coastal Resource Management (OCRM) visited the Island to inspect potential marine sanctuary sites. However, it was not until 1981 that serious consideration was given to the establishment of a National Estuarine Sanctuary under Section 315 of the Coastal Zone Management Act.

Cultural and Historic Resources

The Reserve and adjacent areas contain several important archaeological sites. A large Indian settlement was located at the Carmen site adjoining the Reserve. The casual discovery of stone figurines ("Cemí") in the Central Aguirre area reflects settlements of the Taino Indians, the most important indigenous cultural group of the Island. However, the area has never been systematically surveyed by an archaeological team (Fewkes, 1904; Anon. 1975), and it is possible that other important archaeological sites may exist (Ovidio Davila, pers. com.).

The Aguirre Sugar Mill itself is an important cultural and historic asset. In 1898, an American company bought the Aguirre properties. They modernized the sugar production technology and developed a complex on Jobos Bay that included the sugar mill and refinery, plus administrative, commercial, institutional, recreational, and residential areas. The recreational facilities included a golf course, a hotel, a swimming pool, and a social club. The residence of the company's president was located on the highest point of the property, and commanded an excellent vista of the Bay. The house is typical of the architectural style of the great plantation mansions of the southeastern United States.

Ecological Significance

The Reserve is a very important habitat for endangered species. The brown pelican, the peregrine falcon, the Puerto Rican plain pigeon, and the yellow-shouldered blackbird are endangered bird species found in JBNERR. Two other endangered species encountered in the Reserve are the hawksbill sea turtle (Eretmochelys imbricata) and the West Indian manatee (Trichechus manatus). The hawksbill turtle forages in shallow waters and feeds on the bottom of reef areas and thalassia beds. It has a preference for invertebrates, algae, and submerged roots.

The manatee historically was found in shallow coastal waters and inland lakes throughout much of the tropical and subtropical regions of the New World Atlantic, including the Caribbean islands. However, at the present time, manatees are rare or extinct in most parts of their former range (Brownell, 1980). Recent surveys indicate a total Puerto Rican population of less than 100 animals. Jobos Bay has the second largest manatee population in Puerto Rico. Small groups are frequently sighted elsewhere on the south coast and around the estuary of the Fajardo River on the East Coast.

Protection Efforts

Designation of Management Sectors.

In order to promote multiple use of the Reserve while, at the same time, protecting its special ecological attributes, a three-way sector classification has been established, within which compatible uses will be allowed (Figure 6). Hunting and the use of jet skis will not be allowed in any area of the Reserve.

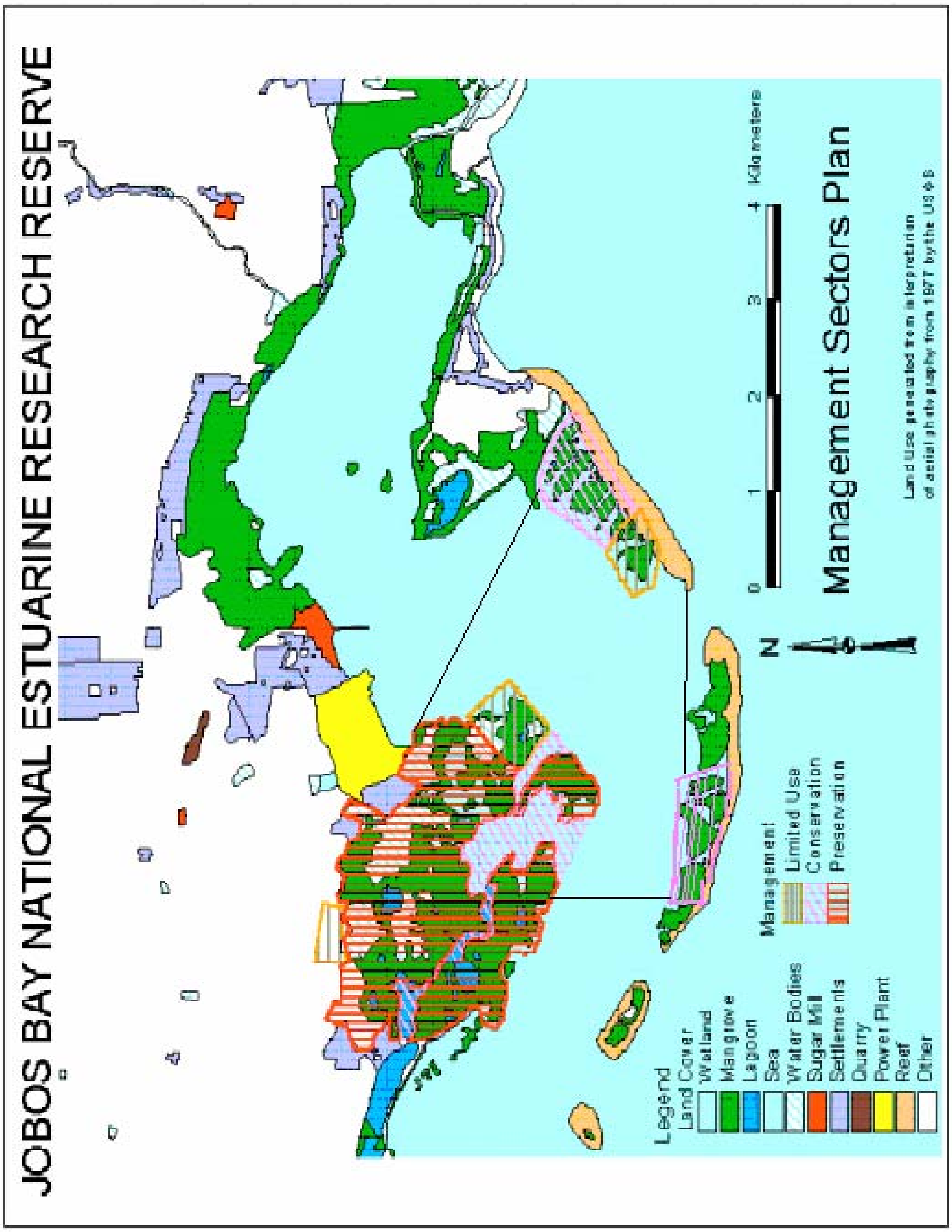


Figure 6. Jobos Bay National Estuarine Research Reserve

1. Preservation Sector

   These are areas that require a high degree of protection due to their vulnerability, ecological importance, presence of flora and fauna, and/or historic or archeological values. Physical and biological assessments have shown the need to designate preservation sectors in the Mar Negro area that meet these criteria. Many of the areas classified for preservation include coves, shallow semi-enclosed areas, and fringing mangroves within the lagoon system. These have been identified as spawning areas and nursery grounds for valuable commercial fish species and habitat for endangered species. The preservation of these resource areas is vital to maintaining the equilibrium and population dynamics of the estuary.

   Activities in designated preservation sectors will be limited to research, monitoring and restoration, if appropriate.

   Fishing, hunting and the use of motor vehicles will not be allowed in these areas. However, traditional shellfish harvesting from mangrove roots will be allowed. Shellfish fishermen will be encouraged to provide harvesting reports at the Reserve.

2. Conservation Sector

   The vast majority of the Reserve, including Mar Negro and Cayos Caribe, has been classified as a conservation sector. These are environmentally sensitive areas, and include wetlands, mangrove areas, and scenic outlooks that require protection against inappropriate or excessive use.

   In order to provide access to the Las Mareas Community, a right-of-way for boat traffic has been made available through the main channel of Mar Negro. Principal users of this waterway are local fishermen. Boat size will be limited to a maximum of 22 feet, and speed will be limited to five knots. Hook and line fishing will be allowed, but with emphasis on the importance of releasing small or immature specimens in order to ensure sustainability. Pot and net fishing will not be allowed inside the Mar Negro area.

   Passive recreation activities such as bird watching, snorkeling, kayaking and diving will be promoted as part of Reserve's education outreach plan.

3. Limited Use Sector

   These are areas designated for education, outreach and passive recreation activities. Interpretative trails, boardwalks, limited docking piers for public use, and minimum use facilities will be constructed as required.

   There are no picnic or camping areas designated in the Reserve. However, various points will be identified as sites where visitors to the Reserve can find temporary shelter for eating and resting.

   Anchoring and mooring in designated areas will be limited to a maximum of three hours. Provision for docking and anchoring will be made and appropriate signage will be posted. These measures will allow access to more users, while managing public use of these sites in a manner that will not threaten or significantly disturb the natural ecosystems.

Passive recreation such as bird watching, hiking, swimming, and snorkeling will be encouraged.

Resource Protection Guidelines

The Reserve shall be managed to maintain its biological and ecological integrity, primarily as a natural field laboratory for non-manipulative research and education, in keeping with the NERRS regulations. (Appendix A) However, external factors could significantly impact the integrity of natural systems within the Reserve. Accordingly, a Special Area Planning (SPA) process that includes participation by Commonwealth, Federal and local agencies has been initiated to address issues that threaten Reserve resources arising from outside the Reserve boundary. As a participant in the SPA Inter-Agency Committee, the Reserve management will play an active role in reviewing and responding to proposed developments within the Jobos Bay watershed that are likely to impact Reserve resources.

National Recognition : Jobos Bay National Estuarine Research Reserve

The Jobos Bay National Estuarine Research Reserve (JBNERR) was designated in September 1981 by agreement between the Commonwealth of Puerto Rico Department of Natural Resources (DNR) and the National Oceanic and Atmospheric Administration (NOAA). Designation established Jobos Bay as the eleventh site in the National Estuarine Research Reserve System, as defined in Section 315 of the Coastal Zone Management Act of 1972 (CZMA), as amended. With this designation, Puerto Rico reaffirmed its commitment to develop an estuarine research and education program, preserving, through fee simple acquisition, valuable coastal mangrove forests and associated habitats for the benefit of the general public and ensuring their long-term availability as natural field laboratories to provide information for coastal decision-making.

The NERRS Program

Mission of the National Estuarine Research Reserve System

Section 315 of the CZMA of 1972, as amended, establishes the National Estuarine Research Reserve System. Under the System, healthy estuarine ecosystems which typify different regions of the U.S. can be designated and managed as sites for long-term research, and used as a base for estuarine education and interpretation programs. The System also provides a framework through which management approaches, research results, and techniques for estuarine education and interpretation can be shared with other programs.

As stated in the CZMA the National Estuarine Research Reserve System has the following mission: "…the establishment and management, through Federal-state cooperation, of a national system of Estuarine Research Reserves representative of the various regions and estuarine types in the United States. Estuarine Research Reserves are established to provide opportunities for long-term research, education, and interpretation."

The NERRS was established by the CZMA to help address the problem of current and potential degradation of coastal resources brought about by increasing and competing demands for these resources. The NERR system is designed to improve scientific understanding of estuarine processes in order to improve management through a program of national coordination. The NERRS research, education, and resource stewardship programs are tools that can help fill gaps in knowledge, and guide decision-making so that our estuaries can sustain multiple uses over the long term.

Goals of the National Estuarine Research Reserve System

The goals of the NERR system, established by Federal Regulation, are as follows:

- Ensure a stable environment for research through long-term protection of National Estuarine Research Reserve resources;
- Address coastal management issues identified as significant through coordinated estuarine research within the System;
- Enhance public awareness and understanding of estuarine areas and provide suitable opportunities for public education and interpretation;
- Promote Federal, state, public and private use of one or more Reserves within the System when such entities conduct estuarine research; and
- Conduct and coordinate estuarine research within the System, gathering and making available information necessary for improved understanding and management of estuarine areas.

Biogeographic Regions

NOAA has identified eleven distinct biogeographic regions and 29 subregions in the U.S., each of which contains several types of estuarine ecosystems. When complete, the NERR System will contain examples of estuarine hydrologic and biological types characteristic of each biogeographic region. Each reserve will be responsible for conducting research and providing educational and interpretive services that are applicable to its region.

Mission of the JBNERR in Relation to the NERRS Program

Research Goal:

The primary research goal of JBNERR is to promote and coordinate high quality scientific research to expand knowledge of significant tropical estuarine resources in order to improve coastal management decision-making.

Research Objectives:

- To promote and conduct long-term baseline studies to characterize flora and fauna within the Reserve and gain an understanding of the ecological inter-relationships between organisms and their environment;
- To promote a better understanding of tributary water quality conditions, particularly spatial and temporal dynamics, requirements for growth and survival of living resources, and contribution and effects of point and non-point pollution;

- To promote a better understanding of the physical processes operating within the estuary and watersheds, such as tidal influence, circulation dynamics, freshwater inflow, stratification patterns, and sediment dynamics;
- To encourage and facilitate studies that make effective use of past research and address data gaps in the Reserve's information base;
- To provide for effective communication and exchange of research results; and;
- To encourage studies that promote a better understanding of human uses of the estuary, as well as the changes that have occurred as a result of human activities.

Resource Protection Goals:

The overall resource protection goal of JBNERR is to protect the natural integrity of the Reserve's ecosystems in order to provide a stable environment for research and education. The following are set forth as specific resource protection goals:

- To protect significant natural estuarine sites within the Reserve for the purpose of research, education, and interpretation;
- To protect the Reserve from unduly disruptive or unlawful activities occurring inside or adjacent to its boundaries; and
- To protect the Reserve's variety of natural habitats, including coral reefs, mangrove forests, seagrass beds, saltflats, and freshwater marshes, as well as its biological components.

Resource Protection Objectives:

- To acquire key land and water areas that merit protection, through conservation easements, management agreements, land trusts, fee-simple acquisition, donation, or other means;
- To manage public use of the Reserve sites in a manner that will not threaten or significantly alter the integrity of its natural ecosystems or natural resources;
- To monitor the extent to which public use impacts selected sites within the Reserve, especially with respect to habitat alteration, over-use, and other impacts related to human activities;
- To monitor non-public use impacts for change, particularly with respect to point and non-point sources of pollution, including changes associated with agricultural land use, hydromodification, construction, urban run-off, and marina and docking facilities;
- To provide adequate surveillance and enforcement of existing resource protection laws and regulations, including the Reserve's own resource protection rules, and to establish new mechanisms to increase resource protection, when deemed necessary; and,
- To provide for adequate public participation as a mechanism to promote compatible uses of the Reserve's resources, and to increase awareness of the need to protect sensitive and fragile areas. (Appendix A and D)

Education Goal:

To enhance public awareness, understanding, and wise use of estuarine resources in the Jobos Bay Estuary and its tributaries, the Reserve itself, and tropical estuaries in general.

Education Objectives:

- To provide educational and interpretive services;
- To promote knowledge of the research reserve, its resources and its programs, as well as knowledge of broader coastal issues and concerns related to estuarine management and protection;
- To provide the basis for improved decision-making by resource managers and public officials at the local, Commonwealth and Federal levels.
- To incorporate research and monitoring, and resource protection results into educational activities;
- To provide opportunities for teacher training, student projects, and internships where enrollees can participate in research activities, gain field experience, and learn about research project results; and
- To provide appropriate facilities for education, interpretation, volunteer work, and research uses of the Reserve.

CHAPTER 2. **ENVIRONMENTAL SETTING**

by Dr.Jorge Capella

ORIGIN AND EVOLUTION OF JOBOS BAY ESTUARY

Geological Progression

Puerto Rico emerged about 135 million years ago as part of the process in which the Caribbean and North American plates collided (Joyce, 1992). During the Cretaceous period, the area now occupied by Puerto Rico was a shallow sea or basin of deposition surrounded by islands built up by the lava and ash which poured forth from a series of active volcanoes. The material from these volcanoes built large cones down whose flanks flowed the lava from successive eruptions to spread over the islands and out into the adjacent sea (Berryhill, 1960).

The young volcanic mountains were weathered by rainfall, heat and wind. Clays washed down while spreading waters sorted the soils and rock fragments, concentrating pebbles and boulders at the shoreline and carrying the finer material into the central part of the basin. Meyerhoff (1933) theorized that subsidence was prolonged but intermittent. When it came to a temporary halt, the depression filled with sediments, especially near the shore. Marshes were formed and, as they extended inland, their brackish waters freshened. Coral reefs fringed the volcanic islands and during periods of quiescence they extended over vast shallow areas (Berryhill, 1960).

A tropical swamp flora grew luxuriantly, forming mats of partly decayed vegetation that were buried and transformed into peat. Basal gravels and sand containing petrified wood were posteriorly concealed by clays and marls which now extend into the hills west of Jobos Bay. After the sedimentation started in the Juana Díaz depression, the sea spread laterally along the mountain front until it reached from Cabo Rojo to Salinas. The Ponce limestone, a well stratified formation containing chalky material and a limited quantity of reef organisms and shell deposits, followed accumulation of the Juana Díaz shales.

During the early part of the Tertiary period the Antillean mountains of Puerto Rico stretched eastward to the Virgin Islands and westward to the Dominican Republic.

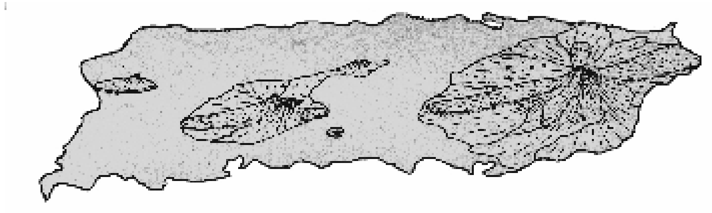


Figure 7. Puerto Rico in the Upper Cretaceous Period (Adapted from Meyerhoff, 1933).

Fluvial erosion was cutting into the anticlinal axes, and tropical weathering was deeply affecting the rocks that formed the lower slopes and folds (Meyerhoff, 1933).

Approximately 60 million years ago, limestone along the southern coast began their formation beneath a warm, tropical sea. These coastal deposits continued accumulating through the Tertiary period, to the Quaternary, and thereafter to the present (Cruz-Báez & Boswell, 1997). The fine-grained rocks and reef-type limestone found in the upland adjacent to Jobos Bay were either deposited during such a period or they formed at some distance from a center of volcanic activity (Berryhill, 1960).

In the Oligocene epoch of the middle Tertiary, a sag developed, trending across what are now the highest elevations of Puerto Rico. The sea entered its lowest points near San Sebastián, north of the mountain axis, and in the neighborhood of Juana Díaz to the south. Highlands separated these two basins, the latter receiving its waters from the Caribbean Sea, thus accounting for the marine and brackish depositions.

The geological history of the coastal plains region is also tied to the beginning of the Quaternary period. With the formation of huge glaciers in the Northern Hemisphere, sea level fell, resulting in an increase in river gradients. The limnetic flows carved deep valleys that filled with sediments. Some of these former valleys exist today as submarine canyons on the northern and southern marine flanks of the Island (Cruz-Báez & Boswell, 1977). Sea level eventually rose after the partial melting of the northern ice caps. This process was instrumental in the formation of the south coast lowlands. With sea level rise, the lowest areas were inundated, as evidenced by the large shell deposits found in the upland adjacent to Jobos Bay, and the coral reef fossils found in the hills immediately to the northwest of the Bay (Laboy, personal observations).

The watershed of the southern coastal plain of Puerto Rico, particularly between Ponce and Guayama, consists of a series of large fan-shaped alluvial deposits, composed of poorly sorted detritic fragments originating from higher elevations to the north (Galiñanes, 1977). These deposits show a slight slope toward the south. Their main component consists of gravel which is concentrated along most of the shoreline of the southern plain. This probably accounts for the prevalence of small pebble deposits in the Cayos Caribes islets, and the paucity of uplands area in Mar Negro.

Figure 8 shows the exposed geological units of the Jobos Bay upland. Most of the exposed land of the Bay consists of swamp deposits. Limited beach deposits occur along the land fringe west (Camino del Indio) and southeast (Punta Colchones) of Mar Negro,

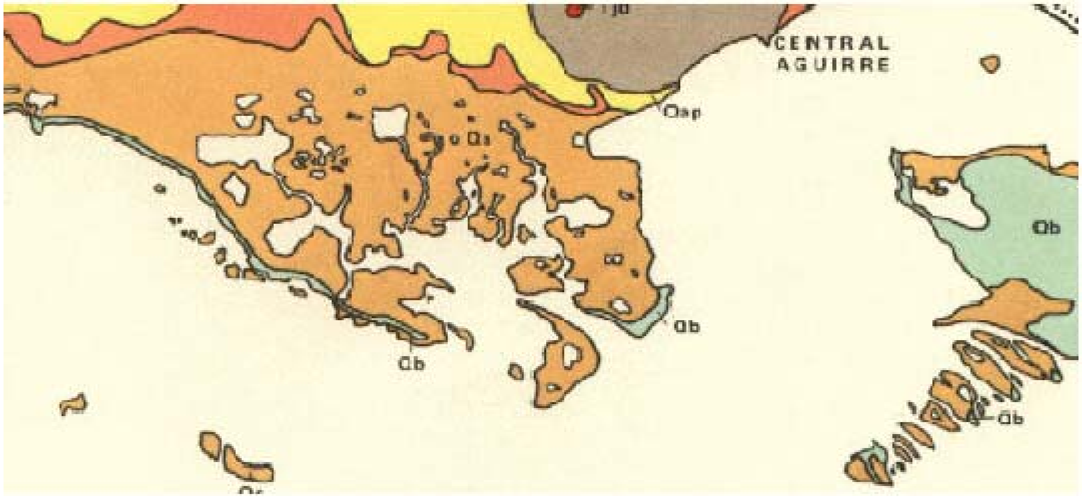


Figure 8. Rock/soil deposits from the Jobos Bay watershed.
Qap = alluvial, Qb = beach, Qs = swamp deposits (PRWA, 1972).

and the upland of Cayo Caribe. The predominant lagoon and swamp deposits consist of unconsolidated clay, silt and humic material. Mangroves and seagrass beds cover these deposits almost entirely. The beach deposits are composed of sand, gravel, volcanic rock cobbles, and coral reef debris. Beaches are composed mainly of calcareous sand. Swamp deposits belong to the swamp-marsh soil association, while alluvial and beach deposits are classified within the Jacana-Amelia-Fraternidad group (Boccheciamp, 1977).

An ancient inactive fault, known as the Esmeralda Fault, runs in a northwest-southeast direction north of Jobos Bay. Projections of the fault suggest that it probably passes under the Bay in an offshore direction. There are no metallic mineral deposits of commercial value in the general area of the Reserve. However, small calcite, hematite and gypsum veins can be found the hills adjacent to Jobos Bay.

ESTUARINE GEOMORPHOLOGY

Centered at about 18° 15'N and 66° 30'W, at the eastern end of the Greater Antilles, Puerto Rico is part of a volcanic island platform that includes the U.S. and British Virgin Islands. The Virgin Islands and Puerto Rico comprise a segment of the Caribbean Island Arc which arose along the leading edge of the Caribbean Plate from the subduction of the North American Plate. (Fig. 1).

The Puerto Rico Trench subduction zone, north of Puerto Rico, is the deepest area in the North Atlantic. Recent studies define the Puerto Rico and Virgin Islands platform as the main part of a microplate within the Caribbean Plate. The Caribbean Plate is bounded by the Puerto Rico Trench to the north, Anegada Passage to the east, Muertos to the south, and an extensive fault system underlying the island of Hispaniola to the west (Dillon et al., 1998).

The islands of the north Caribbean, from Cuba to Anegada, are aligned east west along the edge of the Caribbean-North American Plate boundary. These islands are situated atop ridges that extend to great depths in the North Atlantic to the north, and in the Caribbean to the south. Tilting of this ridge boundary due to the interaction of the major plates reflects dipping of the Pliocene platform limestone to depths of 5,000 m in Puerto Rico (Mousa et al., 1987).

Caribbean island formation occurred over the last 65 million years. The period of volcanism lasted from Cretaceous through Eocene time, but Puerto Rico's actual shape and size was essentially completed 40 million years ago (Morelock et al., 1999). Puerto Rico is a 55 by 175 km (35 by 110 mile) rectangle of volcanic flows filled in by limestone and subjected to periods of intense deformation to form an extensively folded and faulted island.

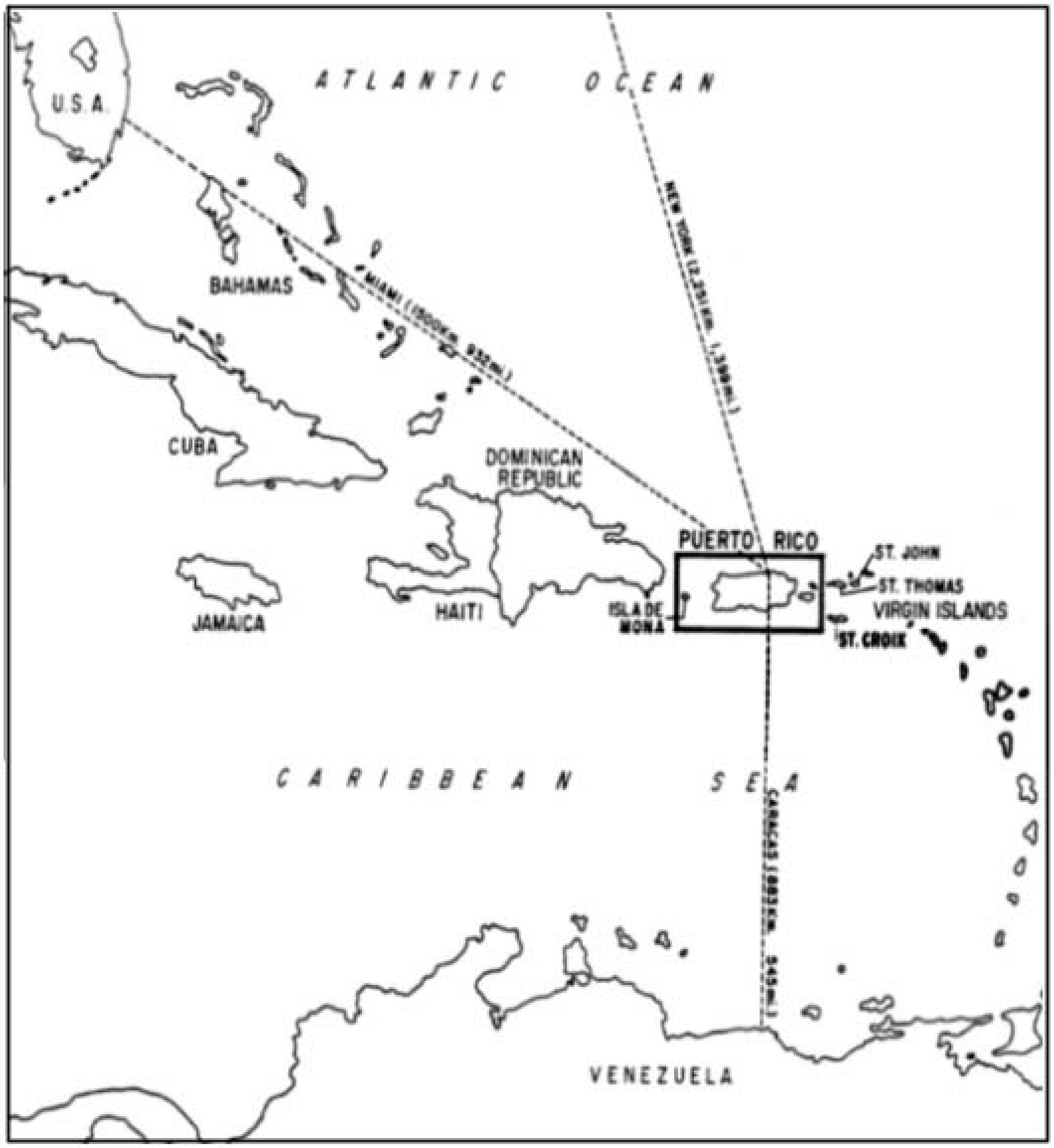


Figure 9. Puerto Rico in the Caribbean Plate.

As the smallest of the Greater Antilles, Puerto Rico is still a giant among the other islands in the Puerto Rican Archipielago (Vieques, Culebra, Mona, Monito, Desecheo, and Caja de Muertos), the Virgin Islands, and the many islands of the Eastern Caribbean. Roughly 75 percent of Puerto Rico's 9,104 km^2 of total surface area is mountainous. The Cordillera Central, or central mountain range, crosses Puerto Rico from east to west, dividing the Island into the north and south coastal regions. The Island is bordered by approximately 501 km of coastline. Limestone deposits with karst erosion patterns, clastic coastal plains and alluvial fans to the north and south define the Island's principal physiographic units. The north coast, which is wider and receives most of the river drainage, is typical karst country. The south coast is significantly drier and also has a limestone-based terrain.

Along most of the north coast, the ocean's bottom slopes steadily northward into the Puerto Rico Trench, with depths of over 10,000 m occurring 100 km from shore. An insular shelf is basically non-existent along this stretch of coastline. An irregular insular shelf, 3-8 km wide, borders the south and west-southwest coastlines abruptly dropping to deep water offshore. The marine ecosystems along the north and northwest insular shelf are significantly different from those found along the west, south and east shelves. The large variations in the character of the marine coastal habitats may be accounted for by the differences in land surface topography, fresh-water budgets, wave and current energies, sediment types and sediment influx, and bottom features around the perimeter of the Island.

Close to JOBNERR, near the Central Aguirre sugar mill, local bedrock hills protrude above the alluvial cover. The geological formations and units in the JOBNERR region (the Central Aguirre quadrangle) were mapped by Beryhill (1960). Topographic features are available from the Central Aguirre quadrangle of the USGS-DTPW 7.5 minute topographic map series.

CLIMATE, WEATHER, AND WAVES

Climate and Weather

Major Weather Determinants: Local weather conditions in the northeastern Caribbean are determined by the interplay between island topography, the North Atlantic mid-latitude high-pressure cell, westward traveling tropical waves, and migrating cold fronts from the north and northeast.

Trade Winds: The northeastern Caribbean lies along the northern edge of the Trade Wind belt which circles the globe from east to west. Locally, the Trade Winds are associated with the mid-latitude high pressure cell, whose center is periodically displaced along the Bermudas-Azores latitude band. This clockwise rotating, high surface pressure system generates easterly winds (Trade Winds) over the Caribbean. The actual wind direction varies from northeast to southeast, depending on the geographical distribution of pressure gradients over the North and Tropical Atlantic.

Monthly mean wind speeds for the south of Puerto Rico (years 1862-1973) peak during December-January at 23 km/h (12.8 kts) and are weakest in October at 18 km/h (9.8 kts). Over the South Coastal Plain winds regularly come from an easterly direction, mostly southeasterly, at mean speeds of 10 km/h (6 kts) or less (McClymonds and Díaz, 1972). Weak seaward winds are often observed at night in the Reserve as part of the daily land-sea breeze cycle. Punta Pozuelo, Mar Negro, Cayos Caribe, Cayos de Barca, Cayos de Pájaros, and mainland Puerto Rico effectively protect Jobos Bay. As a result, the waters of the Bay are generally calm. The usual daily pattern in Jobos Bay is for low velocity northeast winds in the early morning, giving away to brisk southeast winds as the day progresses.

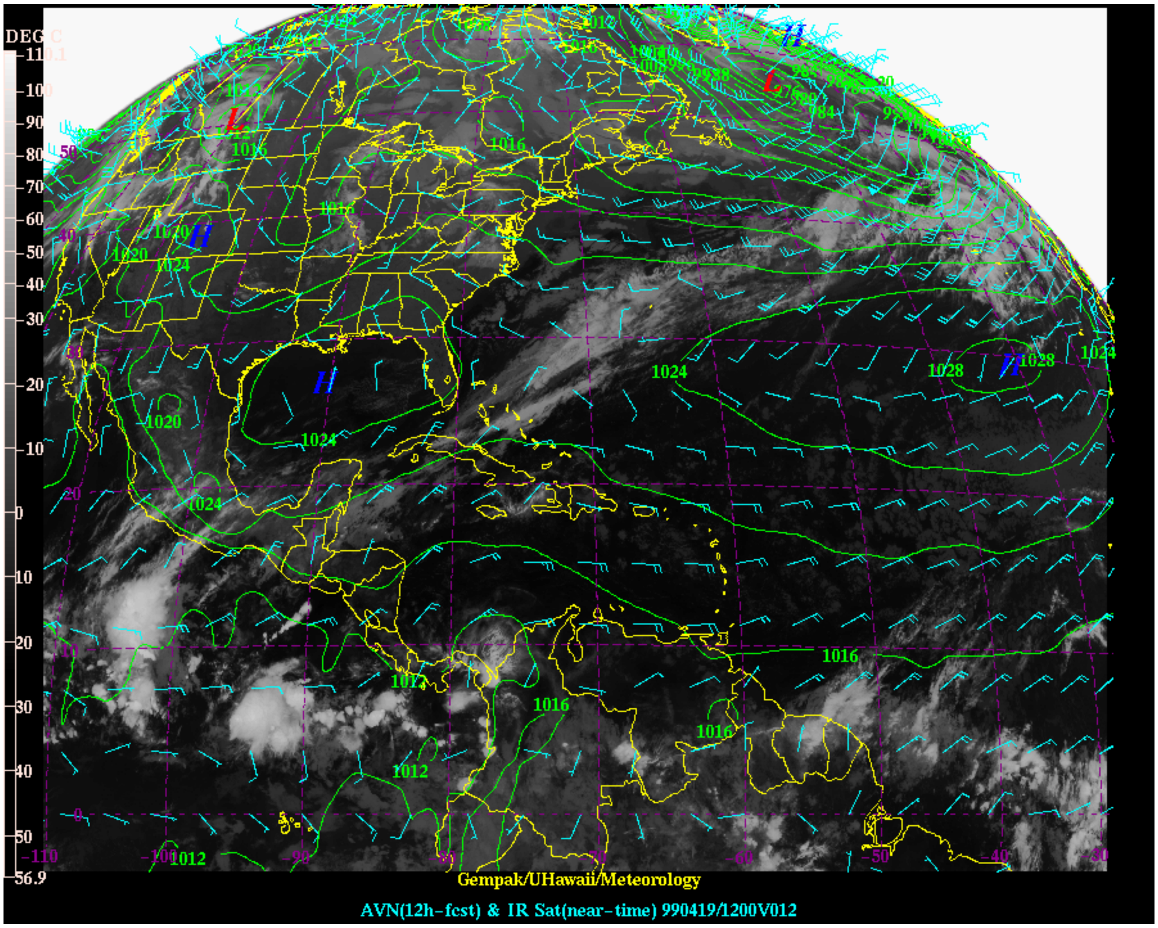


Figure 10. Trade winds belt

Temperature: Temperatures at JOBNERR are high throughout the year. Climatological mean monthly temperatures at Central Aguirre for the 30-year period between 1968 and 1998 range from 29.7°C (85.4°F) in February, to 32°C (89.6°F) in August.The highest daily temperature for this period was 36.7°C (98°F) recorded on September 8, 1997, and December 24, 1976. Daily lows of 13°C (55°F) occur from November to March.

McClymonds and Díaz (1972) show a climatological daily mean temperature range of 19.5-32° for the South Coastal Plain.

Precipitation: A strong seasonal pattern is also observed in the mean monthly rainfall data for Central Aguirre, from 1968-1998. Precipitation lags temperature by 1-2 months, with October being the wettest month (7.73 inches), and minimum rainfall occurring in March (1.22 inches).

The wettest October on record occurred in 1970 when 27.91 inches was recorded. The single-day record is 12.3 inches, in October 7, 1985. The rain shadow over the South Coastal Plain occurs from the influence of the tall Cordillera Central on the prevailing easterly Trade Winds. Puerto Rico's asymmetric north-south topographic profile, with a wider North Coastal Plain, traps rainfall over the north apron of the Cordillera under both

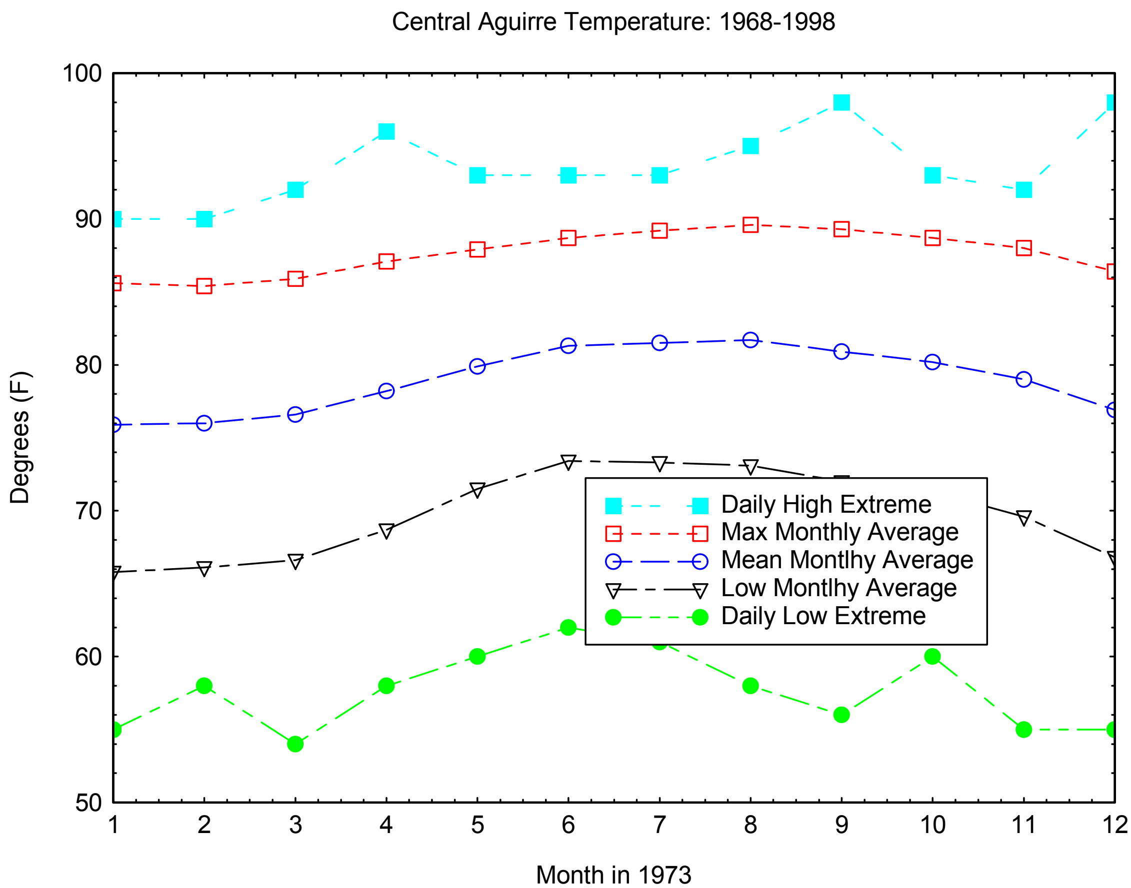


Figure 11. Seasonal variation in temperature for Jobos Bay Watershed.

northeasterly and southeasterly prevailing winds. Orographic steering yields to thermal-convective conditions driving a land-sea breeze cycle under low wind conditions. Whereas afternoon thunderstorms are frequent over the west coast of Puerto Rico, rainfall in the southeastern coastal region is more frequent during early morning hours.

Atmospheric Waves and Pressure Cells: Westward moving tropical waves in the lower atmosphere are best known for the "low" part of the surface pressure cycle as the "highs" are indicative of dry, windy, weather (good weather). On the average, tropical lows generally exhibit weak variable winds, and increased cloudiness and precipitation. Wave conditions under a tropical low are usually calmer, except near centers of strong precipitation, which are accompanied by strong winds (and high seas) of short duration.

During the Atlantic hurricane season, from June to November, high sea surface temperatures and favorable atmospheric conditions allow tropical lows to develop into tropical depressions, tropical storms, and hurricanes. The wet season is characterized by an increase in the frequency of arrival of these tropical waves which are associated with the maximum northward excursion of the Inter Tropical Convergence Zone. Whereas tropical waves move westward, mid-latitude weather systems propagate towards the east.

Frontal Systems: Frontal systems over the North American continent result from the surface displacement of cold air masses from the high latitudes (Alaska and Canada).

These systems move towards the south and east and sustain strong winds along the cold-warm air boundary. As these systems exit the east coast of the U.S. towards the Atlantic, the strong winds excite high seas that in turn decay into large swell waves propagating southwards into the northern Caribbean. Large swell (12-16 sec periods, breakers of 6-8 feet, but up to 10-12 feet) is common along exposed northern coastlines during the winter season (roughly November-April). Its arrival at the islands is easily predicted by following the quasi-periodic behavior of the continental cold fronts. The arrival of a cold front generally means large swell along the north coast and flat seas along the south coast of most islands. Such is the case for JOBNERR. During cold fronts, large swell conditions occur along the north coast while the south coast is usually flat calm.

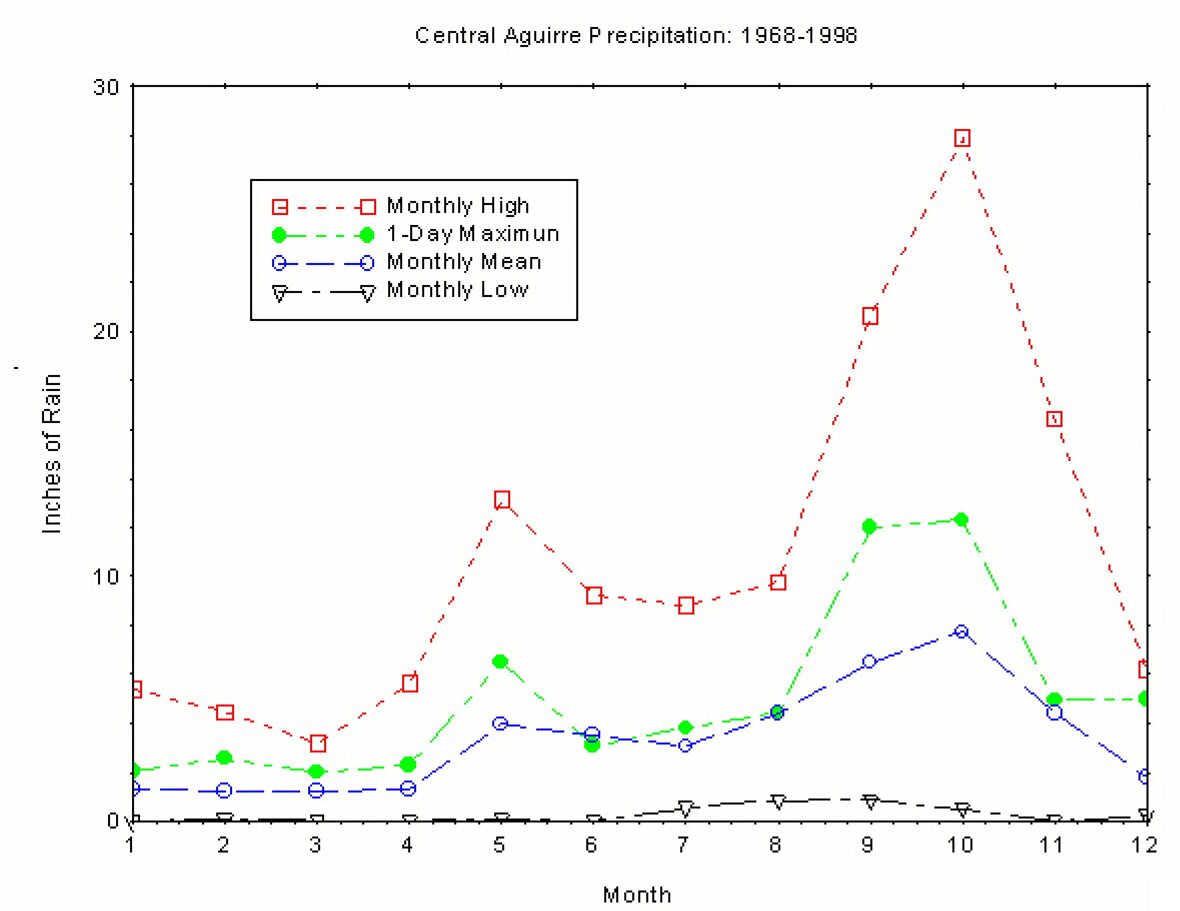


Figure 12. Seasonal variation in precipitacion for Jobos Bay Watershed.

Ocean Waves and Swells: The typical (most frequent) wind-driven wave system along the south coast consists of a background field of southeastward seas and swell generated by the Trade Winds. The wave system is locally modified by bottom topography and by the behavior of the wind as it hits the chain of islands. As the easterly waves approach the islands and make contact with the sea bottom, they refract and turn towards shore, creating a westward longshore current. Under steady southeasterly winds, a south-facing coastline, like the south face of Punta Pozuelo and the Cayos, receives wind and swell head-on throughout the day. A typical forecast under these conditions is for 1-2 meter (3-5 feet) waves and swell across the exposed southern shelf waters. Conditions are usually much calmer inside the Cayos, with the trend continuing into Jobos Bay. The east-west orientation of the Puerto Rico-Virgin Islands platform causes north-south gradients in the surface wave field so that under northeasterly winds, the north coast is exposed to wave action while the south coast is more protected. This situation reverses under southeasterly winds and is modified by the land-sea breeze diurnal cycle.

The combination of local shadow zones from the prevalent Trade Winds, wave refraction due to bottom topography, and the interference patterns created by multiple wave sources creates complex wave patterns around the Cayos and Punta Pozuelo, as revealed in satellite imagery for the region. Under "normal" conditions treacherous waves may develop in narrow channels between the islands due to the focusing of wave energy by the bottom topography.

Winds also induce surface currents in the tide channel, which are further augmented by the surface waters of Jobos Bay and the open ocean currents through the fringing Cayos Caribes and Boca del Infierno. The westerly flow of surface currents is replaced by upwelling of bottom water along the Bay (Figure 13).

Geostrophic influences, tides and wind effects, either separately or by interaction, are factors that generate and control currents and the exchange and renewal of water in Jobos

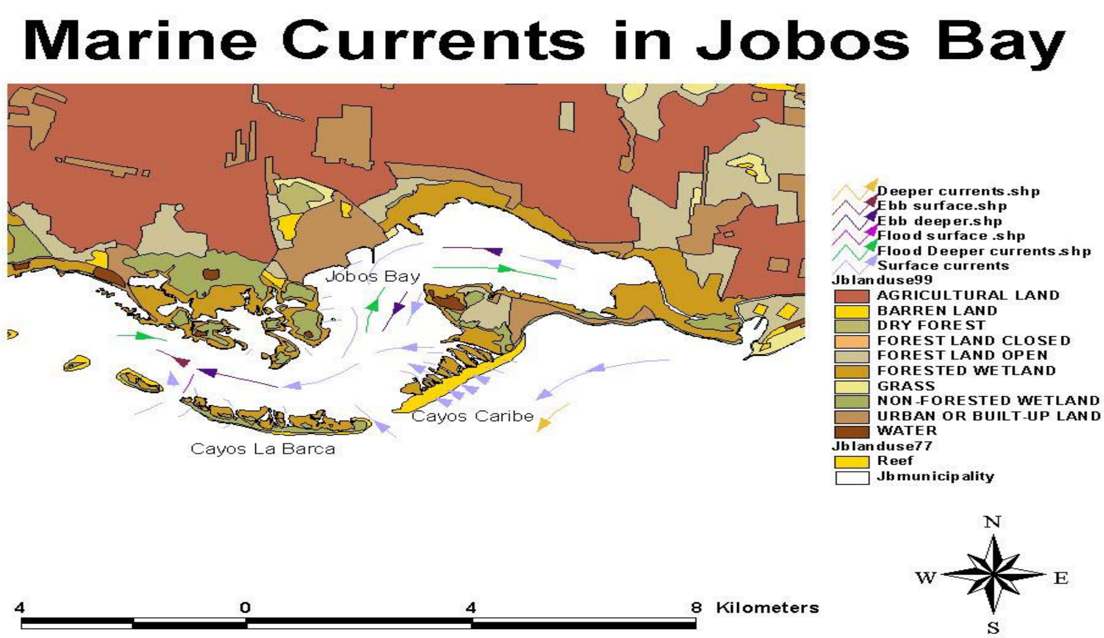


Figure 13. Marine current flow in Jobos Bay.

Bay. Winds blowing mainly from the east generate westward surface currents that are deflected by the labyrinth of mangrove channels and prop and aerial roots from mangrove trees. Jobos Bay is gradually being closed by the advance of mangrove forests and by the expansion of coral reefs, a process that occurred in the former Las Mareas Bay, which is presently a series of interconnected lagoons in Mar Negro.

The tidal excursion (the average distance traveled by a water particle during a half-tide cycle) is around 600 meters, decreasing eastward. Considering tidal and wind effects, the mean residence time of a water mass in Jobos Bay is approximately 5.5 days. The volume of water displaced daily from the Bay averages 30.5 million cubic meters. The peak tidal surge elevation that can be expected to occur at Jobos during a probable maximum hurricane would be about three meters (PRWA, 1972).

Extreme precipitation, wind, and waves (seas, swell, and surge) accompany the arrival of tropical storms and hurricanes. Hurricanes can develop 15-20 meter waves near their center and swell is radiated asymmetrically along their trajectory. During September of 1998 JOBNERR suffered the effects of Hurricane Georges, and in October 1999 those of Hurricane Jose. Hurricane tracks over the last 30 years demonstrate the vulnerability of JOBNERR to such extreme weather events. Long-time scale variability, decadal and longer, in North Atlantic weather patterns is bringing a multi-decade period of average to above-average storm formation after several decades of below-average statistics (See Figure 14).

HYDROLOGY

Semiarid conditions characterize most of the South Coastal Plain, including JOBNERR, with a mean annual rainfall of 106-114 cm (41.6-45 in). The stratigraphy described under ESTUARINE GEOMORPHOLOGY leads to efficient recharging of the aquifer through riverbed infiltration, especially along the upper part of the fan deltas (McClymonds and Díaz, 1972). Quiñones-Aponte, et al. (1997, abbreviated to QGR97), describe the geohydrology of the Salinas to Patillas area of the South Coastal Plain aquifer system, and document the construction, calibration, and application of a three layer, digital ground-water flow model. QGR97 also briefly review relevant, prior work on the water resources in the Salinas to Arroyo region, based upon which they estimate that 5-12 percent of the rainfall results in aquifer recharge.

Aquifer Subsystems: JOBNERR is located along the land-sea boundary of the South Coastal Plain aquifer, which extends from Ponce to Patillas. QGR97 define the Jobos Area subsystem.of aquifers in terms of four layers of equal geohydrological characteristics (Figure 15). From bottom to top these are (1) the regolith bedrock, (2) the principal flow zone, composed of fan-delta and alluvial deposits of sand and gravel, (3) the confining clay geohydrologic unit, a hydrologically impermeable slab of sediment that effectively traps the water above and below, and (4) a top layer of sand and gravel deposits. Approximately 80 feet below JOBNERR, the main aquifer slowly flows towards the sea as a 60 ft thick river of water trapped between the regolith and the confining clay (layer 2). The source of fresh water to this aquifer resides further up, in the high-rainfall Cordillera Central mountain slopes where the aquifer is unconfined. The confining clay layer only extends as much as 2 mi inland in the Jobos Area sub-system.

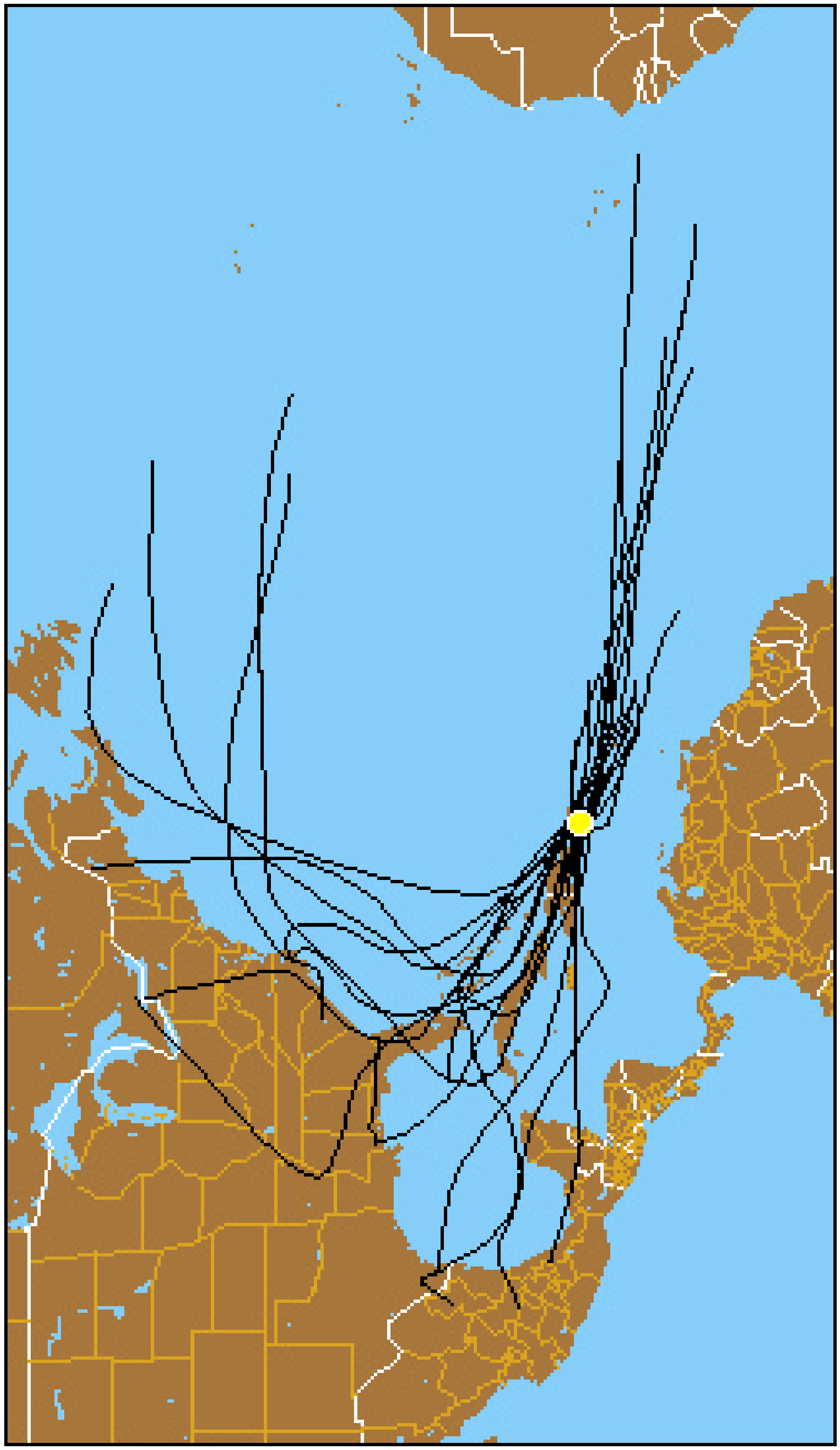


Figure 14. Atlantic hurricane tracks crossing near Puerto Rico.

Since the main aquifer is confined, this water is under pressure and flows freely towards the surface. The confining layer works just as effectively in blocking the penetration of surface water and, therefore, the coastal water table at the JOBNERR site of Mar Negro is very shallow. The shallow coastal aquifer provides the principal source of fresh water to the system through a loosely-defined, distributed system of wetlands (coastal swamps and springs), and by seepage to lower river reaches, discharge to the seabed, and evapotranspiration to the coast. The shallow water table, not the deep aquifer, seems to be the main source of freshwater to the JOBNERR coastline. PRDNR (1983) reports on the existence of springwater upwellings along the bottom of Jobos Bay. However, their location is not specified.

Stream System: Río Seco is the only river draining into Jobos Bay east of the Reserve. From east to west, in the Salinas to Patillas region, are found the Río Salinas (also known as Río Nigua, and not to be confused with the Río Nigua in Arroyo), Río Seco, Quebrada Melanía, Río Guamaní, Río Nigua, and Río Grande de Patillas (QGR97 and Figure 15). Several small tributary streams and small intermittent streams also flow through the region, most notably Quebrada Aguas Verdes and Quebrada Coqui which feed directly into Jobos Bay. QGR97 report that most streams maintain year-round flow downstream only to the point where they meet the highly porous fan deltas. From there on they become the most important source of groundwater recharge to the underlying aquifer.

Irrigation Canals: Agricultural irrigation in the Salinas to Patillas area is achieved through the use of a network of man-made canals which transport surface water from the Patillas and Carite reservoirs. Large-scale use of this system started in 1914, when sugarcane was the main agricultural product. The two principal canal irrigation systems in the region are the Canal de Patillas and Canal de Guamaní.

The combination of surface water together with a shallow coastal water table necessitated the construction of drainage canals and pumping stations in order to reclaim swampy areas for agriculture. Canal construction in the 1930's (QGR77) was also a response to the threat of malaria.

LAND AND WATER USE

Land Use

Agriculture: From Spanish Colonial times up until the 1970's, the principal use of lands around JOBNERR was for agriculture. Sugarcane fields extended throughout the South Coastal Plain with coconut plantations bordering the shoreline. As of 1995, most of the land area falling within the Jobos Bay Special Planning Area (SPA) was still devoted to agriculture. However, the remaining vestiges of sugarcane lands are steadily being supplanted by fruit and vegetable cultivation. The decline of sugarcane cultivation in Puerto Rico since the 1960's resulted in the closing of Central Aguirre. Banana and plantain farms exist north of Mar Negro, outside Reserve boundaries, extending toward the higher, cooler mountain areas. Pasturage is also a principal agricultural use.

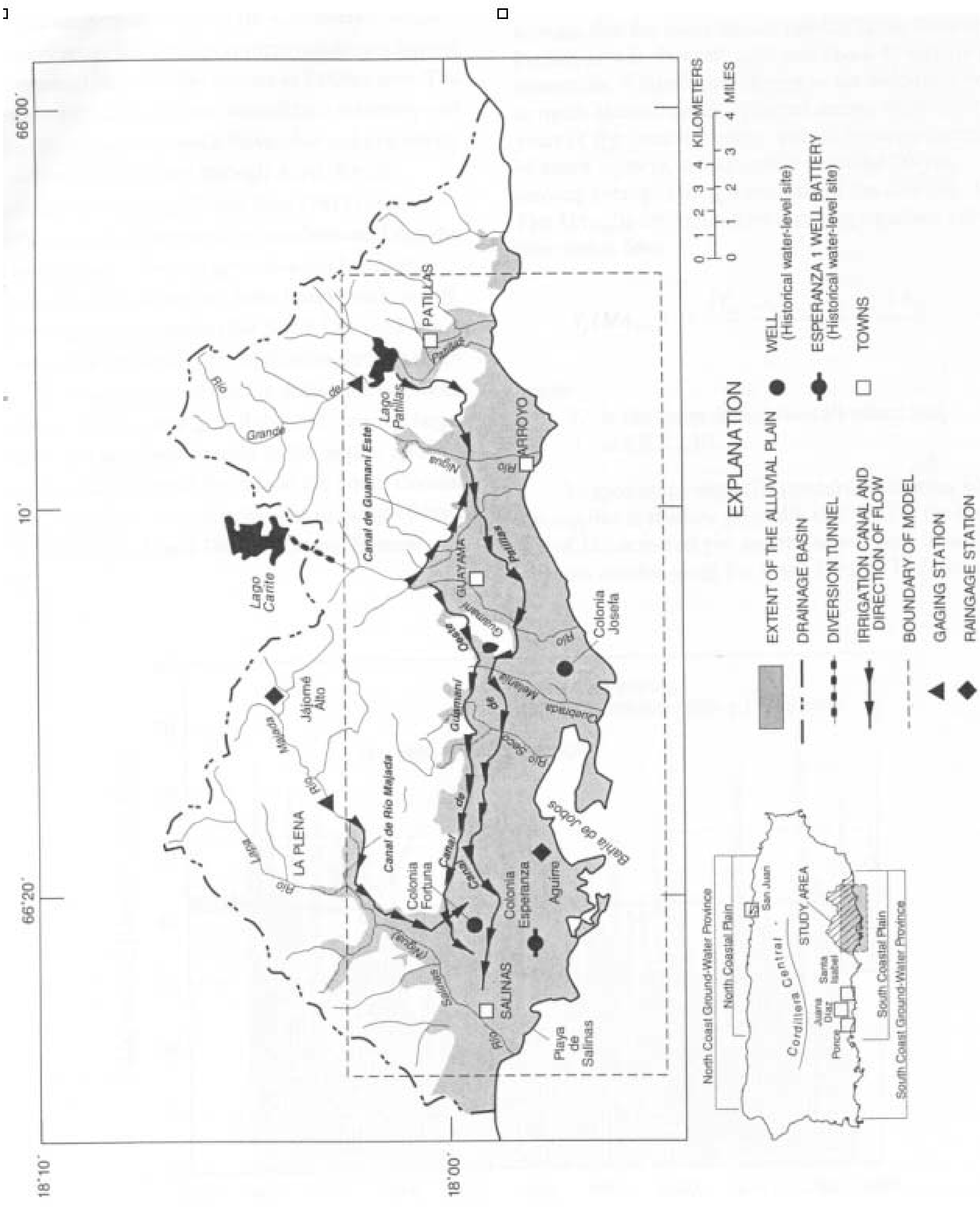


Figure 15. South Plain Aquifer system from QGR77.

Industry: Other major uses within the SPA, close to the Reserve, include a poultry processing plant, a landfill, and a race car track Along the Jobos Bay coastline, towards the northeast, is the Aguirre thermoelectric plant, a tire recycling plant, and the old Central Aguirre sugar mill. The JBNERR Visitor's Center is situated in the center of the coastal residential community. Further to the east, near the west end of the Bay, a major chemical and pharmaceutical complex has developed. The Phillips Petroleum refinery is located just to the east of Jobos Bay. Current development proposals include a major regional landfill north of JOBNERR and construction of a coal-based cogeneration plant near Phillips Petroleum.

Water Supply: The availability of large supplies of water from the aquifer and the suitability of local soils for farming has prompted agricultural and industrial development. The region has also benefited by the protected waters in Jobos Bay and the availability of a local power source, the thermoelectric power generating facility. Despite promotional efforts by the Puerto Rico Industrial Development Administration (PRIDCO), no new heavy industrial uses have been established in the region.

Land Use Inventory: Under the NOAA-UPR sponsored project ("The use of a Geographic Information System and Remote Sensing Technology for monitoring land use and land cover of the Jobos Bay Estuarine Research Reserve"), Prof. Linda L. Velez (UPR-RUM) developed a complete GIS inventory of resources, land use and landcover.

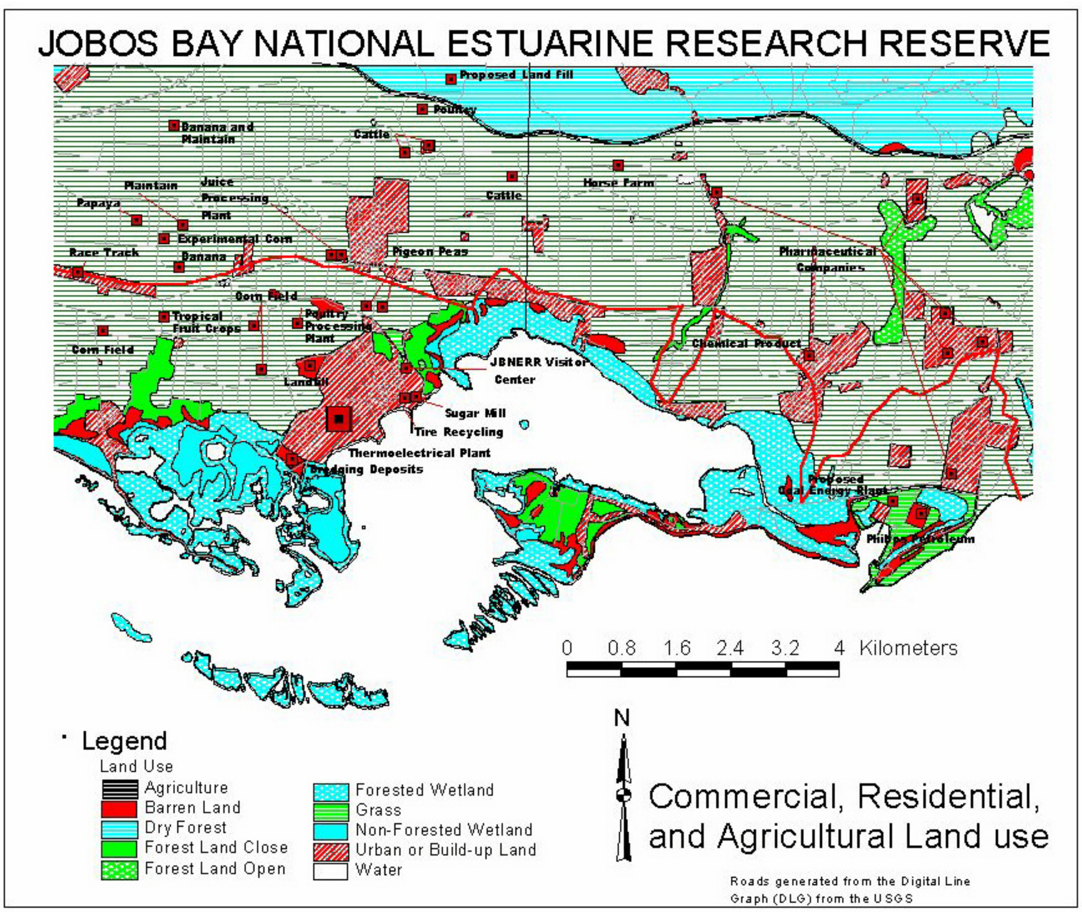


Figure 16. Commercial, residential and agricultural land use of Jobos Bay Watershed.

The land use classification used in the inventory followed U.S. Geological Survey guidelines.

Population and Settlement Patterns: The Reserve is located in the Barrio Aguirre (Aguirre Ward) sector of Salinas and Barrio Jobos (Jobos Ward) of Guayama.). Aguirre was originally built around Central Aguirre, and the distinctive architectonic style of the early-century sugar plantation structures has been preserved.

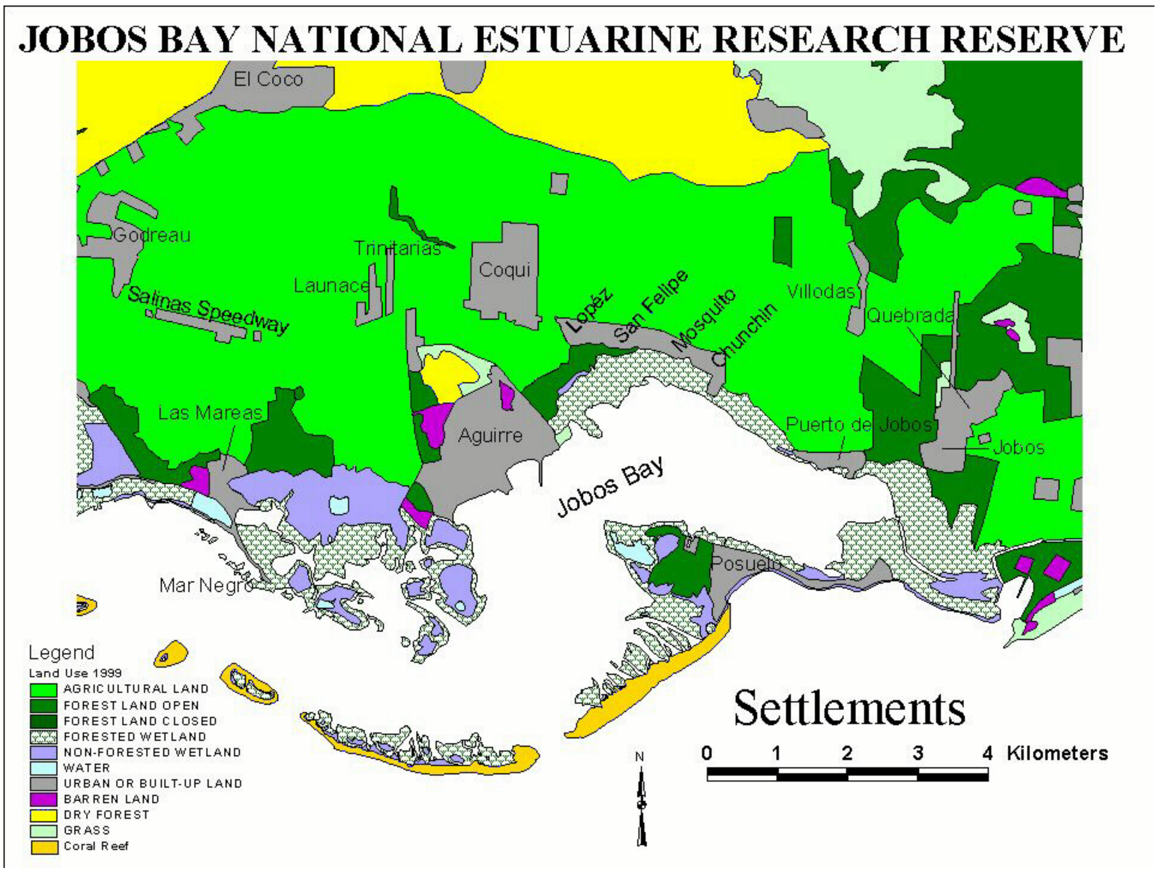


Figure 17. Settlements in Jobos Bay Watershed.

Recent Census Bureau estimates place the population of Guayama at 43,105, a 3.6 percent increase over the 1990 census figure of 41,588. The estimated population of Salinas is 29,997, a 5.8 percent increase over its 1990 population of 28,335 (U.S. Census Bureau web site). Existing coastal communities and squatter settlements are steadily growing, while new coastal urbanization is accelerating (DNER, 1998).

Coastal Facilities: Various docking facilities and boat ramps have been constructed along Jobos Bay. A fisherman's pier and the Guayama Yacht Club marina are located in Punta Pozuelo. Larger docking facilities have been constructed to support industrial operations, since fuel for the thermoelectric plant and crude oil for the refinery complex in Guayama arrives by sea. Several canals have been dredged in Jobos Bay to accommodate maritime access to the various piers. However, the only dredging permit that is currently active belongs to PREPA, a governmental entity that operates the thermoelectric facility.

The north coastline of Jobos Bay borders the Reserve. To the east and along the coastal fringe is the Aguirre State Forest, the Aguirre thermoelectric power plant and the old Central Aguirre sugar mill. The Las Mareas community in Salinas borders JOBNERR to the west, while agricultural lands are found along the north boundary. Hypersaline lagoons and salt flats border the Reserve's western boundary north of Mar Negro. These lands are currently owned by the Puerto Rico Department of Housing and are potential development sites.

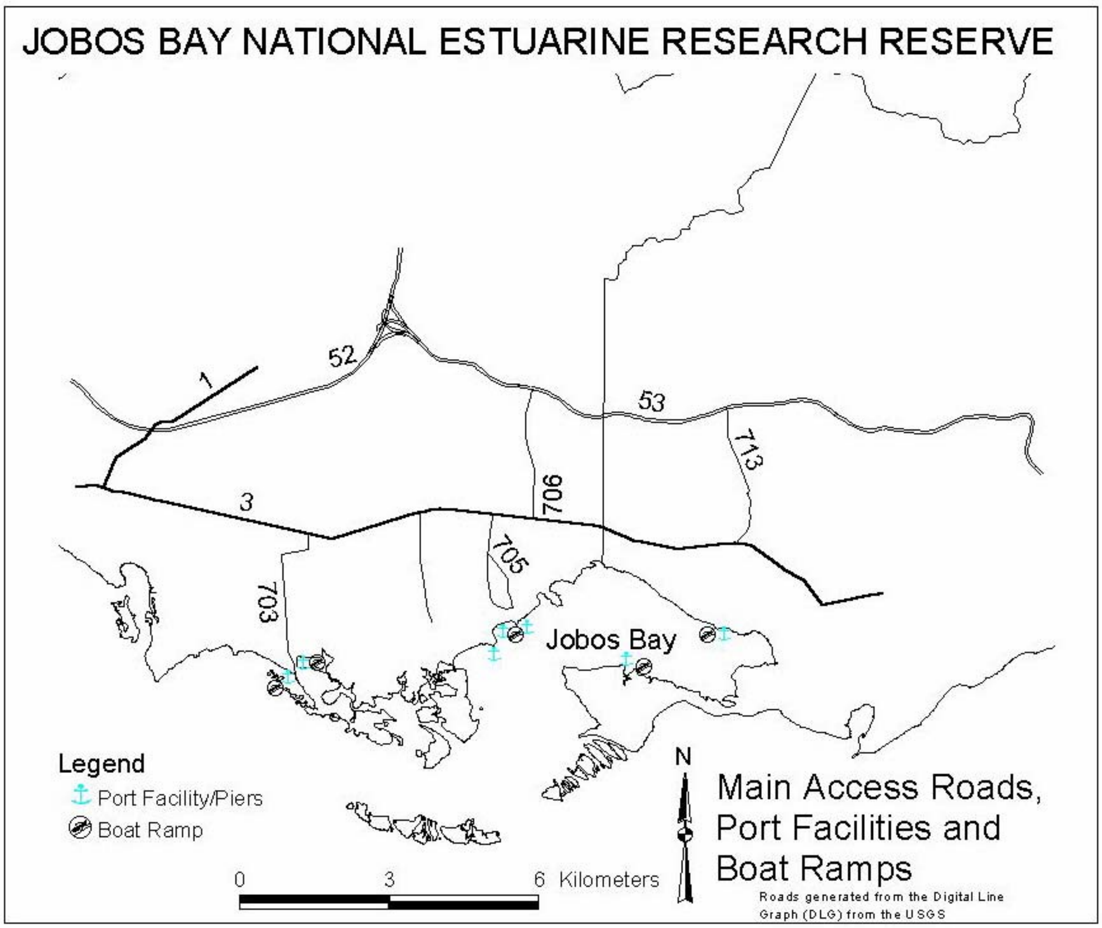


Figure 18. Main access roads, ramps and facilitites in Jobos Bay Watershed.

Ground Water Extraction: The South Coast Aquifer is the main source of freshwater throughout the Guayama-Salinas Region. More than 125 wells are registered in the municipality of Salinas alone. Well locations are shown in Figure 19.

Current estimates place extraction at 1.5 Mgal/day in the Aguirre area (DNER, 1998). Extraction volume is expected to increase with growing urbanization. El Coquí, San Felipe and Centro Urbano communities are connected to the Guayama Regional Wastewater Treatment Plant. Otherwise, over 90 percent of the domestic waste is disposed of through septic tanks or discharged directly into Jobos Bay. The local sewer system discharges into the Bay. Raw sewage from Aguirre is also discharged into Jobos Bay.

Fishing: Fishing of the traditional artisanal variety is a common occupation among the various coastal communities. There are four commercial fishermen associations along the Guayama-Salinas coastline. Fishing is usually conducted from small wooden boats, or yolas, that accommodate 1-4 fishermen. Fishing techniques include the use of fish and lobster traps, various types of nets, hook and line, and trolling.

Recreation: Local recreational facilities include the Central Aguirre Golf Club, and the beach at Punta Pozuelo. The region is known for its ecotouristic appeal. Many visitors are attracted by the easy access to varied coastal and marine ecological settings. JOBNERR and its Visitor's Center, Punta Pozuelo Beach, a multitude of small, undeveloped beaches, the Cayos, and the mangrove forest-canal system are pricipal attractions. Cayos Caribe, a part of JOBNERR, has been a popular weekend picnicking-camping area although lacking any permanent camping and sanitary facilities.

MARINE ENVIRONMENT

Water Temperature and Salinity

Offshore Caribbean waters are stratified by depth. As a result, fluid moves in different directions at varying depths based on the sources and sinks for each water mass. These conditions vary throughout the Caribbean. Just three miles south of JOBNERR, the following strata have been identified:

- Caribbean Surface Water, the local mixed-layer, whose lower boundary is known as the seasonal thermocline (technically it is the pycnocline but these two boundaries approximately coincide in depth);
- Subtropical Underwater to about 180 m;
- Sargasso Sea Water to about 325 m;
- Tropical Atlantic Central Water to just over 700 m;
- Antarctic Intermediate Water to 900 m; and
- North Atlantic Deep Water reaching all the way to the bottom at ca. 4,000 m.

It may be noted that the island passages, with a maximum sill depth of about 1,800 m, do not allow any Atlantic bottom water to enter the Caribbean.

Caribbean Surface Water: The structure and composition of the Caribbean Surface Water, that which bathes the JOBNERR shoreline and in which most human activity occurs, exhibit a well-defined seasonal pattern.

In the northeastern Caribbean Sea the depth of the thermocline reaches a maximum of close to 100 m in the spring (January-March) and a minimum of about 25 m in the fall (September-October). Density, temperature, and salinity follow the same seasonal pattern with temperatures ranging from 26 to 30 °C and practical salinities from 36.3 to 34, respectively (CEER, 1980-1981).

The large range in offshore surface salinities is due to the northwards advection-mixing of South American riverine outflow in the eastern Caribbean Sea, specially from the Orinoco River. The seasonal surface salinity range is therefore narrower northwards into the North Atlantic (Morrison and Nowlin, 1982).

While the Orinoco effect creates a seasonal north-south surface salinity gradient in the eastern Caribbean, the Amazon River outflow becomes entrained in pools or eddies that,

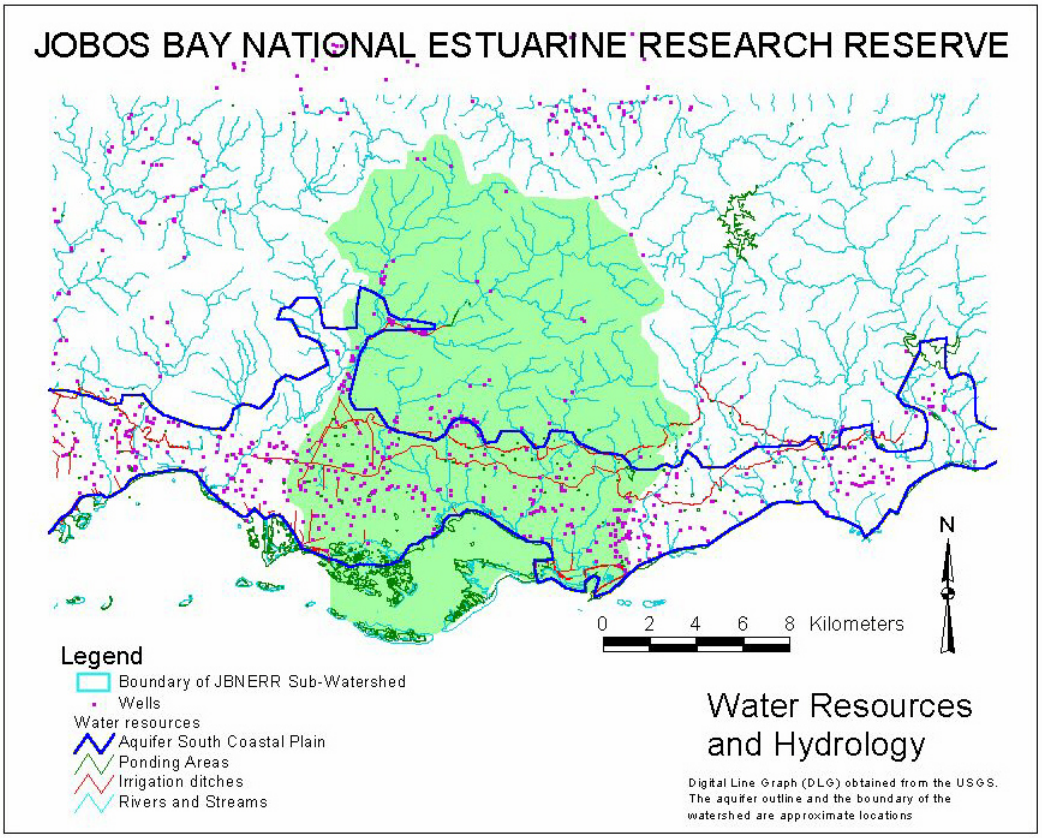


Figure 19. Water Resources and Hydrology of Jobos Bay Watershed.

after a circuitous trajectory through the Tropical Atlantic, arrive at the Windward Islands as pools of green (high chlorophyll content, low salinity) water, and enter the Caribbean from the east.

PRNC (1971 and 1975) collected temperature records at multiple sites and depths throughout the Jobos Bay region from 1970-1975. Figures 21 and 22 show yearly records of water temperature at several stations near the warm water discharge (a) February to December, 1973, and (b) January, 1974 to February, 1975. Data was also collected during January-December, 1971 (not shown). At the single 1973 station, located 500 m southwest of the Aguirre power plant's dock towards Mar Negro, temperatures exhibited a seasonal pattern ranging from 26.2°C in December, to 30.0°C in September, while salinities ranged from 33.6 in August, to 36.3 in April. The peak temperature during 1975-1975 was 35.89°C, sampled on May 31, 1974, near the thermal discharge. Minimum temperatures were observed in January, 1974 (24.95°C) and January, 1975 (25.40°C).

Generally, temperature-salinity patterns at Jobos Bay oppose one another as high salinities occur with low temperatures during the dry winter months (December-April), while the opposite situation prevails in the wet summer (May-November), (PRNC, 1975). Waters near the power plant outfall were as much as 0.5°C warmer than elsewhere in the Bay. Large interanual variability between 1973 and 1974 occurred due to the frequency and timing of low salinity values occur in the top 1m of the water column after high precipitation events, often associated with westward traveling tropical waves (lows) in the atmosphere. These data are consistent with temperature and salinity values in PRWRA (1972).

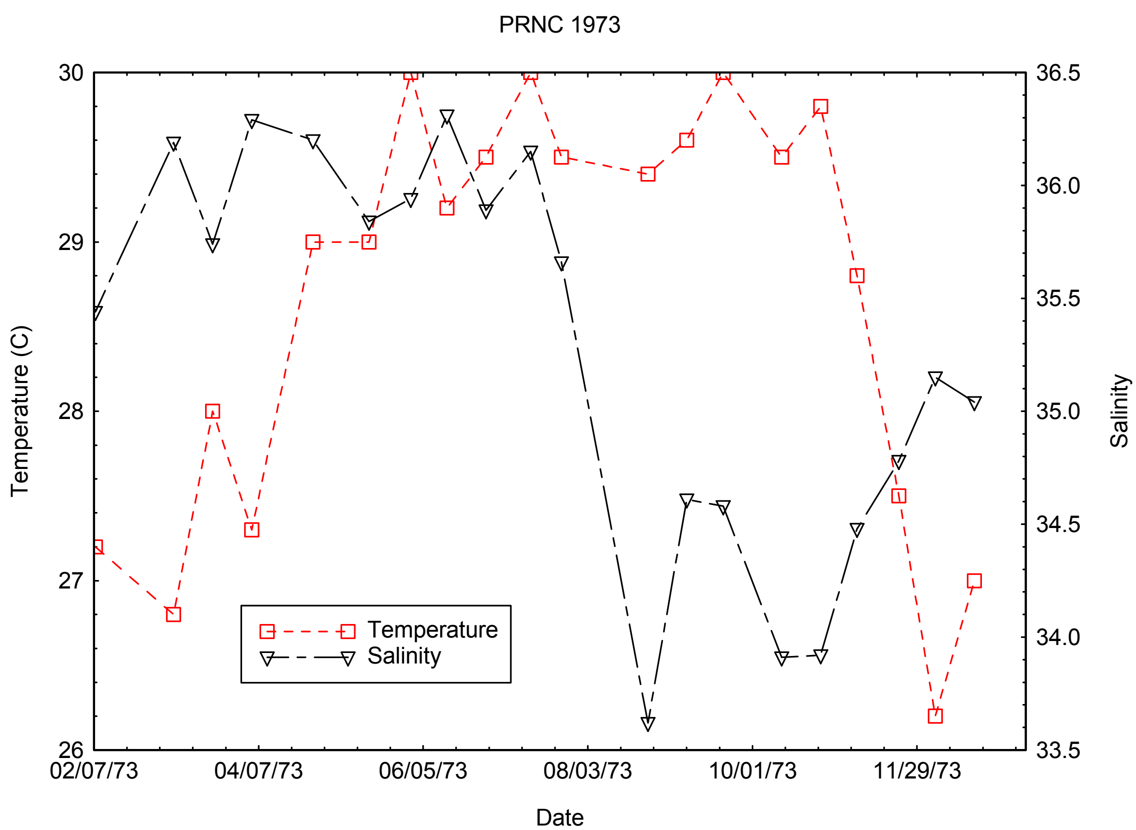


Figure 20. Puerto Rico Nuclear Center temperature and salinity in 1973.

Offshore Currents and Circulation

Regional Circulation Pattern: Passages between the various islands allow the inflow of North Atlantic, Tropical Atlantic, and Equatorial waters into the Caribbean Basin. The main outflow is towards the west through the Yucatan Channel between Cuba and the Yucatan Peninsula. The expected mean circulation pattern of the wind-driven offshore surface waters around the PR-USVI-BVI shelf is, therefore, in a west-southwest direction, joining the general western flow of the Caribbean towards Yucatan Strait. The

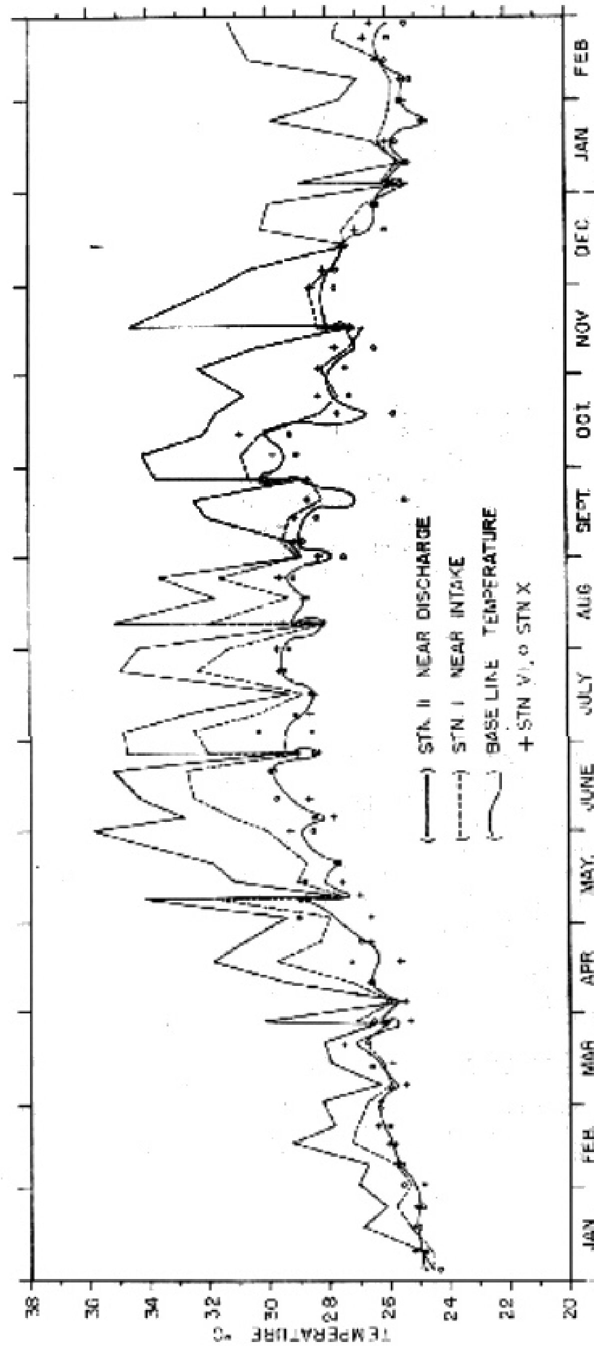


Figure 21. Puerto Rico Nuclear Center temperature and salinity in 1974

expected long-term, mean flow between Puerto Rico and Santo Domingo is through Mona Passage and through Anegada Passage to the east. Recent, long-term, direct observations across Mona Passage place the mean meridional transport at 1-2Sv into the Caribbean (one Sv = one million cubic meters per second). The total outflow through the Florida Straits, which is mostly composed of the integrated Caribbean inflow, is in the order of 30 Sv. Deep waters off southeastern Puerto Rico, in the Witting Basin south of JOBNERR, are bathymetrically connected to Anegada Passage inflow.

Caribbean Circulation Pattern: In the Caribbean Sea, the meridional distribution of the zonal wind stress generates a circulation cell where deep waters are upwelled along the north coast of South America, and surface waters (enriched by upwelling and by the Orinoco loading) are advected northwards into our region, especially during the fall season. Satellite images in the visible spectrum (CZCS and SEAWIFS) clearly show the meridional spreading of green water in the eastern Caribbean (Müller-Karger et al., 1989). The northward edge of the Orinoco plume does not extend far to the north of Puerto Rico. The convergence of these two distinct Caribbean and North Atlantic dynamical regimes define our region as a boundary zone, with the edge of the green Orinoco plume often referred to by local researchers as the Caribbean Front.

A persistent feature of the geostrophic flow just south of Puerto Rico in the CEER data is the generally eastward transport in the upper 100m, in a direction that is the opposite of the expected westward advection of wind-driven Caribbean Sea waters. Eastward geostrophic flow is generally limited to near surface waters, while deeper flow is generally westward. These observations are consistent with those of Morrison and Nowlin (1982) and indicate that eastward geostrophic transport in the northeastern Caribbean, south of the Puerto Rico-Virgin Islands platform, is a common feature of the regional circulation.

Fornshell and Capella (1984) conducted Lagrangian drifter measurements off the southeast coast of Puerto Rico during seven weeklong cruises between March and September of 1982. On an eighth cruise additional drifters were released near Grappler Seamount. Figure 22 shows the drifter trajectories obtained in this study; the buoys were drogued at 50m and 100m or 200m on each cruise.

There were essentially four flow regimes observed on the eight cruises: southerly flow, easterly and stalled flows, west-northwest or onshore flow, and southwest flow with bathymetric steering. The unusual southerly flow tracked by some of the drifters is consistent with the CEER geostrophic flow contours. The highest velocities were observed when the drifters moved steadily towards the southwest during August 30 to September 2, 1982. The mean flow during the seventh cruise was towards 243° at 20.3 cm/s. These results are consistent with observations by Goldman (1980).

The insular shelf south of Puerto Rico is very narrow, only 3-5 km wide, from Punta Tuna to Salinas, where it widens to ca. 10 km towards the west. Topographic steering results in the southward veering of the offshore westward trajectories south of JOBNERR. Persistent eastward tracks were observed.

The Anegada-Jungfern Passage is the only Atlantic-Caribbean connection for waters below sill depth (ca. 1,800 m) in the northeastern Caribbean. Metcalf (1976) and MacCready et al. (1999) have observed the flow to be from the Atlantic into the Caribbean, through this passage, below 700m. In October, 1994, south of La Parguera, current readings, over a 2-week period, were recorded at a depth of 650m (1500m bottom depth). The resultant record velocity was towards 87° at 2 cm/s.

Maps of the mean seasonal surface circulation in the Caribbean Sea are found in Wüst's (1964) atlas, in the Pilot Charts, and in the body of oceanographic literature for the region (a good review up to the early eighties can be found in Kinder, et al, 1985). Seasonal changes associated with the north-south excursion of the Inter Tropical Convergence Zone (ITCZ) result in maximum mean surface currents in the central Caribbean during the summer. Superimposed on the mean circulation, tidal currents are the dominant component of the offshore currents.

Satellite altimetry and numerical modeling studies have shown high levels of mesoscale activity superimposed on, or averaging into, the mean circulation of the Caribbean Sea and of the western Tropical Atlantic to the east. Just upstream from the eastern Caribbean, these mesoscale features consist of anticyclonic (clockwise) eddies that arrive at the eastern Caribbean from interaction of the equatorial long-wave field with the Brazil Current Retroflection. Model simulations show the dissipation of these eddies upon impact with the southeastern Antilles, in the vicinity of Barbados and the transfer of mass, energy, and vorticity into the Caribbean resulting in the spawning of new eddies west of the islands.

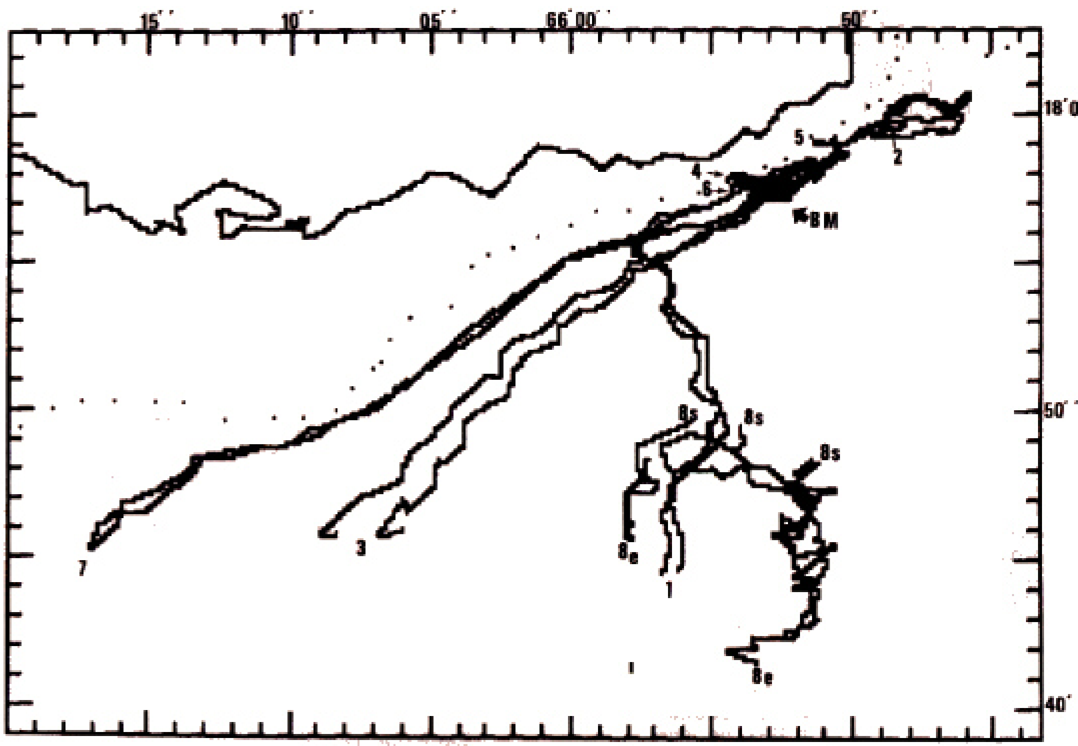


Figure 22. Drifter trajectories south of Puerto Rico from Fornshell and Capella (1984).

Both cyclonic and anticyclonic eddies have been observed inside the Caribbean Basin where they are advected westward, in the direction of the mean flow (Murphy and Hurlburt, 1999). Computer modeling and satellite altimetry studies (Geosat and TOPEX – POSEIDON) show eddies moving westward south of Puerto Rico and reaching all the way to the Yucatan Channel where they have a profound effect on the Loop Current in the Gulf of Mexico (Nystuen and Andrade, 1993; Andrade and Barton, 1999). Several mechanisms have been proposed for the formation of eddies inside the Caribbean Sea: island-flow dynamics, bottom-flow dynamics (due to the Aves Ridge and other bathymeric features), and eddy-boundary dynamics. TOPEX sea surface elevation and geostrophic current contours covering our region, which often show eddy-like features south of Puerto Rico, can be found at the TOPEX web site.

Coastal Currents

General Findings: Coastal current around PR-USVI are mainly tide and wind driven. The North Equatorial Current, flowing in a west-northwesterly direction, dominates the entire south coast of Puerto Rico. Oceanic currents are to the west off Jobos Bay. However, on a localized basis, special hydrographic conditions can modify the nearshore coastal currents.

The narrow and shallow shelf is, in most places, directly exposed to the open ocean, especially along the north coast. With the exception of bays and lagoons, coastal flows are steered by the coastline-shelf topography and are, therefore, east-west along the north and south coasts, north-south in Mona Passage, and variable on the shallow VI platform. Typical peak tidal speeds of 10-20 cm/s have been observed at numerous sites in the region; the mean vector-averaged velocity is usually less than 5cm/s. The typical pattern is that of oscillatory currents parallel to the coastline.

The local wind stress, dominated by the easterly Trade Winds, pushes surface waters towards the west, the same direction as the large-scale offshore mean flow. However, during times of weak easterly winds, near bottom waters are commonly observed to flow towards the east. This behavior is known to occur along the north and south coasts of Puerto Rico and has been attributed to (1) a reverse pressure gradient resulting from the action of the mean flow on the abrupt island topography (Tyler, 1992), and/or (2) an unknown mean eastward external pressure gradient.

Current Flows for Jobos Bay and South Coast: PRNC (1971 and 1975) describe the circulation in Jobos Bay during periods of southeasterly winds as a westerly flow of surface water, replaced by upwelling of bottom water throughout the length of the Bay. The upwelled bottom water source is the open sea, which supplies the water through the deep channels at the west end of the tide channel (Figure 13).

Open ocean waters flow easterly along the bottom of the Aguirre Ship Canal and into Jobos Bay. The typical tidal flow pattern is for westward flow during ebb tide and eastward flow during flood, a pattern that is overridden near the surface by strong winds. The prevailing easterly and southeasterly winds intensify westward flow during ebb tide and might cancel, or even reverse, the eastward, flood surface flow. The mean flow through Cayos Caribe is towards the northwest, into the mouth of the Bay and Mar Negro. The tide channel, which contains the ship canal, is 25 to 35 feet deep and connects to the sea through shallow surge channels between the islets of Cayos Caribes, Cayos La Barca, and through Boca del Infierno. Surface currents in the Bay and the ship canal normaly average 10 cm/s, ranging from 0.0 to 25 cm/s.

Tyler (1992) measured shelf currents at La Parguera and Guanica and pressure at La Parguera and Salinas over a one-year period; his results were later summarized in Tyler and Sanderson (1995). Tyler measured currents approximately 1.5m above the bottom at depths of less than 10m. Low-passed wind and current data from Tyler (1992) are shown in Figure 23.

These low-passed, near-bottom currents reach speeds in the order of 10 cm/s, whereas the raw, unfiltered, data exhibit higher magnitudes. The original data collected by Tyler is available for further, in-depth, analysis of coastal currents outside of JOBNEER.

The subsurface currents in Guayanilla Bay, approximately 60 km west of JOBNERR, are tidally driven, following the prevailing diurnal tide with a weak semidiurnal component. Tidal current vectors rotate along a topographically flattened tidal ellipse in a clockwise sense. As expected, the tidal currents lag the tidal elevations by a 6-hour time lag. These tidal currents are bottom-intensified and could well account for the high levels of turbidity observed in Guayanilla Bay. Residual near-bottom currents enter the bay along the eastern side of the channel and exit along the western side, suggesting a counterclockwise residual flow within the Bay. Tidal volume exchange across the entrance channel exceeds previous estimates and is calculated on the average to be at least in the order of 15-40 percent of the volume of the Bay. The mean observed currents are from Tallaboa Bay into Guayanilla Bay (east to west).

Tides

Tidal Patterns: Tides throughout the northeastern Caribbean Sea exhibit a complex behavior. Along the south coasts of Puerto Rico and Vieques the tide is principally diurnal (one cycle per day; i.e., 24h period) while the tide along the north and west coasts of Puero Rico is semidiurnal (two cycles per day; i.e., 12h period). The JOBNERR is located within a geographical band of diurnal tides that actually extends south across most of the Caribbean and is surrounded by areas where the semidiurnal tide is stronger. This is further complicated approaching Vieques due to the presence of the semidiurnal (M2) anticlockwise rotating amphidromic system, centered south of St. Croix. Kjerfe (1981) and the CD titled "A Collection of Global Ocean Models" (includes 10 global ocean tide models and many graphs, and can be ordered at http://podaac.jpl.nasa.gov) show significant predictive variability for the deep ocean tides in this region and for the position of the amphidrome. Accurate numerical prediction of the oceanic tide close to the islands becomes rather difficult due to the steep bathymetry of the Antillean Island Arc (and the lack of high resolution bathymetry), and the proximity of the M2, N2, and S2 amphidromes.

Tidal Range: Average tide heights at the Arroyo station (18° 54’’N, 66° 04’’W) range from 18 cm below mean sea level to 12 cm above, for a total mean tidal range of 30 cm (about a foot). The Arroyo tide may be predicted from NOAA sources or by tidal prediction software that use the appropriate tidal constants (i.e., TIDE.1 software from Micronautics). Other sites along the south coast for which tidal elevation predictions are available are Maunabo, Santa Isabel (Playa Cortada), Ponce (Playa de Ponce), Guanica, and Lajas (Isla Magueyes). PRNC (1971) analyzed tide data from Cayo Lulu, sampled every three hours over a period of 100 days from 22 Febryary 1971, to 1 June 1971. A dominant daily peak (one day) with fortnightly (13.3 days) modulation is the dominant structure in these data.

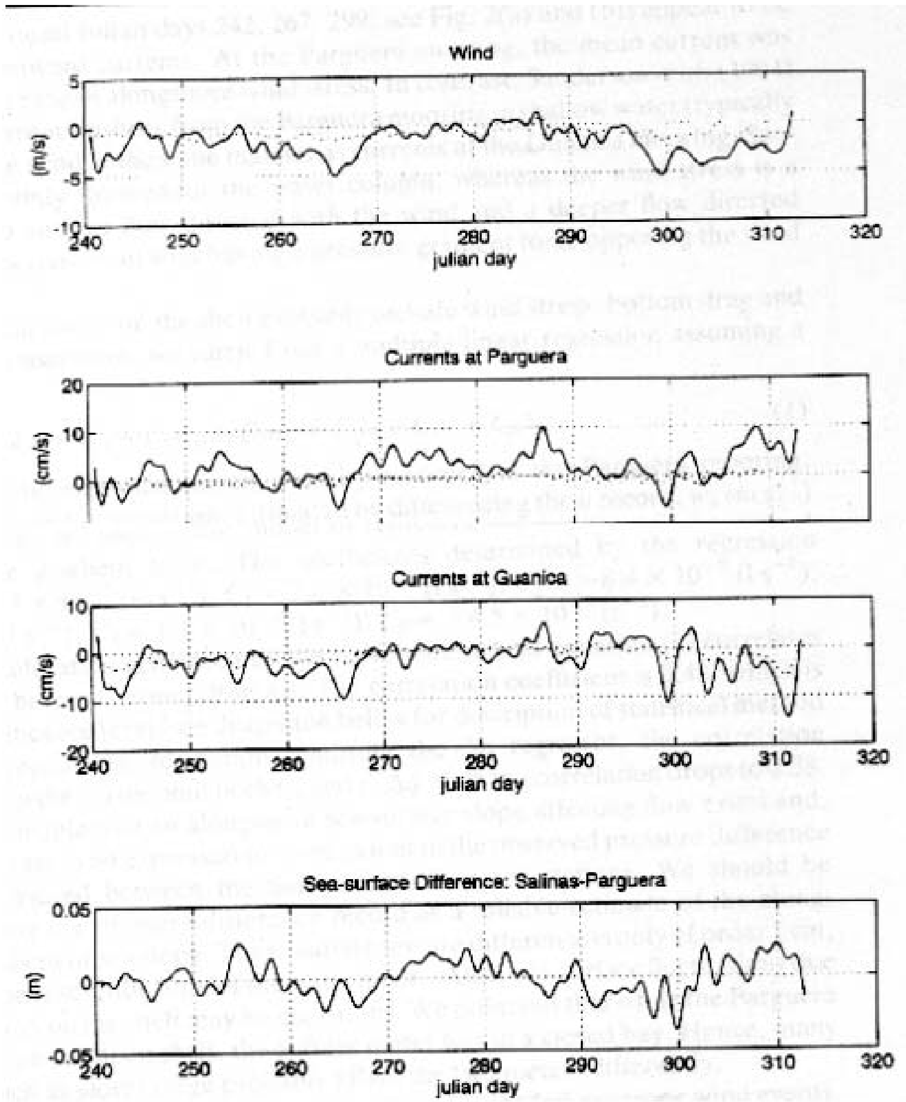


Figure 23. Wind Currents: a) wind speed, b) currents at La Parguera, c) currents at Guánica, d) sea-surface differences: Salinas-Parguera.

Yearly tidal maxima occur when a lunar perigee coincides with a new or full moon. This alignment usually occurs twice a year and evolves from year to year in response to lunar orbital characteristics. Coastal tidal currents generally lag the phase of the predicted surface tide by a quarter of a cycle (6 hours for the diurnal tide). Vertical oscillations in the water column driven by the barotropic tide, known as internal tides, are observed to extend from the seasonal thermocline to the maximum observed depth in stratified offshore waters south of PR. The amplitudes of these tidal oscillations are inversely proportional to the stability of the water column, resulting in a general increase in amplitude with increasing depth.

CHAPTER 3. BIOLOGICAL SETTING

by Dr. Eddie N. Laboy

BIOTIC HABITATS

Small variations in the hydrology, soil content, elevation and salinity are the main natural factors responsible for the relatively low floral diversity of the Jobos Bay NERR. Even though the Bay has been substantially altered by catastrophic events (hurricanes, floods, oil spills, dredging and filling, urban and agricultural encroachment), it is believed that most of the existing habitats are representative of what was present a century ago. With or without anthropic disturbance, none of the estuarine communities is static in terms of the distribution and abundance of marine and terrestrial species. In a very limited area (1,140 hectares), the Jobos Bay NERR encompasses five major habitats. These include the mangrove forest which covers nearly 90 percent of the Reserve's surface area, the evergreen littoral woodland (limited to Cayo Caribe, El Cocotal and Camino del Indio), mudflat patches within Mar Negro, seagrass beds of the benthic substrata, and coral reefs Each habitat shelters a variety of organisms, particularly halophytes, xerophytic shrubs, marine and terrestrial invertebrates and birds.

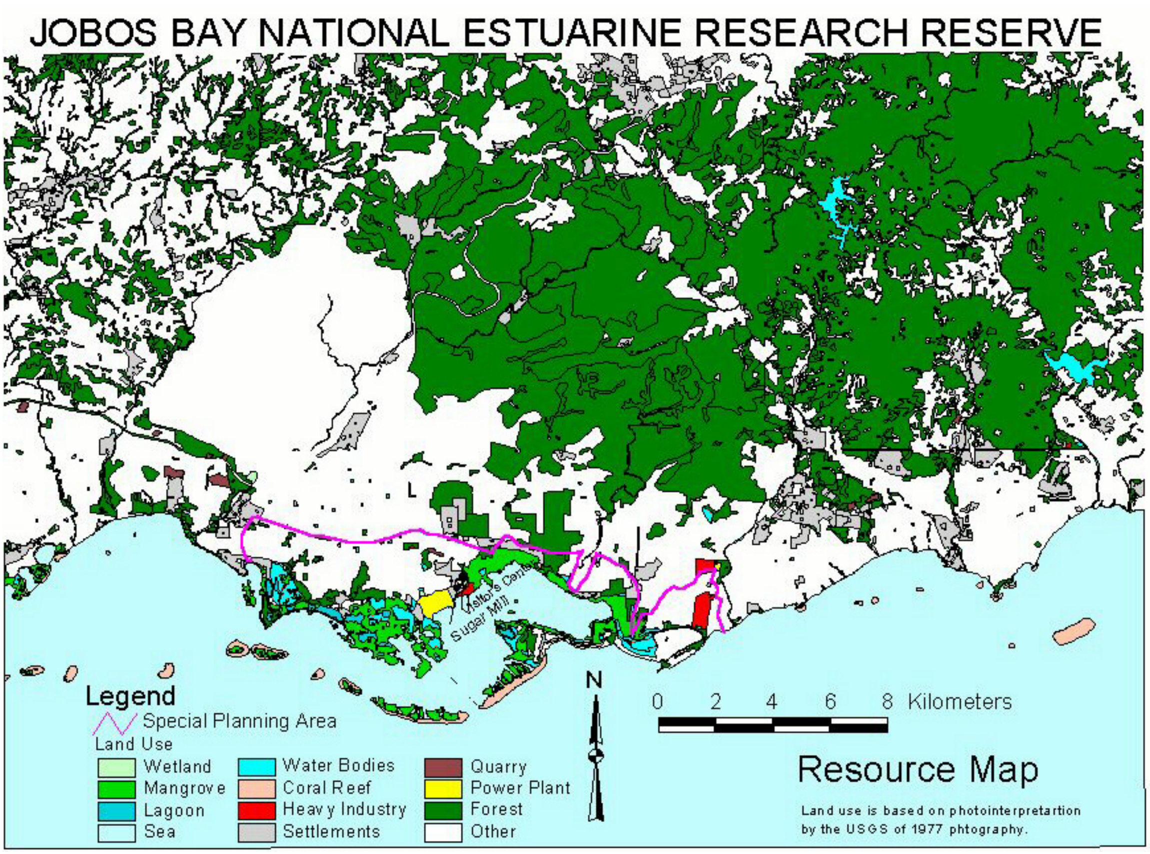


Figure 24. Jobos Bay N.E.R.R. Natural and Anthropic Resources (DNER, 1998)

The Mangrove Forest

The distribution, structure and physical conditions of the mangrove forest of the Jobos Bay estuary were extensively studied by Martínez et al. (1979). These investigators concluded that the 400 hectare mangrove forest at Jobos represented 42.6 percent of this habitat type on the southern coast of Puerto Rico, thus, establishing the estuary as a site of unique ecological value. Over 90 percent of the land area of the Reserve lies above deep and very poorly drained swamp deposits which form narrow strips adjacent to the ocean. Although slightly above sea level, the soils are saturated by salt or brackish water at high tide (USDA,.1977). The high concentration of salt inhibits the growth of all vegetation, except the halophytes, the salt tolerant plants of which mangroves are the dominant plant association

.**Mangrove Attributes:** Mangroves are salt-tolerant, open forest ecosystems of tropical and subtropical intertidal regions. Mangroves have a net import of nutrients, freshwater, and sediments from terrestrial environments and a net outflow of organic matter and water to marine or estuarine waters (Cintrón *et al*., 1985). Mangroves act as sediment traps that reduce water movement and retain suspended materials, gradually raising the land level by producing a rich organic soil. Being swampy and salty, mangrove ecosystems do not support a diverse flora, but contribute to estuarine and terrestrial food chains, to improved water quality and to the maintenance of coastal geomorphology (Cintrón *et al*., 1985). The rich, protected substrate provides habitat for a large variety of organisms which, in turn, serves as the food base for marine and estuarine heterotrophic species.

Physiographic Types: Of the six physiographic types of mangrove forests (Lugo & Snedaker, 1974), three are found in Jobos Bay: basin, fringe and overwash forests.

- Basin forests develop inland and are characterized by slow sheet flows over wide areas of low topographic relief. This forest is normally separated from direct contact with the ocean, except during high tides or storm surges. It receives substantial amounts of freshwater during the rainy season, and in the dry season, salinity increases as the salt water intrudes.
- Fringe forests occurs along the seaward edge and along the coastal lagoons and channels that connect the entire system to the open sea.
- Overwash mangrove forests develop offshore over shallow calcareous platforms.

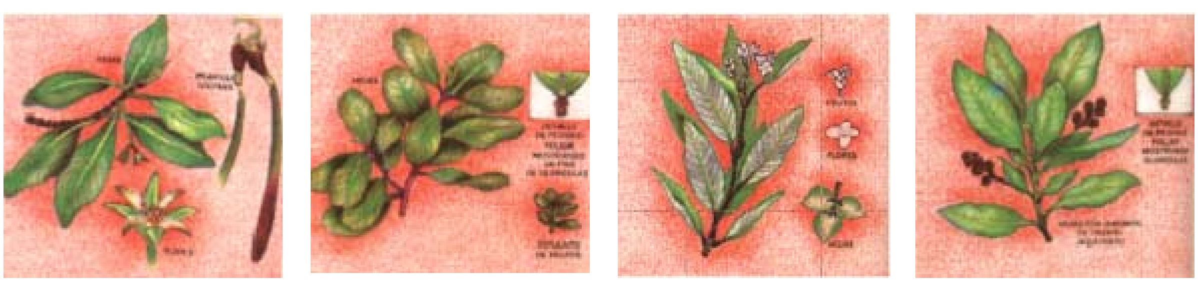
Both fringe and overwash mangrove forests are flooded daily by high tides and by periodic storm surges, thus, sustaining a relatively constant regime with respect to salinity, oligotrophic conditions, and exposure to winds. The degree and structural dynamic of these two forests are controlled primarily by the quality of the soil and wave intensity. The water temperature in the fringe and basin forests at Jobos is directly proportional to, and higher than, the air temperature (Lugo *et al*., 1987). The geometry, shallowness and high surface area of the mangrove fringe contributes to a high degree of physical exchange with the surrounding water, thus affecting the water temperature and oxygen diffusion (Laboy-Nieves, 1997). Figure 25 presents the mangrove forest types of Jobos Bay.

Morphology: Tidal energy dissipates rapidly with distance from shore. The inland reduction of flushing results in a salinity gradient, with higher levels prevailing inland. Tidal amplitude determines the degree of flow and renewal of superficial and interstitial water. This water dynamic promotes the aeration of the substrate and the outflow of salts and noxious gases. Because of the terrain level, tidal changes and flood frequency give rise to depth gradients affecting the zonation patterns of the four species inhabiting JBNERR's mangrove forest (Cintrón and Schaeffer-Novelli, 1983): red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*) white mangrove (*Laguncularia racemosa*) and buttonwood (*Conocarpus erectus*). Figure 26 presents the morphological characteristics of these species.

Fringe Forest Overwash Islet Basin Forest

Figure 25. Basic physiographic mangrove forests found in Jobos Bay (© Eddie N. Laboy Nieves)

Red Mangrove (*Rhizophora mangle*): The red mangrove pioneers the formation of a mangrove swamp. This species, which is highly adapted for life in warm, shallow and saline waters, produces salt-tolerant viviparous seeds. A small root forms before the seed drops from the parent. When released, the seedling floats on the currents for long distances and extensive periods of time. After it reaches shallow waters or runs aground



Rhizophora mangle *Laguncularia racemosa* *Avicennia germinans* *Conocarpus erectus*

Figure 26. General morphological traits of the four mangrove species inhabiting the Jobos Bay N.E.R.R. (adapted from Pannier and Fraíno de Prannier, 1989)

in mud, rapid growth occurs. The plant produces many arching prop roots that vegetatively propagate to form a mass of interconnecting roots and above-water growth (Krohne, 1998). Over time, small islands are formed, and the root labyrinth slows the flow of water, allowing silt and humic material to precipitate, gradually building up the substrate (Figure 27).

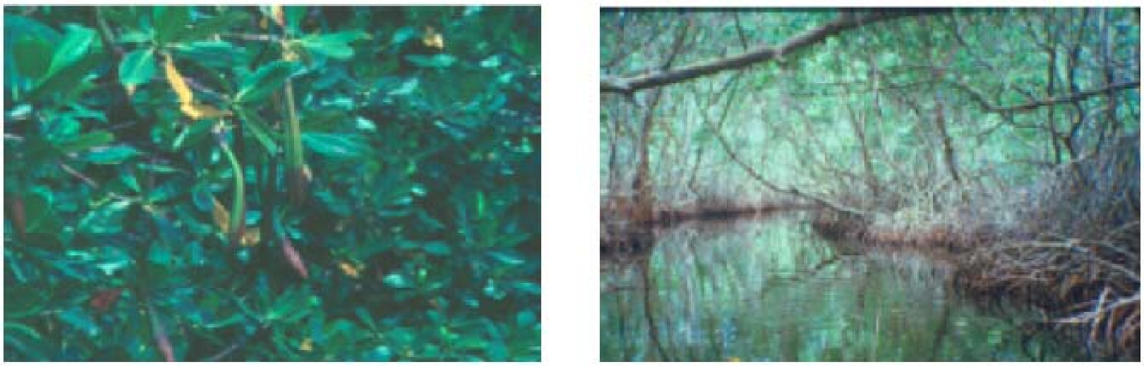


Figure 27. Seedlings and prop roots of *Rhizophora mangle* (© Eddie N. Laboy Nieves).

After many years, a stable mudflat develops in the basin of these islands, and hypersaline conditions are established. The red mangrove no longer tolerates this environment and is succeeded by black mangroves. In sectors with higher freshwater inputs, white mangrove predominates. Both of these latter species produce small seeds that floats in the slow sheet flows of the basin, and pneumatophores, a bottom-up root projection that provides ventilation and anchorage.

The pneumatophore mat within the basin permits the accumulation of sand and humic deposits that elevate the terrain, providing habitat for the least salt-tolerant mangrove species, the buttonwood. This species lives as a shrub or tree, peripheral to landward areas of the basin. This natural successional pattern has been altered by anthropic factors, especially the construction of permanent structures and irrigation channels. For instance, Villamil and Canals (1981) reported that the construction of the Aguirre Railroad in the 1940's changed the flow of ground water to such a degree that interstitial salinity south of the railroad was 36 ppm, while north of it the values were around 2 ppm. In the last three decades, all of the land adjacent to Jobos Bay has been significantly impacted by human activities, modifying the hydrology and nutrient dynamics, precluding the establishment of mangrove species and associated communities.

The red mangrove grows best in shallow, silty soils under the influence of salty and brackish tidal water. This conspicuous tree represents most of the shoreline of Jobos Bay. In the borders of Cayo Caribe, this species attains a height and basal area of 4.9 m and 11.5 m^2/ha, respectively, while in Mar Negro the respective values are 7.6 m and 18.5 m^2/ha (Villamil & Canals, 1981). Trees size declines inland as interstitial salinity increases, establishing a forest with low (~2 m high) canopies (Figure 28).

The ephemeral four-petal flower is about 2.5 cm wide, coriaceous, and yellowish. Flowers occur on single reproductive axes that originate on the terminal portion of branches, in the axil of a leaf pair. The fruit germinates while on the tree and hangs for several months, a phenomenon typical of viviparous trees. Fully developed seedlings are rod-shaped, elongated and composed of two parts; a short plumule that consists of a pair of stipules protecting the first pair of leaves, and a long, heavy hypocotyl composed mainly of endospermous aerenchyma tissue (Juncosa, 1982).

Figure 28. Dwarf-like trees of *Rhizophora mangle* (© Eddie N. Laboy Nieves).

During the juvenile stages, red mangroves develop a short-lived subsystem of primary terrestrial roots, while in mature stages the tree develops an arching aerial root system that extends around the trunk or branches and emerges perpendicular to the ground. A lenticel system is responsible for aerating the roots while flooded. The roots provide anchorage for the tree while producing an extensive capillary root system that traps intertidal debris, which further produces a thick fibrous soil (Jiménez, 1985a).

White Mangrove (*Laguncularia racemosa*): White mangrove grows under a wide variety of conditions. It is generally found on the inner fringe of the mangrove forests, on elevated soils where tidal inundation is less frequent and intense, and in basin mangrove forests where tidal flushing is limited. This species has greenish-white pentamerous flowers, with ten stamens and two ovate bracteoles. The flowers are supported on a terminal panicle or solitary spike emerging from the leaf axil. Leaves are glabrous, obovate or elliptical, and characterized by the presence of a pair of glands at the base of the blade. Insects pollinate the fragrant flowers. Fruit production peaks in September and October. Normally, the fruit drops from the parent tree and the radicle protrudes after a few days. Seedlings float and are dispersed by water. Floating is aided by a thick pericarp. Fruits sink after a floating period of about four weeks, and growth begins while the seed is still submerged (Jiménez, 1985b).

White mangroves possess a shallow root system, with roots that radiate from the trunk and produce projections of peg-roots that are geotropically negative (pneumatophores). These peg-roots seem to be associated with tidal fluctuations. They are club-shaped and their terminal heads contain ventilating tissues. In individual white mangroves growing in basin forests, aerial adventitious roots sometimes emerge from the lower section of the trunk. In the basin of Cayo Caribe, this species attains a height and basal area of around 3.0 m and 1.5 m^2/ha, respectively, while in Mar Negro the respective values are 9.1 m and 20.5 m^2/ha (Villamil & Canals, 1981). However, there is a stand on the northeast boundary of the Reserve inhabited by individuals that is about 15 meters high.

Black Mangrove (*Avicennia germinans*): Black mangrove grows in the tidal areas of basin forests with salty or brackish waters, over a broad range of soil salinity (0 - 100 ppm). It grows on sandy, silty or clay soils, and in low areas inland from the fringe where tidal flooding is less frequent. Under high salinity conditions, structural development is suppressed and leaves excrete salt through specialized glands and are salt-covered, thus contributing to salty throughfall. Flowers are found in axillary and terminal inflorescences, with one to 15 pairs of flowers per spike. They are small and with imbricate bracts. The corolla has four lobes with fragrant yellow petals. Flowering is sporadic throughout the year. The species is considered viviparous because germination occurs while the embryo is still enclosed in the oblong fruit. Fallen seedlings float and are transported by tidal currents. The propagule sheds its pericarp and produces roots within three weeks of dispersal. Seedlings can become waterlogged and their establishment is limited to areas above water level at low tide and temperatures below 39ºC (Jiménez & Lugo, 1985).

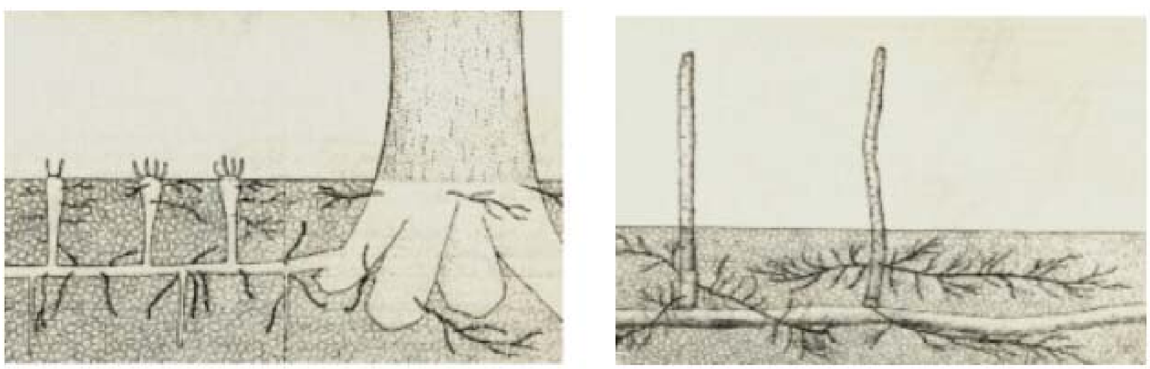


Figure 29. Schematic diagram of the pneumatophores of *Laguncularia racemosa* (right) and *Avicennia germinans* (left) (Cintrón and Shaeffer-Novelli, 1983)

Black mangrove is characterized by a shallow underground root system with thin sinker roots and negatively geotropic pneumatophores that develop from lateral horizontal roots (Figure 29). As in white mangrove, pneumatophores are responsible for gas exchange processes, but unlike those of former species, the number of pneumatophores in black mangroves reaches over 600/m^2. The superficial root systems make this species easily windthrown. Therefore, most of the trees at Jobos are short (about five meters tall), with exceptional individuals ranging up to 12 meters. Black mangrove is highly susceptible to changes in hydrological regimes. Drought or flooding can cause extensive mortality. Despite the vulnerability of this species, in the middle of the Mar Negro basin there is an individual black mangrove that has a dbh of 76 cm, representing the largest tree of this species on the south coast of Puerto Rico.

Buttonwood (*Conocarpus erectus*): The buttonwood is not considered a real mangrove species, but a peripheral tree that constitutes the ecotone between the mangrove and the upland. It occurs in elevated and low saline (< 5 ppm) soils. It frequently grows as a shrub, but trees can reach heights of around eight meters, particularly in Cayo Caribe and Camino del Indio. The species has terminal globular inflorescences with bisexual greenish white fragrant flowers (Little *et al*., 1977). Each globule becomes a rounded brown aggregate fruit containing many seeds.

<u>The Evergreen Littoral Woodland</u>

Most of the upland littoral vegetation (other than mangroves) in Jobos Bay is shrubby and secondary, and has been altered almost entirely by agriculture, industry, urban development, and recreation. Gleason and Cook (1926) described the original vegetation surrounding the Bay as a semi-evergreen seasonal forest dominated by *Bucida buceras* (úcar) and *Guazuma ulmifolia* (guácima). According to Villamil and Canals (1981), the vegetation of the scarce upland in Jobos Bay represents the evergreen littoral woodland. The buttonwood, the dominant tree species in this habitat, is found in three sites on the Reserve: Cayo Caribe; Camino del Indio to the west of Mar Negro, and; a coconut plantation in the center of Mar Negro.

This forest is composed of native and exotic trees shrubs, herbs and vines. Figure 30 presents some of the relatively abundant species in the littoral woodland forest. Table 1 lists the species that comprise the evergreen littoral woodland in Jobos Bay.

As previously stated, anthropic and natural phenomena continuously disturb this habitat. For example, within the entire propery of the Reserve, only on Cayo Caribe was a single individual of the native milktree (*Plumeria alba*) found. The cactus *Pilosocereus royenii* is scarcely found either on Cayo Caribe or Camino del Indio. However, the exotic aloe plant *(Aloe vera,* sávila) and wild tamarind (*Leucaena leucocephala*, zarcilla) are gaining ground on Cayo Caribe.

Figure 30. Representative sites of the evergreen littoral woodland in JBNERR.

Permanent freshwater springs within the mangrove forests permit the development of hypohaline ponds (Laboy-Nieves, 1994). Although small and dispersed, these ponds meet the conditions for the establishment of trees not typically found in intertidal zones, such as *Roystonea borinquena, Tabebuia heterophylla, Ficus laevigata* and *Bursera simaruba*. Sharpe (1999) suggested that the annual leaf production of plants, particularly ferns, in Jobos Bay decreases with the impact of hurricanes. Lugo (1983) concluded that the littoral zone is an area of high environmental stress and sharp environmental gradients**,** with marked ecotones among plant associations. Trees, shrubs, herbs and vines need to develop the requisite structural and physiological specialization to deal with salinity, winds, shifting soils and waterlogging, not withstanding the impact of human activities upon their survival.

Figure 31. Representative species from the littoral woodland of Jobos Bay (from left to right): Milktree *(Plumeria alba),* giant milkweed (*Calotropis procera*); gumbo-limbo (*Bursera simaruba)*; coconut palm (*Cocus nucifera*) (© Eddie N. Laboy Nieves).

Table 1. Common plants, vines and tree species of the littoral woodland in Jobos Bay.

Common Name	Scientific Name
Herbs, Small Plants, Shrubs	
Salt plant (yerba de sal)	*Batis maritima*
Salt plant (verdolaga)	*Sesuvium portulacastrum*
Periwinkle (flor playera)	*Catharanthus roseus*
Bellyache bush (tautúa)	*Jatropha gossypifolia*
Beachgrass (yerba de playa)	*Sporobolus virginicus*
Cudjve wood (barbasco)	*Jacquinia arborea*
Beach sedge (junco)	*Cyperus planifolius*
Bushy spurge	*Chamaesyce articulata*
Red sage (cariaquillo)	*Lantana involucrata*
Cork tree (emajaguilla)	*Thespesia populnea*
Sensitive plant (moriviví)	*Mimosa pudica*
Goat-weed (té criollo)	*Capraria biflora*
Dove plant (tabaco marino)	*Solanum erianthum*
(Poleo)	*Lippia stoechadifolia*
Cat tail (enea)	*Typha domingensis*
Mangrove fern (helecho gigante)	*Acrostichum danaeifolium*
Vines	
Wild balsam apple (cundeamor)	*Momordica charantia*
Beach bean (haba playera)	*Canavalia maritima*
Passiflora (bejuco de playa)	*Passiflora suberosa*
Beach vine (bejuco de puerco)	*Ipomea quinquefolia*
Beach vine (bejuco de playa)	*Ipomea pes-caprae*
Butterflypea (crica negra)	*Clitoria virginiana*
Santiago's vine (cachimbo)	*Aristolochia trilobata*
Vanilla (vainilla)	*Vanilla planifolia*
Palinguam (palo de burro)	*Caparis flexuosa*
San Juan vine (bejuco de San Juan)	*Stigmaphyllon emarginatum*
Crab eye vine (peronías)	*Abrus precatorius*

Trees	
Shortleaf fig (jaguey)	*Ficus laevigata*
Sea grape (uva playera)	*Coccoloba uvifera*
Manchineel (manzanillo)	*Hippomane mancinella*
Wild tamarind (zarcilla)	*Leucaena leucocephala*
Mesquite (bayahonda)	*Prosopis juliflora*
Sweet acacia (aroma)	*Acacia farnesiana*
Kinep (quenepa)	*Meliococcus bijugatus*
Tamarindo (tamarindo)	*Tamarindus indica*
Soldierwood (mabí)	*Colubrina reclinata*
Sea hibiscus (emajagua)	*Hibiscus tiliaceus*
Jacocalalu (guácima)	*Guazuma ulmifolia*
Baycedar (temporana)	*Suriana maritima*
Coconut palm (palma de coco)	*Cocus nucifera*
Royalpalm (palma real)	*Roystonea borinquena*
White cedar (roble blanco)	*Tabebuia heterophylla*
Logwood (campeche)	*Haematoxylum campechianum*
Brisselet (rocío)	*Erythroxylum rotundifolium*

Mud Flats

Mud flats are important soft-bottom littoral systems. They are formed inland from the mangrove forest as a result of reduced water runoff, higher evaporation rates and drought. Their existence is also a by-product of two other factors: (1) the prevalence of offshore barriers (typically mangrove fringe forests and coral reefs) to moderate the waves, and (2) the upward sloping of the bottom so that tidal waters can spread and deposit the silt, mud and organic debris imported from open waters. Salt and mud flats are at least superficially depauperate in species; i.e., the diversity of emergent plant life is not conspicuous (Khrone 1998). In Jobos, where vegetation exists, it consists mainly of the grasses *Sporobolus virginicus* and *Fimbristylis cymosa* and the halophytes *Batis maritima* and *Sesuvium portulacastrum*.

Mud flats are common to all intertidal marshes. The flats exposed at low tide contain considerable quantities of detritus, a mixture of sand and mud, and plant and animals remains resulting from the action of the water. As the tide ebbs, broad areas of seemingly barren mud or sand are exposed, but the appearance is deceiving. From a few millimeters below the surface of the mud flat, sometimes down to more than a meter, the moist humic bottom supports bacteria, fungi, diatoms and a veritable universe of marine animals, including clams, worms and nematodes.

Seagrass Beds

Seagrasses are aquatic angiosperms that are generally restricted to soft sediment habitats. Their leaves and stems provide the primary substratum for the attachment of epiphytes within seagrass meadows, and they are the basic structural component in which the grazer-epiphyte interaction occurs (Jernakoff et al., 1996). The seagrass beds cover around 70 percent of the shallow (< 3m) substrata in Jobos Bay, and about 30 percent in deeper areas down to 10 meters (PWRS, 1972). *Thalassia testudinum, Syringodium filiforme* and *Halophila decipiens* are the three main angiosperms that, together with a wide variety of algae (Appendix C), comprise the submerged grassland of the Bay.

Seagrass beds have long been recognized as one of the most productive biological communities in the world (Zieman, 1982). They provide nursing ground, food and shelter for most fish and invertebrate species in Jobos Bay.

Seagrass beds develop mainly in low energy zones protected from fringing reefs and mangroves. Light penetration, salinity, temperature and turbidity of the water column (Zieman, 1972), and the natural and anthropic mechanical disturbance of the substratum are the major factors that inhibit their distribution (Zieman, 1976; Duarte *et al*., 1997; Laboy-Nieves, 1997). Seagrass beds encourage accumulation of sediments by binding the substrate, protecting it from erosion, and creating a baffle in which the fine sediments can settle, providing suitable habitat (Patriquin, 1975).

Typically, blowouts (bare muddy or sandy benthic depressions) are formed within seagrass beds Migration of blowouts results in periodic disruption of large parts of the seagrass community, and turnover of associated sediments. The most important effect of this instability on the ecology of the seagrass beds is to limit seral development. In the area where extensive blowouts have occurred, a well-developed epifauna and flora, characteristic of advanced stages of seral development, is absent, testifying to this phenomena. *Syringodium* frequently precedes *Thalassia* in the colonization of blowouts, apparently because of its greater tolerance to environmental stress and higher rhizome growth rates, but *Thalassia* is invariably the terminal dominant of the Caribbean seagrass community in shallow waters (Patriquin, 1975).

The seagrasses are the primary producers in the submerged habitat of Jobos Bay. It is inferred that the productivity of the beds may be due to the shallowness of the Bay, which permits an abundance of light penetration to provide energy to the phytoplankton, algae and seagrasses. In this habitat, phytoplankton comprise the foundation of all food production, and the zooplankton, particularly copepods, make for the broad pasturing that can result in planktonic explosions that attract other primary

Figure 32. Different scenarios in the Jobos Bay seagrass beds (from left to right): the holothurid *Isostichopus badionotus* feeding on a microbial mat in a blowout; epiphytes on the leaves of *Thalassia testudinum;* the alga *Caulerpa sertularoides* on a muddy substratum (© Eddie N. Laboy Nieves)

and secondary consumers.

Coral Reefs

The coral reef is a nearshore community confined to shallow circumtropical waters. Together with mangroves and seagrass beds, coral reefs form one of the most complex, diverse and productive coastal associations in the world. Their superstructure is the product of tiny colonial animals (polyps from Phylum Cnidaria) that attach to the hard surfaces of the sea floor. By releasing calcium carbonate from seawater, they build skeletal structures in an infinite variety of shapes and sizes. For coral reefs to develop, the delicate polyps must flourish. This requires several critical environmental factors including water temperature, movement, salinity, transparency, and a firm base for attachment (Humann, 1996). The coral reef is one of the best examples of mutualistic symbioses in tropical marine waters, performed by the polyps and the alga *Zooxanthellae* sp.

The corals at Jobos Bay are representative of the typical zonation of Caribbean reefs. Most of the coral reefs in Jobos Bay are located.between the Cayos Caribe islets. The reef

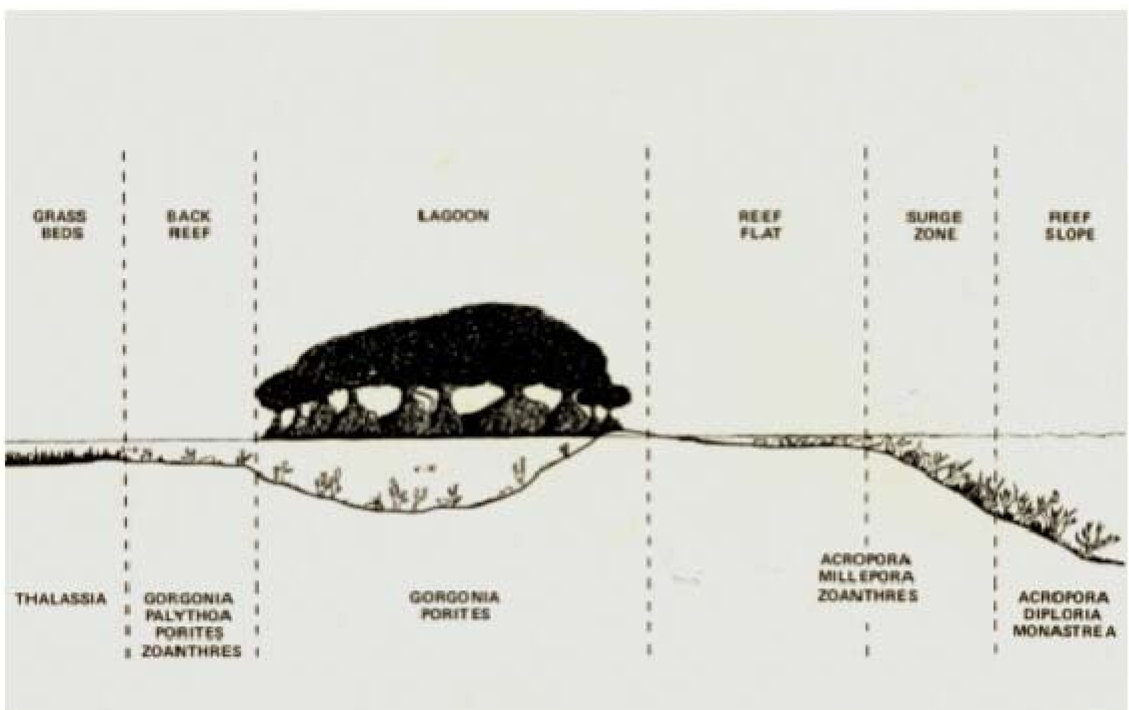


Figure 33. Cross section of Coral Zonation at Jobos bay (PRWA, 1972)

flat, usually less than 0.5 m deep and exposed during low tides, is dominated by an intermixed association composed of isolated coral heads of finger coral (*Porites porites*), fire corals (*Millepora complanata*) and zoanthids (*Zoanthus sociatus*). The reef surge zone is a high wave energy area that ranges in depth from one to six meters. The dominant coral species in this area are the fire coral and the elkhorn coral (*Acropora palmata*). The reef slope drops off to about 18 m, and contains massive heads of the brain coral (*Diploria clivosa*), star corals (*Montastrea annularis*) and soft corals.

FAUNA ASSOCIATED With INTERTIDAL And UPLAND HABITATS

The emergent segments of the prop roots of the red mangrove, as well as the stems of the white and black mangroves, the littoral woodland and the salt and mud flats are used as substrate, feeding, perching, and nesting sites by a wide variety of invertebrates, especially insects, crustaceans and mollusks, as well as birds. These animals represent endemic, native, migrant and exotic species that enrich the trophic scenery of the Jobos Bay NERR. Figure 34 presents a sample of the fauna of the Reserve and Appendix C lists selected species from these groups of animals.

Figure 34. Animal species common in the upland habitats of the Jobos Bay N.E.R.R. (clockwise from upper left): kestrel (*Falco sparverious)*; treehoppers (*Umbonia crassicornis)*; *West Indian nighthawk (Chordeiles gundlachi);* spiny spider (*Nephila clavipes);* red-tailed hawk (*Buteo jamaicensis);* great egret fledging (*Chartartes albus)*; land crab (*Cardisoma guanhumi)*; walking stick (*Philobalosoma sp*.); turkey vulture (*Chatartes aura)*; snowy egret *(Egretta thula)*; ghost crab (*Ocypode quadrata*); Zenaida dove (*Zenaida aurita*) (© Eddie N. Laboy Nieves).

Associated with the submerged prop roots characteristic of the red mangrove is a rich community containing a wide assortment of organisms Figure 35 studied by Kolehmainen (1972). Competition for space on these roots is high. Among the most abundant groups are oysters, tunicates, sponges, crustaceans, cnidarians and algae. Appendix E presents a partial list of the species found in the epiphytic community on the submerged roots of the red mangrove in the channels of Mar Negro. According to Díaz et al. (1985) and Laboy-Nieves (1997) it is inferred that the abundance and distribution of

Figure 35. Epibiota associated with the submerged prop roots of the red mangrove (*Rhizophora mangle)* (from left): mangrove oysters (*Cassostrea rhizophorae* and *Mytilopsis domingensis)*; pongae (*Tedania ignis* (orange) and the green alga (*Halimeda goreaui)* (© Eddie N. Laboy Nieves).

the species in this community are byproducts of the currents, transparency, dissolved oxygen, salinity, nutrients and other physical, chemical and biological conditions of each locality. Therefore, the existence of an epibenthic community on the red mangrove rhizosphere is more imminent in clearer and less disturbed waters which, in the Jobos Bay NERR, are predominantly found in the inner channels of Mar Negro.

Table 2. Selected list of epibionts associated with the submerged red mangrove rhizosphere.

Group	**Scientific Name**
Algae	Caulerpa racemosa
	Caulerpa sertularioides
	Caulerpa verticillata
	Acanthophora spicifera
	Amphiroa fragilissima
	Chondria tenuissima
	Hyldenbrabdia prototypus
	Hypnea spinella
	Jania adherens
	Dictyota volubilis
	Dictyota ciliolata
	Dictyota bartayresii
	Valonia ventricosa
	Laurencia obtusa
	Murrayella periclada

Animals	Tedania ignis *Crassostrea rhizophorae* *Caloglossa leprieril* *Aplidium lobatum* *Brachydontes recurvus* *Ostrea equestris* *Ostrea frons* *Acanthochitona pigmaea* *Bostrychia tenella* *Bostrychia rivularis* *Pyura momus* *Isognomon alatus* *Isognomon bicolor* *Chondrilla nucula* *Haliclona hogarthi* *Porites branneri* *Lissodendoryx isodictyalis* *Sigmadocia caerulea* *Sabela melanostigma* *Ecteinascidia turbinata* *Ficopomatus miamensis* *Struvea anastomosans* *Aratus pissoni* *Goniopsis cruentata* *Ucides cordatus* *Ophiothrix angulata* *Prachygrapsus gracialis* *Prachygrapsus transversus* *Hypselodoris* sp. *Stenorhynchus seticornis* *Balanus eberneus* *Petrolistes polistes* Ascidia nigrans

Fauna Associated With Mud Flat Habitat

For many years, it was generalized that deposit-feeders are more abundant in muddy habitats than filter feeders, because the former, through amensalistic interactions, excludes the latter. Snelgrove and Butman (1994) conducted a critical re-examination of the data on animal-sediment relationships. They suggested that many species are not always associated with a single sediment type, and that suspension-and deposit-feeders often coexist in large numbers, and that many species alter their trophic mode in response to water flow and food flux. Therefore, the species distribution and abundance of the mud flat, particularly the infauna (benthic invertebrates that live largely within the mud bed), seem to be directly related to sediment pore, organic matter content, pore-water chemistry, microbial abundance, larval supply, and climatic and hydrologic conditions.

The muddy flats, exposed at low tides, contain considerable quantities of detritus resulting from plant and animal remains carried by currents and filtered in the mangrove fringe. Around the mud flat edges and above the reach of the highest tides, fiddler crabs (*Uca* sp.) forage almost continuously for detritic material, digesting nutrients from the organic portion and excreting the sand, mud and undigested organic remains. Under the surface of the salt flat, bacteria, diatoms, fungi, nematodes, copepods, ostracods, turbellarians, naupli, sipunculids, clams, and worms become potential food sources for deposit-and filter-feeders, carnivorous birds, such as herons and plovers and omnivorous decapods, like the land and the blue crabs, *Cardisoma guanhumi* and *Callinectes* sp., respectively.

One of the relevant trophic events of the mud flats occurs when diatoms and cyanobacteria form microbial mats in the inundated pannes. The carpet of these microorganisms covers the mud at different periods of the day. Diatoms (*Nitzchia* sp.) remain planktonic during the daytime (Talbot *et al*., 1990); thus, they are made available to filter-feeders like clams. Cyanobacteria (*Lyngbya* sp., *Schizotrix* sp.) form a carpet over the substrate, which is further broken by the ascension of air bubbles or currents (Figure 36a). These microorganisms form mucilages, which are the main food source for copepods, isopods, polychaetes and molluscs inhabiting the panne. The enrichment of the panne attracts macroinvertebrates (Figure 36b) and birds to feed in the flat, and a complex food web is established.

Figure 36. Microbial mat flocules (left) and *Callinectes* sp. predating on them (right) (© Eddie N. Laboy Nieves).

Fauna Associated With Seagrass Beds And Coral Reefs

The presence of mangrove fringes, seagrass beds, and coral reefs adjacent to each other in Jobos Bay allows for the establishment of a rich and complex faunal structure in which animals move freely between habitats. It would be erroneous to consider that planktonic, nektonic and benthonic species are resident of only one of these communities. For example, fishes use the red mangrove submerged roots for nursing; as the individuals grow, they move to the coral reefs and usually forage in the seagrass beds. Most of the organisms living in seagrass beds, and their associated blowouts, receive nutrients, directly or indirectly, from the coral reefs and mangrove forests, and vice versa. Thus, the nutrient recycling scenario is always dynamic and highly productive.

The benthos (animals that live on or in the bottom) is dominated by the foraminifers *Quinqueloculina lamarckiana* and *Archais angulatus* on the soft bottoms, and molluscs, crustaceans and echinoderms on the hard substratum of the seagrass beds. Kolehmainen (1972) found that ophiurids represent the largest diversity of echinoderms in the *Thalassia* beds, with 21 species. He also reported only six species of holothurids (updated by Laboy, to sixteen, by personal observations). Crustaceans (brachyuran larvae, amphipods and copepods), tunicates, and gastropod larvae compose most of the zooplankton in Jobos Bay (PRWRA, 1972). In the coral reefs, 20 species of anthozoans and 10 species of soft corals have been identified and associated with over 250 fish species (Villamil & Canals, 1981).

Appendix F lists some of the species of invertebrates while Appendix G lists fishes common to seagrass beds and coral reefs.

The largest animals observed in Jobos Bay all forage in seagrass beds. These include the West Indies manatee (*Trichechus manatus*), the hawksbill sea turtle (*Erectmochelys imbricata)*, and the green sea turtle (*Chelonia mydas*), all endangered species. Figure 37 shows some typical animals in their submerged habitats.

Figure 37. Animals from the marine habitats of Jobos Bay (clowise from top left): *Acropora palmata*, *Millepora complanata*, *Diploria labyrinthiformis, Carpilius corallinus* (© Colin, 1978), *Delphinus delphus, Tripneustes esculentus, Pomacanthus arcuatus, Lutjanus* sp. (© Eddie N. Laboy Nieves).

CHAPTER 4: ECOLOGICAL SETTING

by Dr. Eddie N. Laboy

ENERGY AND NUTRIENT DYNAMICS IN THE JOBOS BAY ESTUARY

All life is energy limited. For instance, the *Thalassia* seagrass and the coral reef community ultimately develop as a result of changes in the ability of plants to obtain solar energy. The reproductive "strategies" of fiddler crabs, mangroves, herons, fishes and many representative estuarine species are also constrained by energy competition. A contest for energy is often a major organizing force in biological communities. Thus, at the ecosystem level, the process of accumulating and dissipating energy defines the structure and dynamic of the communities that comprise the estuary.

The rate of accumulation of energy in organic molecules by photosynthesis is known as primary production. Productivity is difficult to measure in the field because it is determined by the interaction between six major factors: light, temperature, water, nutrients, stress and disturbance. These factors impact ecosystems at different spatial and temporal scales. Among the different units for expressing productivity, biomass is the most practical, because of the fact that the total dry weight of organic matter can be directly correlated with energy content. It is generally accepted that ecosystems with high biomass also have high productivity. However, it is difficult to interpret this generalization. It may be that a large biomass is needed for production to occur at a high rate, or perhaps high production leads to high biomass. After determining the ratio of productivity and biomass (P:B) for various terrestrial and aquatic systems, Whitakker (1975) noted that the ratios fall into three general groups: low P:B (forests and shrub-land habitat); average P:B (grassland-type habitats), and; high P:B (freshwater and marine habitats); the ratio on this last group due primarily to single-celled phytoplankton. Krohne (1998) states that estuaries and coral reefs have about the same productivity as most terrestrial ecosystems. The production in estuaries is more likely to be by multicellular plants, such as mangroves, algae and seagrasses. Reefs are exceptional because the primary producers are algae in symbiotic association with corals. Thus, coral reefs contain more non-photosynthetic tissue than other aquatic systems.

The lack of substantial data from Jobos Bay limits the holistic interpretation of the energy flow in this ecosystem. In order to understand the energy scenario, more information on energy dynamics in Jobos Bay is needed, to be complemented by access to data from homologous tropical estuaries.

Primary Productivity

The primary producers within the submerged environment of Jobos Bay consist of (1) the microbial mats, (2) nearly 90 species of algae (Almodóvar 1964) and, (3) the dominant seagrasses that include *Thalassia testudinum*, *Halodule wrightii* and *Syringodium filiforme*. Diatoms and dinoflagellates dominate the phytoplanktonic community. Preliminary data suggest that phytoplankton exhibits a spatial pattern in its abundance, with densities ranging from 200 cell/ml in the oceanic habitat near Cayos Caribe, to 1,150 cells/ml in the mangrove channels within Mar Negro (DNER, 1997).

According to Talbot et al., (1990) diatoms exhibit a daily abundance rhythm. They form dense mucilaginous patches over sandy and muddy substrates. In the morning, they free their mucous cover and migrate to the aerobic zone of the reef, and they become the prey for suspension feeders. At dusk, while migrating to the sea floor, they synthesize the polysaccharide-rich mucilaginous. After adhering to the sediment, they become the prime food source for many deposit feeders. But as time passes, the mat turns anoxic and sulfidic by the interaction of cyanobacteria (Stal, 1995), and this implies inhospitable conditions for suspension and deposit feeders like bivalves, holothurians, polychaetes and sipunculids. It is suggested that these organisms may migrate or cease metabolic activities to avoid anoxic stress, and also, that the rhythmic appearance of diatoms and cyanobacteria seems to trigger the distribution and abundance of predators on a daily basis (Laboy-Nieves, 1997).

The abundance and distribution of most aquatic primary producers is closely related to a combination of salinity, temperature and light conditions (Dawes *et al*., 1985). Epibenthic algal mats are characteristics of mangrove lagoons and closed embayments at Jobos. Species like *Enteromorpha clathrata*, *E. flexuosa* and *Ulva fasciata* are common inhabitants around or under mangroves, rocks, buoys, and mangrove channels (Almodóvar, 1964, Santana-Ferrer et al., 1996). Under very calm conditions and humic inputs, phytoplankton and periphyton bloom. In warm temperatures, the dinoflagellate *Pyrodinium bahamense* flourish, accounting for the spectacular bioluminescence within the waters of Mar Negro during the summer months (Laboy, personal observations). During the hurricane season (June-November), sluggish, high currents and windy conditions dominate the water of the Bay, and the macrophytes drift westward (Laboy, personal observations). Therefore, most of the variation in planktonic and substrate primary producers at different sites seems to be related to the local energy regime, as suggested by Bell & Hall (1997). Also, the bloom of phytoplanktonic species and macroalgae observed in the Bay could be an indicator of eutrophic conditions, and it seems to represent a way by which stressed ecosystems give off excess nutrients and biomass (Pizzolon 1996).

Seagrass beds are among the most productive ecosystems in the oligotrophic coastal waters of the Caribbean (Zieman *et al*., 1989). They grow in soft or sandy bottoms of estuaries and coral reef lagoons, where they support complex food webs by virtue of both their physical structure and primary production (Short & Willie-Echeverria, 1996). Seagrass density, growth, biomass and primary production vary in response to local fluctuations in environmental conditions such as salinity, exposure to air, water clarity, sediment depth, nutrients (van Tussenbroek, 1995, Lee & Dunton, 1996) and natural and human-induced disturbance (Short & Willie-Echeverria, 1996). Turtle grass, *Thalassia testudinum,* dominates these beds and is the main contributor to primary production. Total production of this species is difficult to assess, since most of its biomass is below the substratum (van Tussenbroek, 1995). Lee and Dunton (1996) reported that biomass of *T. testudinum* in Texas changed significantly with season. It was found that values ranged from 454 to 885g dry wt/m^2 from March to September, and suggested that temperature and underwater irradiance have been considered as a major factor controlling seasonal leaf growth at an exponential trend. A substantial fraction of seagrass carbon enters coastal and estuarine food webs through microbial transformation and particulate detritus.

Natural disturbances that are most commonly responsible for seagrass loss include hurricanes, earthquakes, diseases and herbivory. Human activities most affecting seagrasses are those which alter water quality or clarity, nutrient and sediment loading from runoff and sewage disposal, dredging and filling, pollution, upland development and certain fishing and recreational practices (Short & Willie-Echeverria, 1996). Almost every year, Jobos Bay experiences the impact of tropical storm winds and siltation from heavy rain runoff. These two factors, together with the agricultural, thermoelectric production, urbanization and filling activities immediately adjacent to the Reserve's property, and the weekly traffic of boats, barges and jet skis, suggest that seagrass beds are being threatened. The mechanical perturbation of seagrass beds promotes the exodus of invertebrates (Roenn et al., 1988), accelerates sediment resuspension and its transport to coral reefs (Wolanski and Gibbs, 1992), diminishes primary productivity (Short & Willie-Echeverria, 1996), affects species abundance (Laboy-Nieves, 1997) and buries macrophytes with sediments (Duarte et al., 1997). The decline of these beds will result in the wanton destruction of submerged habitats and will jeopardize the fragile trophic trama within the Jobos Bay.

Growth and production of seagrass beds are also limited by nutrients and disturbances (Zieman *et al*., 1989, Short & Willy-Echeverria, 1996, Alcoverro et al., 1997). A similar dynamic occurs in phytoplankton from the Atlantic Ocean, where productivity seems to be limited by iron inflows (Behrenfeld & Kolber, 1999). Nutrient limitations affect primary production. Therefor, the availability of organic compounds to marine heterotrophs seems to be directly or inversely related to nutrient inflows. Coral reefs also respond to pulsating nutrient inflows to a point that hurricanes, upwelling of cold waters and freshwater inflows have been accelerating the degradation of this community in the whole Caribbean region (Hughes, 1994, Laboy-Nieves, et al., 2000). The reefs in Jobos Bay are no exception. A combination of natural and antropic disturbances have destroyed almost 90 percent of the coral reefs in the Bay. The chain of events linking primary productivity, respiration and degradation of nutrients are as complex as the Jobos Bay ecosystem itself, and ought to be monitored on a long-term basis in order that crucial dynamics can be interpreted.

Autotrophic production by phytoplankton and phytobenthos in the adjacent aquatic system is partly the result of mangrove leaf and litter decomposition (*López et al*., 1988). The physiognomy of the Jobos Bay mangroves is not impressive. Trees are not large and there is an abundance of stunted trees growing around hypersaline lagoons. However, red mangrove leaves are relatively large and seedling density and growth in the forest floor are high and luxuriant, suggesting favorable growth conditions.

In the premier, and only, nutrient dynamic study conducted in Jobos Bay, Lugo *et al*., (1987), found that peak litter fall followed peak rainfall events in May and September.

However, about 60 percent of nitrogen and 80 percent of phosphorous was retranslocated prior to leaf fall. Flushing results in low storage and high litter turnover. However, nutrients are not lost because mangroves have a high rate of nutrient use efficiency.

Litterfall was estimated at around 19 ton/ha. A high portion of this litterfall occurs during the hurricane season, when the forest experiences sustained high winds. But the flushing of forest floor litter contributes to low biomass storage which, coupled with the high rate of litterfall, results in high litter turnover. This could cause problems to nutrient recycling because of leaching and loss to the system. The problem is mitigated by the high rates of retranslocation of nutrients before leaf falling. For instance, black mangrove in Jobos Bay has one of the highest reported phosphorous retranslocation rates (~85 percent).

Tidal regime and upland runoff regulate the residence time of litter on the forest floor, and partially control litter decomposition rates and exports. Fringe forests are subjected to continuous flooding, and litter is exported with decomposition occurring elsewhere. Basin forests develop in more protected inland areas and litter accumulates, decomposes in situ, and less particulate debris is exported from the system. Decomposition starts with leaching of soluble inorganic and organic compounds. Soon after, bacteria and fungi colonize the litter surface reducing the C:N ratio (López et al., 1988). Litter material is gradually reduced in size by microbial and grazing activities. These particles are then consumed by detritivores that derive their nutrition from the microbial and meiofaunal assemblage associated with the debris.

Cycling of organic matter in mangrove forests depends on the magnitude of abiotic factors that regulate mineral inputs and flows into, through, and out of the system, together with abiotic factors that incorporate those elements, essential for the function of the forest (Lugo & Snedaker, 1974). Hydrological flows transport and distribute nutrients throughout the mangrove forest where they are sequestered in plant tissues or the underlying sediments. These nutrients are fixed into organic compounds by plants and are returned to the forest via litterfall and grazing. The same abiotic and biotic factors act in the recycling of nutrients. Animals move and redistribute nutrient and organic compounds within and outside the systems. Consequently, the net results of these cycling processes in mangroves is the import of inorganic components from adjacent systems and the export of organic products to the sea (Lugo & Snedaker, 1974). Mangroves also import some inorganic components from the sea due to tidal flooding (as evidenced in Figure 38, and from the air by wet and dry deposition (López *et al*., 1988).

Trophic Interactions

A food web diagram illustrates the inter-relationships of species within the same community, from adjacent communities, or from non-related communities. Species lists for macrofaunal invertebrates are available. From them, it is known that the taxonomic (genera) composition of West Indian mangrove communities is similar to other tropical and subtropical areas (López *et al*., 1988). Describing a food web for Jobos Bay ought to include a complex inventory of the species present in the four main estuarine communities: the mangrove forest, seagrass beds, coral reefs and, salt/mud flats. At present, this inventory is very incomplete at Jobos because benthic and demersal invertebrates associated with this ecosystem, particularly protozoans and meiofauna, have barely been examined, and trophic interactions have not been studied. Invertebrates undoubtedly represent a critical link between detrital and/or dissolved organic carbon sources and the macrofauna.

According to López *et al*. (1988), information on the pelagic community of the Caribbean estuarine/wetland system is limited to independent characterizations of phytoplankton, macrozooplankton and fish populations. The taxonomic structure of the bacterioplankton, planktonic copepods or jellyplankton, and interactions among them are not fully known. The lack of a systematic approach has precluded the understanding of their processes in the marine food webs. Despite these limitations, a hypothetical model for trophic interaction can be adapted to Jobos Bay based on information from similar systems. The most suitable models are those explained by López *et al*. (1988), in which three types of food webs are described: detritus-based, primary producers, and planktonic and benthic invertebrates. Information from those models were applied to represent a thophic pyramid for several communities in Jobos Bay (Figures 39, 40 and 41).

Figure 38. Flooding of mangrove and upland in Jobos Bay during Hurricane Lenny in 1999 (© Eddie N. Laboy Nieves)

Complex trophic interactions characterize even the most simply structured community. A focus on strong interactions can simplify food web structure and identify those species responsible for most of the energy flow in communities, but many factors contribute to such interactions. It is well known that pollution promotes the loss of sessile and mobile species in mangroves (Ellison & Farnsworth, 1996). Environmental variability also affects the distribution and abundance of benthic species in seagrass beds and coral reefs (Laboy-Nieves, 1997), and the feeding activities of a few key species may control the whole structure of a community (Molles, 1999). Therefore, modeling the food web or trophic pyramids for Jobos Bay, or any other system, requires holistic approaches to understanding-dimensional biological and physical factors that regulate the complex dynamics of intra-and interspecific interactions.

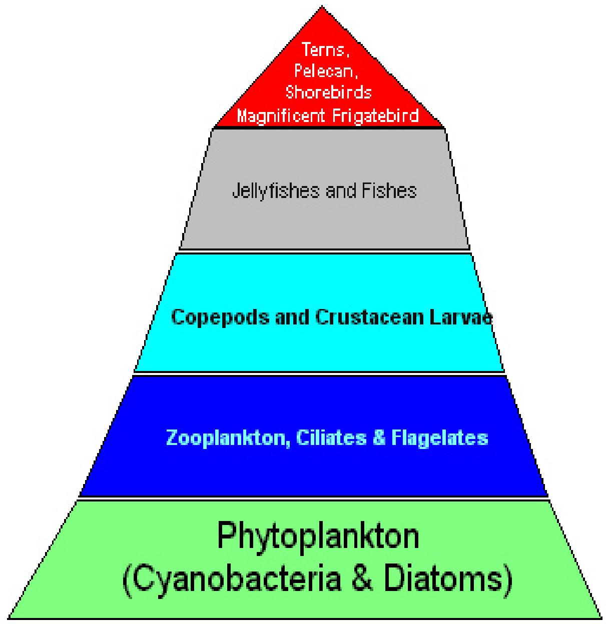


Figure 39. Trophic pyramid based on terrestrial primary productivity

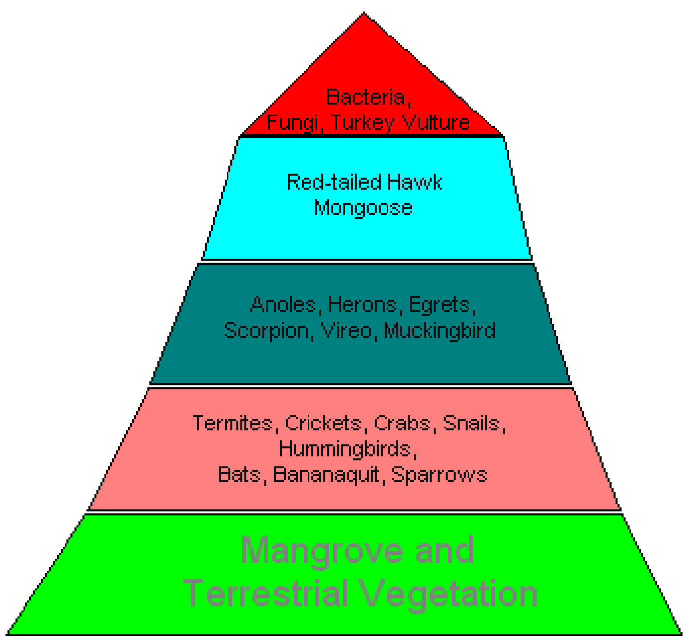


Figure 40. Trophic pyramid based on planktonic productivity

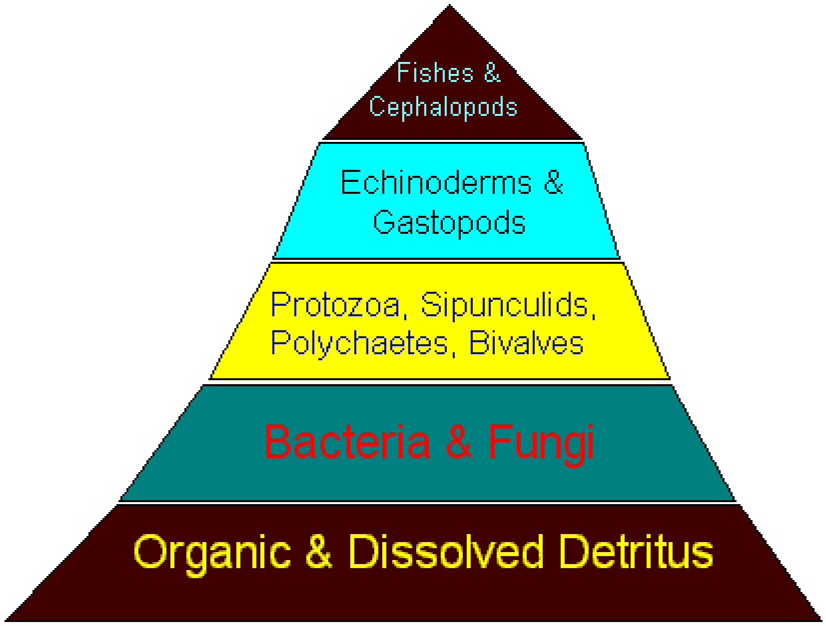


Figure 41. Trophic pyramid based on detritus consumption

CHAPTER 5. RESEARCH AND MONITORING

by Carmen M. González and Dr. Pedro O. Robles

5.1 Introduction

The Jobos Bay National Estuarine Research Reserve offers an opportunity for utilizing scientific and technical research to address problems of coastal resources management. The Reserve's research and monitoring program is comprehensive, interdisciplinary and coordinated. Guidance in program design is provided by the National Estuarine Research Reserve System that identifies goals, priorities and implementation strategies for conducting estuarine research and monitoring.

The Reserve's research and monitoring activities are combined with education and outreach programs. The net effect is to provide resource managers, decision makers in state and federal agencies, academic institutions, and the general public. with the requisite information and monitoring results for protecting and improving natural processes in the estuary.

A competitive Graduate Research Fellowship Program aimed at improving coastal zone management is conducted through NERRS. It provides the opportunity for undertaking high quality research focused on coastal management issues identified as having regional and national significance. Fellowships provide graduate students with funding for up to three years to conduct research at designated NERR sites. As part of this program students are required to provide up to 15 hours per week of assistance to the Reserve. This assistance, designed with the reserve's staff, may include on-site monitoring, sampling, research assistance or laboratory analyses. The training may take place throughout the school year or concentrated during specific seasons. Students are encouraged, but not required, to incorporate these training activities into their own research programs.

The NERRS System-Wide Monitoring Program (SWMP) consists of three phases: abiotic, biotic and land use/habitat change. The abiotic phase includes monitoring of a uniform suite of water quality and weather data that serve as important indicators of change (e.g., dissolved oxygen). Automatic sondes measure basic water quality parameters, and a weather station registers basic climatic data. The abiotic phase has been operational since 1996. The weather data collections began in 2001. The biotic and land use/habitat change phases are being developed, and methodologies are being tested for future inclusion into SWMP. Special monitoring programs will be developed at the Jobos Bay Reserve to address specific local issues such as groundwater quality and the presence of contaminants.

5.2 Research Facilities

Laboratory facilities and dormitories are located at the Reserve's Visitor Center in Aguirre, Puerto Rico. The use of these facilities, utility services, materials, basic equipment, instrumentation, and field support may be used to conduct research on-site. The Reserve has a 22-foot and 17-foot Boston Whaler that may be used for field sampling and transportation. Ground transportation support within the Reserve is limited. All research proposals or projects must follow the Jobos Bay Research and Education Guidelines incorporated in appendix E of this document.

5.3 Management Problems

Management problems facing the Reserve stem from long-term development pressures affecting the south coast, on the one hand, and, on the other hand, from institutional issues of divided responsibility for development decision-making and inconsistency in the enforcement of regulatory measures. The institutional picture is further complicated by the expanding role of local government in planning and zoning. Within a larger context, the ever-present duality in central government policy between economic growth and environmental conservation must also be factored in.

Because of the confluence of these forces, the Jobos Bay estuary is under intensive development pressures. Conflicts in land use and resource protection confront the Reserve with serious and growing management problems. Land use in the Jobos Bay watershed has evolved from predominantly sugarcane cultivation in the early 1900's to increasingly urban and industrial use in the late 1970's. This changing pattern is raising water quality and quantity concerns which, in turn, could imperil the Reserve's sustainability as a pristine estuarine habitat, a key criteria for NERRS designation

Among the primary management concerns are hydrological changes due to reduction or diversion of freshwater input, the quality of surface and groundwater reaching the bay, habitat loss, point and non-point sources of pollution, loss of buffer protection, and expanding urban and industrial development in adjacent coastal and upland areas. There is growing evidence of significant resource degradation that threatens the health of the estuary. In addition, illegal activities occurring within and adjacent to the Reserve are compromising the ecological integrity of the area.

Institutional issues pertaining to development decision-making are particularly germane to the future of the Jobos Bay Estuary. While Jobos Bay is protected by all of the laws and regulations pertinent to, and promulgated by the Department of Natural and Environmental Resources, development decision-making is largely shared between the Planning Board and the local municipalities. Under the municipal reform law, planning authority has .been decentralized. As a result, local governments are now able to assume some control over their own planning process. Both the municipalities of Salinas and Guayama have developed planning documents in which development is centered in the Jobos Bay watershed.

The Puerto Rico Coastal Zone Program has designated Jobos as a Special Planning Area (SPA), but the SPA boundaries that have been established are very limited, excluding important areas of the watershed that are of significant management concern. If the Reserve is to succeed in its mission, the Department of Natural and Environmental Resources must find a way to ensure the long-term integrity of the ecosystem and its continuing suitability for coastal research, monitoring and education.

5.3.1 Hydrology / Mangrove Ecosystem

Changes in hydrology have been attributed to different factors. Among the most important of there are, changes in water demand (extraction), runoff, and the destruction of irrigation channels that once were an important source of aquifer recharge.

New agricultural crops brought forth changes in irrigation practices. Since 1898, Hacienda Aguirre had sugarcane plantations that used furrow irrigation. With the end of the sugar cane era (1994), pivot drip systems and center-pivot sprinkler irrigation system using groundwater wells replaced the traditional flooding irrigation practices. The local aquifer became the main source of water, replacing the irrigation channels. Land use change from monoculture to multi-culture also affected water delivery needs for the new crops. These changes, combined with the increased well water extraction have reduced water levels in the aquifer as well as aquifer recharge potential.

McClymonds and Díaz (1962) conducted a preliminary appraisal of water resources in the Jobos Bay Area. They described the Bay as a 30 square mile belt of coalescing alluvial fans between the foothills to the north and the coastal plain to the south. Perennial streams from the foothills lose all their flow by percolation into the alluvial deposits except during flows. On an average year, recharge from stream flows is about 8,000 acre-feet, about 14,000 acre-feet from irrigation channels, 17,000 from rainfall and 14,000 from return flow from pumpage for irrigation. McClymonds and Díaz suggested that pumping at normal rates during droughts would lower the water table moving the saltwater interface further inland. In March 1996, the U.S. Geological Survey reported a drop of 25 feet compared to the 1986 water levels in wells. This situation is increasing the risk of salt intrusion and also reducing the amount of fresh water input to the estuary.

This decrease in groundwater levels and the changes in hydrological patterns have kept water from running into areas that were previously wet zones. Continuous accumulation of salt due to high evaporation and low or no freshwater input have not allowed salt to wash-off from the soil surface and interstitial waters. High salinity levels (60–130 ppt) have been registered in several monitoring projects. These salinity conditions have affected all mangrove species of this forest, including *Avicennia germinans,* the black mangrove, which is the most tolerant mangrove species of the forest. Mangrove die-off caused a reduction in the amount of leaves, twigs and other parts that decompose and eventually become part of the topsoil in mangrove areas. Wind erosion and tide effects have also contributed to eliminate mangrove forest topsoil leaving the soil unprotected and the mangrove root system exposed (Morris 1998).

In 1994, three center-pivot irrigation systems were installed on the northern boundary of the Reserve for corn cultivation. Because the lower section of the cornfield was located in an area of poor drainage, seven parallel, north-south drainage ditches were excavated. The excavations encroached into the Reserve's mangrove wetlands. The excavated material and cleared vegetation and debris were spread in the vicinity of the channels. Three existing retention ponds were destroyed and the lower dike wall was widened to be used as a road. This reconfiguration of the site and the resulting alteration in hydrological patterns has significantly contributed to mangrove mortality.

On June 26, 1997, EPA signed a consent order with the Puerto Rico Department of Agriculture that called for the following measures:

- No further discharges of dredged or fill material into waters of the United States;
- Removal of the roadway that was previously the southern outer dike of the Aguirre Sugar Mill wastewater disposal area;
- Grading of the land to the grade of the wetlands located on its north and south sides;
- The removed of material, which eroded from the roadway onto the adjacent wetlands to the north and south;
- The completion of a hydrological study;
- The reseeding and restoration of mangrove habitat ; and
- The construction of a wetland filter strip.

Of these activities, the dike was removed and the channels were filled. Piles of dirt and dead vegetation were removed from the area where channels were established. Land contour studies helped to estimate the forest's original soil levels. Other mitigation activities are still pending.

The impact of urban development on groundwater levels is another serious concern in the Jobos Bay watershed. More than 500 housing units have been constructed in the last four years, increasing the volume of groundwater extraction. New projects, like the golf course, hotel, and its Villas Complex, and the AES coal energy generating plant, also require vast amounts of fresh water for their operations.

In October 2001, the U.S. Geological Survey initiated a study to define the hydrologic/hydraulic conditions that may have contributed to mangrove loss. The study will provide alternatives to re-establish the hydrologic/hydraulic conditions prior to changes occurred since 1990. This study looks to define water flow, ground-water withdrawals and water deliveries since 1986.

Previous studies by Cintrón *et. al.* (1978) described the succession in the formation of mangrove rings typical of JBNERR. Otero (1984) defined the relation between mangrove pneumatophores size and lenticels height with changes in water levels. Mussa (1988) studied the regeneration and half-life of mangrove seedlings. He reported that solar radiation and salinity were the two factors that contributed to differences in seedling growth in the inner and outer zones of the studied fringe mangrove. Variation of genetic material was studied by Pérez-Laguillo (1998). This study analyzed and compared enzyme composition of red mangrove among plants collected at Jobos Bay, Dominican Republic, Florida and Panama.

Several other studies have been initiated to gather the information needed to evaluate mangrove health and develop mangrove restoration strategies. Dr. Jose Seguinot from the Department of Environmental Health, University of Puerto Rico, is studying the quality of interstitial water, soil and productivity of the black mangrove system in the Reserve in order to develop a restoration plan for the affected area. Mrs. Rosael Ferrer, from the Interamerican University, is assessing the condition of the soils affected by hydrological changes, yet much more is needed to understand and resolve the hydrology of the watershed and its effects on the mangrove and associated communities.

Needs:

- Complete all activities included in EPA's Consent Order.
- Conduct hydrologic/hydraulic studies and modeling of the watershed including volume and flow of water from seeps, springs and inland runoff.
- Assess soil salinity, grain-size distribution, sediment organic content, sediment microbial biomass, conductivity, pH leaf litter, topsoil availability, and biotic components and their relation to soil quality.
- Mangrove soil infauna, meiofauna, macrofauna diversity, biomass, vertical distribution, species richness and taxonomic composition.
- Additional water quality studies in mangrove zones. Conditions of interstitial water affecting infauna and microbes and their role in mangrove recolonization, establishment and development.
- Conduct halophytic bacteria surveys and soil characterization including account for microbial biomass and circadian rhythms between cyanobacteria and diatoms in mangrove lagoons.
- Mangrove productivity studies, including satellite imagery interpretation and hemispheric photography.
- Define mangrove function, its ecology and the dynamics that determine its structure and integrity.
- Locate the presence of *Typha* and other freshwater vegetation, occurring at the mangrove zones during high rain events.
- Map mangrove and vegetation coverage/ spatial/ change analysis.
- Identify the effects of stressors including: salinity, freshwater input, hurricanes, thermoelectric combustion fumes, mechanical disturbance of submerged

substrates, coral reefs sedimentation and toxic compounds on mangrove productivity.

- Describe leaf degradation rates, seedling density and recruitment, seed production, mangrove litter and diameter at breast height (DBH), using innovative technology.
- Develop bio-indicators related to mangrove ecosystem structure and trophic interactions.
- Determine food web structure among primary producers and consumers.
- Determine dynamic of phosphorous, carbon, nitrogen and other essential nutrients and trace element dynamic and bioaccumulation.

5.3.2 Biodiversity and Productivity

Different native, exotic, endangered and threatened bird species share the mangrove forest as their main habitat. Crabs, insects and gastropods inhabit leaves, branches, roots and even pneumatophores. More complex dynamics can be found on submerged roots where competition for space and light is evident. Algal species, gastropods, crabs, polychaetes, sponges, tunicates and even fishes share these submerged roots as their habitat.

In the 1970 and early 1980's studies were conducted in Jobos Bay in connection with the proposed construction of a nuclear powered generating plant. Because of the existence of a fault line under the site, the project was switched to fossil fuel, and evolved into what is now the Aguirre Power Plant Complex. Many of the inventories of organisms that are known today are the result of the surveys conducted in 1980. Vicente (1975) classified Jobos Bay sea grasses in three categories based on light and benthos characteristics: outer-bay well illuminated hard bottoms, inshore beds with poor illuminated soft bottom and mangrove channel sea grass beds growing in lowlight soft silty bottom. This study included measurements on sea grass biomass, leaf standing crop, growth rate, pigment diversity and epiphytism. The vertical distribution of *Thalassia testudinum*, studied by Vicente and Rivera (1977), correlated depth limits with wave action, turbidity, substrate and hydrostatic pressures. Findings demonstrate a positive correlation ($p< 0.01$) between depth and growth limits of this sea grass. They also reported that the grazing pressure of echinoids also determined sea grass presence in shallower waters where light was not a limiting factor. The Department of Natural and Environmental Resources (1979), Puerto Rico Nuclear Center (1971) and Molinary (1981) conducted bird surveys at Jobos Bay. Molinary reported 87 species of birds for Jobos Bay, with special observations on the large congregations of blue heron (*Ardea herodias*) and American osprey (*Pandion haliaetus*).

In recent studies, Sharpe (1998) compared life history of *Acrosticum* fern between El Yunque and JBNERR populations. Sharpe reported that the mass mortality of ferns in the northern boundary has been attributed to lack of freshwater. García and Castro (1998) conducted assessments on coral reef, sea grass and mangroves. They also reported macrofauna and fishes. Another survey, Nemmeth and García (2001), reported a reduction of coral coverage in Cayo Caribe and Cayo La Barca transects, while algal coverage increased along both sampling sites.

Laboy-Nieves (2001) conducted a full inventory of the marine, estuarine, and terrestrial flora and fauna of the Jobos Bay ecosystem. Mr. Felix Badillo (2002) assessed *Vibrio* species in Jobos Bay and Mar Negro Lagoon. Results showed variation in bacterial presence among the different sampling stations for the sampling period, but significant harmful *Vibro* concentrations. The Department of Natural and Environmental Resources laboratory conducted a two-year (1996-98) assessment on plankton diversity and abundance.

Anthropogenic and natural disturbances have been associated with changes in mangrove coverage and associated communities. Areas that were once populated by mangrove forest are now open salt flat areas. Black mangrove die offs have been documented due to high salinities and low freshwater input. Measurements of primary productivity are important due to their role in the trophic structure of any ecosystem. Little is known about productivity in Jobos Bay.

Needs:

- Inventory of species associated with coral reefs, sea grass beds, mangrove forests, salt flats and lagoons.
- Change analysis for community structures and interactions.
- Inventories of flora and fauna species including surveys on population structure, age, distribution (i.e. fish larval stages, juvenile and adults, spawning zones, nesting areas, plants seedling recruitment, etc.).
- Develop long-term monitoring programs for habitats and essential species.
- Collect data on plankton distribution, diversity, abundance and recruitment.
- Determine estimates of primary production (chlorophyll a) in the water column.
- Assess benthos composition, distribution and productivity.
- Seagrass productivity studies using of remote sensing and other new technologies.

5.3.3 Point and Non-point Source Pollution

Jobos Bay NERR has worked on various efforts with the Puerto Rico Coastal Zone Management Program to address point and non-point source pollution. In conjunction with the Puerto Rico Water Resources Institute, EPA's Better Assessment Science Integrating Point and Non-point Source (BASINS) model was developed for the Jobos Bay. Once the raw data is available, this quantitative tool will help assess cumulative impacts of projects on watershed water quality. In addition, the Non-point Source Committee has included Jobos Bay in the priority watershed list, helping support other research efforts. Because Jobos Bay is an important agricultural watershed, the Natural Resources Conservation Service (NRCS), is also promoting and supporting the implementation of better management practices among farmers in our watershed.

Agricultural practices, like the use of chicken manure and commercial fertilizers, may also be affecting water and air quality. Preliminary studies (Sastre 1996, Altieri 2000, and JBNERR 2000) reveal that pesticides and fertilizers applied in agricultural fields were also being transported to the Reserve. Jobos Bay NERR Monitoring Program studied several freshwater wells in the Jobos Bay watershed. Findings detected high levels of nitrates (90mg/l) in some wells, exceeding the drinking water standard (10mg/l) of the Puerto Rico Environmental Quality Board. Several groundwater wells studied by the Reserve's Water Quality Program have been banned due to high nitrate levels and more stringent management practices have been imposed by the Puerto Rico Environmental Quality Board on the use of chicken manure on farmland.

The U.S. Geological Survey is completing a study that will assess the high nitrate levels in groundwater found by JBNERR Monitoring Program. One of Jobos Bay Fellowship students, Jennifer Bowen, is developing a nitrogen-loading model. This study uses nitrogen isotopes to identify the sources of nitrogen compounds that encroach into the mangrove forest and the ability of mangrove to intercept and immobilize these by-products. Dr. Wilfredo Colon from the East University is looking at the center-pivot irrigation system to improve farming practices. Dr. Jose Dumas from the University of Puerto Rico, laboratory of the Experimental Station, is assessing the presence of phalate and other pesticides in ground and interstitial waters associated with existing agricultural farming practices.

The impact of industrial growth on the Reserve's resources continues to be a major concern. The regional BFI landfill located on the northern boundary of the Reserve is under expansion. A new permit was submitted to increase the landfill area, which has been broadened to twice the size of the original plans. Lixiviates from this landfill may be reaching the aquifer and the bay. The Aguirre Power Plant has also undergone considerable expansion. Other mayor industries like Chevron Phillip Core, Ayers-Wyeth, IPR Pharmaceuticals, Baxter Caribe, Inc, Colgate-Palmolive and ProChem continue their operations while the long-term effects of effluents and emissions on human and natural resources are still unknown. The Reserve has initiated an air monitoring program to assess possible impacts. Most of these plants have air emissions that pass through the Reserve and may affect it through toxic particle deposition. Nitrite and sulfide oxides convert into acidic compounds during rain or agricultural runoff events. These compounds can affect the integrity and health of mangrove ecosystem on a cumulative basis.

Near-shore water quality in the Bay is being affected by increased surface run-off and higher discharge volumes from the regional waste water treatment plant. Urban growth along the coast is invading estuarine habitat and increasing the direct discharge of untreated wastewater from local communities that have no water treatment facilities such as Agirre, Coquí, Mosquito and Las Mareas, among others,. Near-shore water samples have registered very high concentrations of fecal coliforms

Needs:

- Determine the levels of pesticides, fertilizers, PAH's, volatile and semi-volatile compounds and other toxic entities in the mangrove forest.
- Conduct analysis of water, soil, air, and biota to detect toxic or hazardous substances, toxic organic and inorganic compounds, grease, oils, pesticides (i.e. insecticides, herbicides, nematicides) fertilizers, heavy metals (i.e. lead, mercury, iron), and nutrients in water, soil and air.
- Assess the use of vegetative buffers or wetland filter strips to manage agricultural run-off.

5.3.4 Sediment Quality of Jobos Bay

Toxic compounds may be accumulating in the Bay's sediments. Re-suspension of sediments from barge traffic, oil spills, and thermal and chemical discharges may be resulting in cumulative impacts on the ecology of the Bay bottom. These impacts could stem from the operation of the power plant and other industrial facilities. A better understanding of the Bay's conditions and processes is critical for developing objective evaluations of potential future urban and industrial projects.

Due to the relative stability of sediments, they can be an important source of data to help assess past activities/impacts based on the accumulation of particles, metals and other chemical entities that have been deposited or transported into the Bay. No long-term monitoring studies have been conducted to detect or trace changes in sediment quality. Dr. Carlos Rodriguez, from the Department of Environmental Health-University of Puerto Rico will be assessing the presence of toxics and metals in sediments and fish in Jobos Bay (2003). Ivie A. Martínez is developing an oil spill contingency plan for the protection of Jobos Bay’s natural resources. A complete assessment of the different biotic and abiotic components of the Bay is necessary in order to properly address the impacts of land use changes.

Needs:

- Assess the impacts of activities (past and present including industrial and power generating plant processes, boating traffic, dredging, pier construction, fishing and recreation uses) on the marine ecosystems, which include seagrass beds, coral reefs and mangroves.
- Assessments of metals such as lead, cadmium, copper, mercury, selenium, arsenic, chromium, silver and iron.
- Develop sediment size, pH, dissolved oxygen and microbiologic profiles.
- Develop monitoring programs to detect organic compounds (pesticides, polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), diesel, grease/oil, etc.) in the water column, and sediment in the Bay, and assess possible relation to industrial and power plant activities.

- Assess changes in physical-chemical parameters including salinity, specific conductivity, nitrate, nitrite, phosphate, dissolve oxygen, pH, turbidity, suspended solids, fecal and total coliforms, currents and depth (bathymetry).
- Assessments of pesticides, fertilizers, PAH's, volatile and semi-volatile compounds, metals and other toxic entities (toluene, benzene, xylene).

5.3.5 Air Quality

An environmental management characterization study conducted by Dr. Seguinot (2000) within the communities surrounding Jobos Bay identified that a high percentage (almost half) of the individuals suffer from respiratory illnesses. EPA has recently declared the area as having the second most contaminated air quality in Puerto Rico. The Jobos Bay Watershed is also the second most industrialized zone on the island. No major studies have been conducted that attempt to correlate the relation between airborne toxic compounds from urban, industrial and agricultural use and their effects on the Reserve, its watershed, and the local population. The Reserve has just signed a Collaborative Agreement with Dr. Braulio Jimenez from the Center for Environmental and Toxicological Research, University of Puerto Rico, to establish an airborne particle monitoring program. The following projects have been identified as high priority research and monitoring subjects.

Needs:

- General air quality analysis in different areas of the watershed for carbon dioxide, nitrous oxide, lead, particulate matter (both 2.5 and 10 microns), sulfur dioxide, volatile organic compounds, semi-volatile organic compounds, genotoxicity and mutagenic potential
- Develop monitoring programs for metals including lead, cadmium, mercury, arsenic, chromium and zinc and assess the effects of these compounds on the flora, fauna and water resources of Jobos watershed.
- Develop an Air Quality Model for the Jobos Bay Airshed.
- Assess the relation of air quality in Jobos Bay to the health of local communities.

5.3.6 Coastline Erosion

Little is known about coastal erosion processes in Jobos Bay. Severe storms, strong currents and inappropriate use of resources for recreational activities are some stressors that have caused changes along the coastline. Shell sand, dead algal and coral fragments are part of the sediments that constitute Cayo Caribe, one of the islands suffering erosion on two small beach pockets that are located at the eastern side of this island. A current meter deployed for 19 days between Cayo Caribe channels (Capella 2001), showed a mean current speed of 13 ~ I cm/s, while the mean vector was 12.9cm/s towards 2* true, northwards into the Bay. Capella estimated that under the influence of tropical cyclones the flow would far exceed 100cm/s. Under these conditions any small perturbation in the mangrove coverage bordering the shoreline, or in the bathymetric contours, may begin a cycle of erosion that may be hard to stop. Roxana Grafals and Barreto developed a beach profiles for Cayo Caribe coastline during 2001-2002. Data showed beachfront depressions and changes indicating that beach erosion is occurring in this zone.

Needs:

- Coast stabilization and vegetation succession studies.
- Assessment of erosion in other zones within the Reserve.
- Develop a program to monitor tides.

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GLOSSARY (Chapter 2)

CEER	Center for Energy and Environmental Research (UPR)
cm	centimeter(s)
DNR	Department of Natural Resources of the Government of Puerto Rico. Spanish: Departamento de Recursos Naturales (DRN).
DNER	Department of Natural and Environmental Resources of the Government of Puerto Rico. Spanish: Departamento de Recursos Naturales y Ambientales (DRNA).
DoE	US Department of Energy
DTPW	Department of Transportation and Public Works of the Government of Puerto Rico.
EDF	Environmental Development Fund
EPA	US Environmental Protection Agency
EQB	Environmental Quality Board of the Government of Puerto Rico. Spanish: Junta de Calidad Ambiental.
h	hour(s)
in	inch(es)
JOBNERR	Jobos Bay National Estuarine Research Reserve (Spanish: JOBANERR)
km	kilometer(s)
kts	knots (1 knot = 1.8532 km/h = 1.151 statute-mile/h)
m	meters(s)
NERR	National Estuarine Research Reserve
PRIDCO	Puerto Rico Indistrial Development Administration. Spanish: Corporación para el Fomento Economico, or simply Fomento.
PRNC	Puerto Rico Nuclear Center (DoD-UPR)
UPR	University of Puerto Rico
USGS	United States Geological Survey, Department of the Interior.

Appendix A. Marine Plants of the Jobos Bay NERR

Thalophyta

Chlorophyta

Cladophorales

Cladophora rapens
Cladophora dalmatica
Chaetomorpha linum
Rhizoclonium kerneri
Valonia aegagropila

Siphonocladales

Acetabularia sheenkii
Acetabularia crenulata
Cladophoropsis macromeres
Ventricaria ventricosa

Caulerpales

Boodleopsis pusilla
Caulerpa sertularoides
Caulerpa racemosa
Caulerpa mexicana
Caulerpa verticillata
Caulerpa floridiana
Caulerpa cupressoides
Caulerpa vickersiae
Caulerpa prolifera
Halimeda incrassata
Halimeda opuntia
Penicillus capitatus
Penicillus lamourouxii
Udotea flavelum

Rhodophyta

Ceramiales

Acanthophora spicifera
Ceranium fastigiaum
Chondria bayleyna
Chondria floridana
Chondria tenuissima
Haloplegma duperreyi
Jania adherens
Jania rubens
Laurencia corallopsis
Laurencia obtusa
Murrayella periclada
Spyridia filamentosa

Gigartinales

Hypnea cervicornis
Hypnea spinella

Cryptonemiales

Amphiroa fragilissima

Nemaniales

Asparagopsis taxiformis
Galaxaura rugosa

Phaeophyta

Dictyotales

Dictyota linearis
Dictyota cervicornis
Dictyota dichotoma
Dictyota bartayerii
Dictyota ciliolata
Dictyota volubilis
Padina sanctae

Fucales

Sargassum natans
Sargassum fluitans

Spermatophyta

Cymodoceaceae

Halodule beaudettei
Syringodium filiforme

Hydrocharitaceae

Halophila decipiens
Thalassia testudinum

Appendix B. Partial List of the Animal Species Observed in the Upland Habitats of **the Jobos Bay NERR**

Phylum Mollusca

Clase Gastropoda

Littorina angulifera (snail, caracol de mangle)
Melampus coffeus (snail, caracol de mangle)

Phylum Arthropoda

Clase Arachnida

Avicularia laeta (black tarantula, tarántula negra)
Cyrtopholis portoricae (Hairy spider, araña pelúa)
Isometrus sp. (scorpion, escorpión)
Micrathena sexspinosa (spiny spider, araña espinosa)

Clase Diplopoda

Orthocricus arboreus (giant millipede, gongolo)
Phinocricus parcus (ground millipede, gongolí de hojarasca)
Trigoniulus lumbricinis (red millipede, gongolí rojo)

Clase Chilopoda

Scolopendra alternans (centipede, ciempiés)

Clase Insecta

Order Odonata

Erithrodiplax umbrata (dragon fly, libélula)

Order Orthopera

Acheta assimilis (cricket, grillo)
Philobalosoma sp. (walking stick, palito viviente)
Schistocerca americana (grasshopper, saltamontes)
Stenopelmatus sp. (mole cricket, changa)

Order Isoptera

Coptotermes brevis (termite, comején)
Odontomachus raematoda (giant ant, barraco)
Solenopsis germinata (red ant, hormiga brava)

Order Hemiptera

Leptoglossus stigma
Nezara viridula

Order Coleoptera (beetles)

Deracistrus thomae
Diaprepes abbreviatus
Phylophaga citri
Phelypera distigma

Order Homoptera

Umbonia crassicornis (treehopper, cornuita)

Order Lepidoptera

Arsenura armida (moth, alebiya)
Calisto nubila (black butterfly, mariposa negra)
Danaus plexippus (monarch, mariposa monarca)

Order Hymenoptera

Apis melliphera (bee, abeja)
Polistes americanus (wasp, avispón)
Stictia signata (ground wasp, avispa terrera)
Xylocopa brasilianorum (cigarrón)

Phylum Chordata

Subphylum Vertebrata

Clase Amphibia

Bufo marinus (toad, sapo común)

Eleutherodactylus antillensis (tree frog, coquí)
Eleutherodactylus coqui (tree frog, coquí)
Leptodactylus albilabris (sapito de labio blanco)

Clase Reptilia

Ameiva exsul (ameiva, siguana)
Anolis cristatelus (tree anole, lagartijo)
Anolis pulchellus (grass anole, lagartijo)
Anolis stratulus (anole, lagartijo)
Hemidactylus brooki (gecko, salamanca)
Phyllodactylus wirshingi (gecko, salamanca de tierra)
Sphaerodactylus macrolepis (santalucía)
Sphaerodactylus nicholsi (santalucía)

Clase Aves

Order Pelecaniformes

Fregata magnificens (magnificent frigatebird, tijerilla)
Sula leucogaster (brown booby, boba parda)
Pelecanus occidentalis (brown pelican, alcatraz)

Order Ciconiiformes

Ardea herodias (great blue heron, garzón cenizo)
Bubulcus ibis (cattle egret, garza de ganado)
Butoroides striatus (green heron, martinete)
Casmerodius albus (great egret, garza real)
Egretta caerulea (little blue heron, garza azul)
Egretta thula (snowy egret, garza blanca)
Egretta tricolor (Louisiana heron, garza pechiblanca)
Nycticorax nycticorax (black-crowned night heron)
Nycticorax violaceus (yellow-crowned night heron)
Plegadis falcinellus (glossy ibis, coco prieto)
Phoenicopterus ruber (flamingo, flamenco)

Order Anseriformes

Anas bahamensis (white-cheeked pintail, pato quijada-colorada)
Anas discors (blue-winged teal, pato zarcel)

Order Falconiformes

Buteo jamaicensis (red-tailed hawk, guaraguao)
Cathartes aura (turkey vulture, aura tiñosa)
Falco peregrinus (peregrine falcon, halcón peregrino)
Falco sparverious (kestrel, falconcito)
Pandion haliaetus (osprey, guincho)

Order Gruiformes

Gallinula chloropus (common moorhen, gallareta común)
Porzana carolina (sora rail, gallito de mangle)
Rallus longirostris (clapper rail, pollo de mangle)

Order Charadriiformes

Actitis macularia (common sandpiper, putilla)
Anous stolidus (brown noddy, cervera)
Arenaria interpres (ruddy turnstone, playero turco)
Calidris canutus (red knot, playerp gordo)
Calidris himantopus (stilt sandpiper, playero patilargo)
Calidris mauri (western sandpiper, playero occidental)
Calidris melanotus (pectoral sandpiper, playero manchado)
Calidris minutilla (least sandpiper, playero menudo)
Calidris pusilla (semipalmated sandpiper, playero gracioso)
Charadrius alexandrinus (snowy plover, playero blanco)
Charadrius semipalmatus (semipalmated plover, playero acollarado)
Charadrius vociferus (killdeer, playero sabanero)
Charadrius wilsonia (Wilson’s plover)
Gallinago gallinago (common snipe, becacina)
Haematopus palliatus (American oyster catcher, ostrero)
Himantopus mexicanus (black-necked stilt, viuda)
Larus atricilla (laughing gull, gaviota cabecinegra)
Limnodromus griseus (short-billed dowicher, chorlo pico corto)
Numenius phaeopus (whimbrel, playero pico corvo)
Pluvialis squatarola (black-bellied plover, playero cabezón)

Rynchops niger (black skimmer, pico de tijera)
Sterna antillarum (least tern, gaviota pequeña)
Sterna hirundo (common tern, gaviota común)
Sterna maxima (royal tern, gaviota real)
Sterna sandvicensis (sandwich tern, gaviota piquiaguda)
Tringa flavipes (lesser yellowlegs, playero guineilla)
Tringa melanoluca (greater yellowlegs, playero aliblanco)

Order Columbiformes

Columba leucocephala (white-crowned pigeon, paloma cabeciblanca)
Columba livia (rock dove, paloma común)
Columba inornata (plain pigeon, paloma sabanera)
Columbina passerina (ground dove, rolita)
Zenaida asiatica (white-winged dove, tórtola aliblanca)
Zenaida aurita (Zenaida dove, tórtola cardosantera)
Zenaida macroura (morning dove, rabiche)

Order Psittaciformes

Amazona ventralis (Hispaniolan parrot, cotorra dominicana)
Amazona vidirigenalis (red-crowned parrot, cotorra coroniroja)
Melopsittacus undulatus (parakeet, periquito)
Myopsitta monachus (monk parakeet, perico monje)

Order Cuculiformes

Coccyzus americanus (yellow-billed cuckoo, pájaro bobo piquiamarillo)
Coccyzus minor (mangrove cuckoo, pájaro bobo menor)
Crotophaga ani (smooth-billed ani, judío)

Order Strigiformes

Asio flammeus (short-eared owl, múcaro de sabana)

Order Caprimulgiformes

Chordeiles gundachi (Antillean nighthawk, querequequé)

Order Micropodiformes

Chlorostilbon maugaeus (Puerto Rican Emerald, zumbadorcito)
Cypseloides niger (Antillean black swift, vencejo)

Order Coraciiformes

Megaceryle alcyon (belted kingfisher, martín pescador)

Order Piciformes

Melanerpes portoricensis (Puerto Rican woodpecker, pájaro carpintero)

Order Passeriformes

Agelaius xanthomus (yellow-shouldered blackbird, mariquita)
Coereba flaveola (bananaquit, reinita)
Dendroica atriata (blackpoll warbler, reinita rayada)
Dendroica discolor (prairie warbler, reinita galana)
Dendroica petechia (yellow warbler, canario de mangle)
Elaeina martinica (Caribbean elaeina, juí blanco)
Estrilda melpoda (scarlet-cheeked weaver finch, veterano)
Eupletes orix (red bishop, obispo rojo)
Geothlypis trichas (common yellowthroat, reinita picatierra)
Hirundo rustica (barn swallow, golondrina de horquilla)
Hirundo fulva (cave swallow, golondrina de cuevas)
Lonchura cuculata (bronze mannikin, diablito)
Margarops fuscatus (pearly-eye thrasher, zorzal pardo)
Mimus polyglotus (northern mockingbird, ruiseñor)
Mniotilta varia (black and white warbler, reinita trepadora)
Molothrus bonariensis (glossy cowbird, tordo)
Myarchus antillarum (Puerto Rican flycatcher, juí)
Quiscalus niger (Greater Antillean glackle, chango)
Parula americana (northern parula, reinita pechidorada)
Progne dominicencis (Caribbean martin, golondrina de iglesias)
Seiurus aurocapillus (ovenbird, pizpita dorada)
Seirus noveboracensis (northern watertrush, pizpita de mangle)
Setophaga ruticilla (American redstart, candelita)
Tiaris bicolor (black-faced grassquit, chamorro)
Tiaris olivacea (yellow-faced grassquit, gorrión barba amarilla)
Tyrannus dominicencis (gray kingbird, pitirre)
Vireo altiloquus (black-whiskered vireo, bienteveo)

Clase Mammalia

Artibeus jamaicensis (fruit bat, murciélago frutero)
Herpestes javanicus (mongoose, mangosta)
Molosus molosus (house bat, murciélago casero)
Noctilio leporinus (fishing bat, murciélago pescador)
Mus musculus (mice, rajiero)
Rattus norvegicus (rat, ratón)

Appendix C. Representative Genera of the Jobos Bay NERR Phytoplanktonic Community

Chrysophyta
Achnanthes
Actinophycus
Asterionella
Bacillaria
Bacteriastum
Biddulphia
Cerataulina
Climacosphenia
Cyclotella
Cyclophora
Diploneis
Dimeregramma
Entomoneis
Eucampia
Fragilaria
Flore;;a
Gom[honema
Gyrosigma
Hemiaulus
Hyalodiscus
Isthmia
Lampriscus
Licmophora
Lyrella
Mastologia
Melosiva
Navicula
Nitzchia
Oestrupia
Odontella
Pinnularia
Pleurosigma
Plagiotropis
Prustulia
Rhizosolenia
Rhopalopia
Skeletonema
Scoliopleura
Thalassiothrix

Pyrrophyta*Ceratium*
Dinophysis
Gymnodinium
Peridinium
Prorocentrum
Pyrodinium

Chromophyta*Distephanus*
Dictyocha

Appendix D. Partial List of the Invertebrate Fauna Inhabiting the Benthic Substrata of the Jobos Bay NERR

Porifera

Chondrillia nucula
Desmacella jania
Desmonspongia sp.
Haliclona hogarthi
Haliclona variabilis
Haliclona erina
Pellina carbonaria
Tethya actinia

Cnidaria

Hydrozoa

Actinoporus elegans
Cassioppea frondosa
Cladocora arbuscula
Condylactis gigantea
Erythropodium caribaeorum
Phymanthus crucifer
Millepora alcicornis
Millepora complanata
Palythoa caribaeorum
Physalia physalis
Sertularella speciosa
Stylaster roseus
Synthecium tubitheca
Zoanthus sociatus

Anthozoa

Acropora cervicornis
Acropora palmata
Acropora prolifera
Agaricia agaricites
Briareum asbestinun
Diplora strigosa
Eunicea succinea
Favia fragum
Gorgonia flabellum
Meandrina meandrites
Phormidium corallyticum
Plexaura homomalla
Plexaura flexuosa
Porites porites
Siderastrea siderea
Stephanocoenia mechelinii

Annelida

Anamobaea orstedii
Arabella opalina
Arabella iricolor
Bispira brunnea
Eupolymnia crassicornis
Hermodice caruncula
Hesione protochona
Lysidice sulcata
Naineris laevigata
Pontogenia sericoma
Sabellastarte magnifica
Spirobranchus giganteus

Arthropoda

Crustacea

Balanus eberneus
Calappa gallus
Calinectes sapidus
Carpillus coralinus
Chthamalus fragilis
Clibanarius antillensis
Cirolana parva
Excolarana antillensis
Eurydice littoralis
Gonodactylus sp.
Lysia nassa
Micropsis bicornutus
Mythrax sculptus
Mythrax spinosissimus
Pagurites cadenatis
Panopeus herbstii
Panopeus occidentalis
Panuligus argus
Paracereis caudata
Percnon gibbesi
Petrochirus diogenes
Pitho themimeri
Portunus sebae
Rhynchocinetes rigens
Stenopus hispidus
Sternorhynchus seticornis
Upogebia affinis

Ectoprocta

Caulibugula dendrograpta
Reteporellina evelinae
Schizoporella unicornis

Mollusca

Gastropoda

Aplysia dactylomela
Bulla striata
Cassis falmea
Ceritium aburneum
Ceritium eberneum
Ceritium littoratum
Charonia vaiegata
Codakia pectinella
Codakia orbicularis
Codakia orbiculata
Cypraea cervus
Cyphoma gibbosum
Cymbovula acicularis
Haminoea antillarum
Hyalina avena
Jaspidella jaspinea
Lipthopoma tectum
Littorina angulifera
Marginella pruniosum
Modulus modulus
Nassarius albus
Oliva reticularis
Strombus costatus
Strombus gigas
Strombus raninus
Tegula fasciata
Turbo castanea
Tridachia criptata

Amphineura

Acanthopleura granulata
Quadrans lintea
Turbo castanea

Bivalvia

Lima lima
Lima scabra
Pinna carnea
Tellina radiata

Cephalopoda

Octopus briareus
Sepioteuthis sepioidea

Echinodermata

Crinoidea

Comactinia echinoptera
Davidaster rubiginosa

Asteroidea

Astropecten articulatus
Oreaster reticulatus

Ophiuroidea

Chiridota rotifera
Ophiocoma echinata
Ophiocoma riisei
Ophioderma appressum
Ophioderma brevicarudum
Ophionereis reticulata
Ophiothrix angulata
Ophiothrix suensonii

Echinoidea

Arbacia puntata
Diadema antillarum
Echinometra lucunter
Eucidaris tribuloides
Lytechinus variegatus
Tripneustes ventricosus

Holothuroidea

Actinopyga agassizi
Duasmodactyla seguroensis
Euthyonidiella trita
Holothuria arenicola
Holothuria cubana
Holothuria floridana
Holothuria glaberrima
Holothuria grisea
Holothuria mexicana
Isostichopus badionotus
Lytechinus variegatus
Ocnus suspectus
Ophiolepis elegans
Ophioderma appressum
Psolus operculatus
Tripneutes esculentus

Chordata

Ascidiacea

Ascidia curvata
Clavelina sp.
Herdmania momus
Microcosmus helleri
Molgula occidentalis
Policarpa obtecta
Pyura vittata

Appendix E. Common Fishes of the Jobos Bay NERR

Scientific Name	(Common Name)
Chondricthyes	
Ginglymostoma cirratum	nurse shark, tiburón gata
Carcharhinus acronotus	balcknose shark, tiburón jociquinegro
Carcharhinus perezi	reef shark, tiburón coralino
Caleocerdo cuvieri	tiger shark, tiburón tigre
Negaprium brevirostris	lemon shark, tiburón limón
Rhizoprionodon porosus	Atlantic sharpnose shark, cazón
Sphyrna lewini	scalloped hammerhead, cornuda
Dasyatis americana	stingray, mantaraya
Aetobatus narinari	spotted eagle ray, chucho
Osteichthyes	
Elopidae	
Elops saurus	ladyfish, macabí
Megalops atlanticus	tarpon, sábalo
Muraenidae	
Echidna catenata	chain moray, morena de cadena
Gymnothorax funebris	green moray, morena verde
Gymnothorax moringa	spotted moray, morena moteada
Gymnothorax vicinus	purplemouth moray, morena purpurina
Muraena miliaris	goldentail moray, morena brillante
Ophichthidae	
Ahlia egmontis	keyworm eel, anguila llave
Myrichthys acuminatus	sharptail eel, anguila puntiaguda
Myrichthys oculatus	goldspotted eel, anguila manchada
Myrophis punctatus	spected worm eel, anguila pecosa
Clupeidae	
Harengula clupeola	false pilchard, cascarúa
Harengula humeralis	red-ear sardine, machuelo
Jenkinsia lamprotaenia	dwarf herring, minjúa
Opisthonema oglinum	threadfin herring, arenque
Sardinella aurita	Spanish sardine, sardina española
Engraulidae	
Anchoa cubana	Cuban anchovy, anchoveta cubana
Anchoa epsetus	stripped anchovy, bocúa
Anchoa lamprotaenia	longnose anchovy, anchoveta ojona
Anchoa parva	small anchovy, anchovetita
Anchoviella perfasciata	flat anchovy, anchoveta
Cetengraulis edentulus	whalebone, rabo amarillo

Scientific Name	(Common Name)
Synodontidae	
Synodus foetens	galliwasp, doncella
Synodus intermedius	sand diver, lagarto
Gobiesocidae	
Arcus amplycirrhus	emerald clingfish, renacuajo
Arcus rubiginosus	red clingfish, renacuajo rojo
Exocoetidae	
Hemiramphus balao	balao, balajú
Hemiramphus brasiliensis	ballyhoo, balajú
Hyporhamphus unifaciatus	halfbeak, pico fósforo
Belonidae	
Strongylura notata	redfin needlefish, agujón rojo
Strongylura timucu	timucu, agujón timucu
Tylosurus acus	agujon, agujón
Tylosurus crocodilus	hound needlefish, agujón perro
Holocentridae	
Holocentrus ascensionis	longjaw squirrelfish, gallito
Holocentrus marianus	longspine squirrelfish, gallito colorado
Holocentrus rufus	squirrelfish, gallito
Holocentrus vexillarius	dusky squirrelfish, gallito oscuro
Myripristis jacobus	blackbar soldierfish, candil colorado
Syngnathidae	
Hippocampus reidi	longsnout seahorse, caballito de mar
Syngnathus dunckeri	pugnose pipefish, trompetero
Syngnathus elucens	shortfin pipefish, trompetero
Syngnathus pelagicus	Sargassum pipefish, trompetero
Syngnathus rousseau	Caribbean pipefish, trompetero
Centropomidae	
Centropomus ensiferus	swordspine snook, róbalo machuelo
Centropomus pectinatus	tarpon snook, róbalo tablado
Centropomus undecimalis	snook, róbalo flamasón
Serranidae	
Epinephelus adscensionis	rock hind, cabra mora
Epinephelus guttatus	red hind, mero cabrilla
Epinephelus itajara	jewfish, mero grande
Epinephelus striatus	Nassau grouper, merno cherna
Serranus balwini	lantern bass, merito linterna
Serranus tigrinus	harlequin bass, merito tiza

Scientific Name	(Common Name)
Grammistidae	
Rypticus saponaceus	greater soapfish, jaboncillo
Rypticus subbifrenarus	spotted soapfish, jabón
Priacanthidae	
Priacanthus arenatus	bigeye, catalufa
Priacanthus cruentatus	glasseye snapper, toro
Apogonidae	
Apogon maculatus	flamefish, cardenal flamasón
Apogon quadrisquamatus	sawcheek cardinalfish, cardenal
Astrapogon puncticulatus	blackfin cardinalfish, cardenal
Astrapogon stellatus	conchfish, cardenal conchero
Phaeptyx pigmentaria	dusky cardinalfish, cardenal oscuro
Echeneidae	
Echeneis naucrates	sharksucker, remora
Remora remora	remora, remora
Carangidae	
Caranx bartholomaei	yellow jack, guaymen amarillo
Caranx crypsos	blue runner, cojinúa
Caranx hippos	crevalle jack, jurel
Caranx latus	horse-eje jack, jurel ojón
Caranx ruber	bar jack, cibí
Chloroscombrus chrysurus	Atlantic bumper, casada
Decapterus punctatus	roundscad, caballa pintada
Oligoplites saurus	leatherjack, cueriduro
Selene setapinnis	Atlantic moonfish, corcobado
Selene vomer	lookdown, jorobado
Trachinotus carolinus	pompano, pompano
Trachinotus falcatus	permit, pompano
Trachinotus goodei	palometa, palometa
Lutjanidae	
Lutjanus analis	mutton snapper, sama
Lutjanus apodus	schoolmaster, pargo amarillo
Lutjanus cyanopterus	cubera snapper, pargo guasinuco
Lutjanus griseus	gray snapper, pargo prieto
Lutjanus jocu	dog snapper, pargo colorado
Lutjanus mahogoni	mahogony snapper, pargo rayado
Lutjanus synagris	lane snapper, pargo manchego
Ocyurus chrysurus	yellow snapper, colirubia

Scientific Name	(Common Name)
Gerreidae	
Diapterus auratus	Irish mojarra, mojarra
Diapterus plumieri	stripped mojarra, mojarreta
Diapterus rhombeus	rhomboid mojarra, mojarra
Eucinostomus argenteus	spotfin mojarra, mojarra blanca
Eucinostomus gula	silver jenny, blanquilla
Eucinostomus jonesi	slender mojarra, mojarra
Eucinostomus lefroyi	motted mojarra, muniama
Eucinostomus melanopterus	flagfin mojarra, muniama
Gerres cinereus	yellowfin mojarra, muniama
Haemulidae	
Anisotremus surinamensis	black margate, vieja
Anisotremus virginicus	porkfish, canario
Haemulon aurolineatum	tomtate, mulita
Haemulon bonariense	black grunt, ronco prieto
Haemulon carbonarium	Caesar's grunt, ronco carbonero
Haemulon chrysargyreum	smallmouth grunt, saboga
Haemulon flavolineatum	French grunt, condenado
Haemulon macrostomum	Spanish grunt, colombiano
Haemulon melanurum	cottonwick, jenigúa
Haemulon parrai	sailor's choice, arrayado
Haemulon plumieri	white grunt, boquicolorao
Haemulon sciurus	bluestriped grunt, ronco amarillo
Sparidae	
Archosargus rhomboidalis	sea bream, chopa
Calamus bajonado	jolthead porgy, pluma ojona
Calamus calamus	sausereye porgy, pluma
Calamus penna	sheepshead porgy, pluma
Calamus pennatula	porgy, pluma
Sciaenidae	
Bairdiella ronchus	ground drummer, corvino
Bairsiella snactaeluciae	striped croaker, corvino
Cynoscion jamaicensis	mongolar drummer, dientón
Larimus breviceps	shortehead drum, corvino
Menticirrhus martinicus	jewsharp drummer, corvino
Micropogonias furnieri	whitemouth croaker, corvino
Odontoscion dentex	reef croaker, corvino de arrecife
Ophioscion adustus	snake croaker, corvino
Stellifer stellifer	small drum, corvino
Mullidae	
Mulloidichthys martinicus	yellow goatfish, salmonete amarillo
Pseudopeneus maculatus	spotted goatfish, salmonete colorado
Ephippidae	
Chaetodipterus faber	Atlantic spadefish, palometa

Scientific Name	(Common Name)
Chaetodontidae	
Chaetodon capistratus	foureye butterflyfish, mariposa
Chaetodon striatus	banded butterflyfish, mariposa rayada
Pomacanthidae	
Holacanthus ciliaris	queen angelfish, isabelita
Holacanthus tricolor	rock beauty, catalineta
Pomacanthus arcuatus	gray angelfish, palometa
Pomacanthus paru	French angelfish, palometa
Pomacentridae	
Abudefduf saxatilis	sargeant major, sargento
Abudefduf taurus	night sargeant, vieja prieta
Chromis multilineata	brown chromis, burrito marrón
Chromis cyanea	yellowtail damselfish, damisela
Pomacentrus diencaeus	longfin damselfish, damisela
Pomacentrus dorsopunicans	dusky damselfish, damisela parda
Pomacentrus leucostictus	beaugregory, gregorio
Pomacentrus partitus	bicolor damselfish, damisela bicolor
Pomacentrus planifrons	threespot damselfish, damisela
Pomacentrus variabilis	cocoa damselfish, damisela cocoa
Labridae	
Bodianus rufus	Spanish hogfish, perro colorado
Doratonotus megalepis	dwarf wrasse, doncella enana
Halichoeres bivittatus	slippery dick, doncella resbaladiza
Halichoeres garnoti	yellowhead wrasse, doncella amarilla
Halichoeres maculipinna	clown wrasse, payaso
Halichoeres poeyi	blackear wrasse, doncella ojinegra
Halichoeres radiatus	puddin wife, capitán de piedras
Lachnolaimus maximus	hogfish, capitán
Thalossoma bifasciatum	bluehead wrasse, cabeza azul
Scaridae	
Scarus coeruleus	blue parrotfish, brindao
Scarus croicensis	motted parrotfish, bullón
Scarus guacamaia	rainbow parrotfish, guacamayo
Scarus taenipterus	princess parrotfish, loro princesa
Scarus vetula	queen parrotfish, loro reina
Sparisoma aufrenatum	redband parrotfish, loro
Sparisoma chrysopterum	redtail parrotfish, loro
Sparisoma radians	bucktooth parrotfish, loro
Sparisoma lubripinne	redfin parrotfish, cotorro
Sparisoma viride	stoplight parrotfish, loro verde

Scientific Name	(Common Name)
Mujilidae	
Mugil curema	white mullet, jara
Mujil trichodon	fantail mullet, liza
Sphyraenidae	
Sphyraena barracuda	great barracuda, picúa
Sphyraena guachancho	guachanche, picúa parda
Sphyraena picudilla	southern sennet, picuilla
Polynemidae	
Polydactylus virginicus	barbu, barbú
Clinidae	
Acanthemblemaria aspera	roughead blenny, viejita
Acanthemblemaria spinosa	spinny head blenny, viejita
Coralliozetus cardonae	twinhron blenny, viejita
Enneanectes boehlkei	roughhead triplefin, blenio
Labrisomus bucciferus	puffcheek blenny, viejita
Labrisomus gobio	palehead blenny, viejita
Labrisomus guppyi	mimic blenny, viejita
Labrisomus haitiensis	longfin blenny, viejita
Labrisomus nigricinctus	spotcheek blenny, viejita
Labrisomus nuchipinnis	hairy blenny, viejita
Malacoctenus aurolineatus	goldline blenny, viejita
Malacoctenus delalandii	Brazilian blenny, viejita
Malacoctenus erdmani	imitator blenny, viejita
Malacoctenus gilli	dusky blenny, viejita oscura
Malacoctenus macropus	rosy blenny, viejita
Malacoctenus triangulatus	saddled blenny, viejita
Paraclinus cingulatus	coral blenny, viejita
Paraclinus fasciatus	banded blenny, viejita
Paraclinus nigripinnis	blackfin blenny, viejita
Stathhmonotus stahli	eelgrass blenny, viejita
Blenniidae	
Entomacrodus nigricans	pearl blenny, blenio perlado
Hypleurochilus aequipinnis	oyster blenny, blenio ostra
Hypleurochilus springeri	arange spotted blenny, blenio
Ophioblennius atlanticus	redlip blenny, blenio
Eleotridae	
Elotelis smaragdus	emerald sleeper, guabina esmeralda
Gobiidae	
Bathygobius curacao	notchtongue goby, gobio
Bathygobius mysbacium	island frillfin, gobio
Bathygobius soporatur	frillfin goby, gobio
Coryphopterus dicrus	colon goby, gobio

Scientific Name	(Common Name)
Acanthuridae	
Acanthurus bahianus	ocean surgeon, médico
Acanthurus chirurgus	doctorfish, médico
Acanthurus coeruleus	blue tang, cirujano
Trichiuridae	
Trichiurus lepturus	cutlassfish, machete
Scombridae	
Scomberomorus cavalla	king mackerel, carita
Scomberomorus regalis	cero, alasana
Euthynnus pelamis	skipjack tuna, bonito
Stromateneidae	
Nomeus gronovii	man of war fish, pastor
Peprilus alepidotus	harvestfish, papito
Scorpaenidae	
Scorpaena bergii	gousehead scorpionfish, rascana
Scorpaena grandicornis	grass scorpionfish, rascana
Scorpaena plumieri	spotted scorpionfish, rascana
Bothidae	
Bothus lunatus	peacock flounder, lenguado
Syacium micrurum	channel flounder, lenguado
Soleidae	
Achirus lineatus	lined sole, lenguado
Gymnachirus nudus	naked sole, lenguado
Balistidae	
Aluterus achoepfi	orange filefish, lija anaranjada
Aluterus scriptus	scrawled filefish, lija garrapatera
Balistes vetula	queen triggerdish, peje puerco
Cantherhines pullus	orangespotted filefish, lija
Monacanthus ciliatus	fringed filefish, lija frangeada
Monacanthus setifer	pigmy filefish, lija
Ostraciidae	
Lactophrys bicaudalis	spotted trunkfish, chapín
Lactophrys polygonia	honeycomb cowfish, chapín
Lactophrys quadricornis	scrawled cowfish, chapín
Lactophrys trigonus	buffalo trunkfish, chapín
Lactophrys triqueter	smooth trunkfish, chapín

Scientific Name	(Common Name)
Tetraodontidae	
Canthigaster rostrata	sharpnose puffer, tamboril
Sphoeroides greeleyi	Caribbean puffer, tamboril
Sphoeroides spengleri	bandtail puffer, tamboril
Sphoeroides testudineus	checkered puffer, tamboril
Diodontidae	
Diodon holocanthus	balloonfish, guanábano
Diodon hystrix	porcupinefish, guanábano

APPENDIX F: Research, Monitoring, Manipulation and Education Guidelines

Research , Monitoring and Education activities will be promoted and supported at Jobos Bay National Estuarine Research Reserve. Applicants will submit to Jobos Bay manager research proposals for all proposed activities to be carried out at the Reserve for evaluation. Proposals and proposed activities may be also evaluated by the Jobos Bay Research Advisory Committee. The Reserve will inform the applicant about permits and/or additional information required to complete submittal and approval procedures.

Applicants should follow JBNERR Research Proposal Submittal Guidelines that will be available at the Reserve's Visitors Center, Department of Natural and Environmental Resouces and other Research Centers.

According to policies of the Deparment of Natural and Environmental Resources and established regulations for the management of natural resources, procedures for the approval of permits for activities to be conducted at JBNERR are to be coordinated between DNER-Fish and Wildlife Bureau and Jobos Bay National Estuarine Research Reserve. Permits application forms will be available at the Jobos Bay Visitor's Center and at the Department of Natural and Environmental Resources in San Juan. ALL permit applications for Jobos Bay submitted to the Department will be referred to JBNERR for evaluation and comment prior to the issuance of the permit. Permit applications submitted to Jobos Bay National Estuarine Research Reserve will be evaluated and referred to DNER-Fish and Wildlife Bureau.

Manipulation of habitats for resource management purposes shall be permitted only for the following purposes:

a. Protection of public health;

b. Preservation of sensitive natural, cultural, or historical resources that have been listed or are eligible for protection under relevant Federal or Commonwealth authorities; and

c. Restoration of degraded areas in order to improve the representative character and the integrity of the Reserve.

Manipulation for the purposes of restoration may be permitted under policies for soil, hydrology, wetlands, vegetation, wildlife, and fire management. These may provide opportunities for research, as well. However, habitat manipulation activities for research purposes will not be permitted if those activities, or their resulting long- or short-term consequences, have the potential to compromise the representative character and integrity of the Reserve or to adversely impact on Reserve resources.

Conferences, group visits, guided field trips and other requested education activities will be coordinated with the Education Coordinator or designee with at least a month in advance. Application forms for education activities will be available at the Reserve's Offices.

Applicants with proposals for research in Jobos Bay National Estuarine Research Reserve shall submit the following documents to the Reserve Manager's Office.

1. A Research Title Page that should include the following information:

Project Title:

Project Duration:

Project Coordinator: (Lead principal investigator)
(name/position/address/phone/fax/e- mail)

Additional Principal Investigator (s): (name/position/
address/phone/fax/e-mall)

Institution or Agency Supporting the Project: (name/address/
phone/fax/e-mail)

Project Coordinator's Signature and Date:

2. The proposal shall include a two to four page, single space narrative that clearly articulates the following:

A. The objectives of the project and their relationship to Jobos Bay Management Plan.

B. Project Location (s): (Specific site and when posible geographic position where the project is to be conducted)

C. A description of the roles and responsibilities of project participants

D. A description of the methodologies for meeting project objectives

E. A timeline for meeting project objectives

F. Include the product, process or program that will result from successful accomplishment of the project objectives, identify the benefits as well as the beneficiaries of the project results.

3. Budget Summary (must include evidence of available funds to ensure objectives)

Personnel
Permanent Equipment
Materials and Supplies
Travel
Other Direct Costs

4. Requested Support: (Laboratory space, dormitory space, vehicle or boat use, equipment, personnel assistance, etc.)

Apendix G. List of Publications of Jobos Bay National Estuarine Research Reserve

Title	Year	Ref #	Author
Water resources of Jobos area, Puerto Rico, a preliminary appraisal	1962	4	Mc Clymons et al
The marine algae of Bahía de Jobos	1964	1	L.R. Almodovar
A comparison of fish fauna in a highly stressed and a less stresed tropical bay-Guayanilla and Jobos	1971	3	M.F. Douglas et al
Sediments and Physical Oceanography at Jobos Bay	1971	704	J. Morelock et al
Seagrass Bed Communities of Jobos Bay	1976	7	Vance P. Vicente
Depth limits of the Seagrass Thalassia testudinum (Konic) in Jobos and Guayanilla	1976	8	Vance P. Vicente et al
Aspects of Ecology and ethology of Lytechinus variegatus in Jobos Bay, Puerto Rico	1976	202	José A. Rivera et al
Características morfólogicas y químicas de las hojas del Rhizophora mangle, en un bosque de franja	1984	766	Honora Serrano et al
Ciclos diurnos de factores ambientales en un manglar de franja	1984	768	Julio C. Montero et al
Densidad y tamaño de plántulas y neumatóforos en una franja de mangle rojo	1984	767	Ana D. Otero et al
Estudio preliminar sobre la composición arbórea del manglar de Bahía de Jobos, biomasa y nutriente	1984	764	Aurea Berrios et al
Long-term erophysiological studies of mangroves their gas exchange and water relations at the Jobos	1984	407	Dr. William T. Laurence
Relación entre la altura y la densidad de lenticelas y neumatóforos y el nivel de agua en una franja	1984	765	Casilda Otero
Nitrogen fixation by microorganisms on mangrove roots in the Jobos Bay National Estuarine Sanctuary	1985	208	Jean Lodge et al
Mortandades masivas del erizo de mar Diadema antillarum (Philippi) en Puerto Rico	1985	1069	Vance P. Vicente et al
Growth rates of seagrass beds at selected sites at Jobos Bay National Estuarine Sanctuary	1986	367	Dr. Luis R. Almodovar
Interpretación aerea de los cambios geográficos ocurridos en la Bahía de Jobos, Guayama, Puerto Rico	1986	201	Dr. José Seguinot
Microbiology of mangrove roots with emphasis on marine fungi	1987	368	Dr. Luis R. Almodovar
Sedimentation effects on coral reefs at Jobos Bay Estuarine Sanctuary	1987	499	Jack Morelock
Structures and Dynamics of a Mangrove Fringe Forest in the Jobos Bay National Estuarine Research Reserve	1987	9	Ariel Lugo et al
Habitat Needs of Migrant and resident waterbirds at the Jobos Bay National Estuarine Sanctuary	1989	763	Joseph M. Wunderle et al
Seasonal Abundance of shorebirds in the Jobos bay Estuary in southern PR	1989	5	Joseph M. Wunderle et al
Macroalgas de la Reserva Estuarina Bahía de Jobos	1990	2	Luis F. Santana et al

Title	Year	Ref #	Author
A preliminary assessment of pesticide nonpoint source pollution in Jobos Bay , NERR	1995	802	Francisco Fuentes et al
The use of a geographic information system and remote sensing technology for monitoring land use and land cover of JBNERR	1995	827	Prof. Linda L. Vélez
Nonpoint source water pollution in Aguirre forest of JBNERR	1997	998	Santos L. De Jesús et al
Survey of Marine Communities Associated with Coral Reefs Habitats At Jobos Bay, NERR System	1997	844	Jorge R. García et al
Hydrologyc and biological analysis of Jobos Bay Estuary Mangroves Mortality Jobos, Puerto Rico	1999	1202	Gregory L. Morris
Determination of pesticides in surface water and run-off discharge into the Jobos Bay,NERR	1999	1223	Carlos Altieri et al
Biomonitoring of agricultural pesticides in amphibians tissue from Jobos Bay, NERR Puerto Rico	2000	1247	José C. Barrios
Concentraciones de metales pesados en sedimentos y tejidos de ostiones	2000		David Allers
Gestión ambiental de la población residente en la Reserva Nacional Estuarina de la Bahía de Jobos,	2000	1334	Dr. José Seguinot
Status of the Groundwater Quality of the Jobos Bay Estuary Reserve	2000	832	Ermelindo Banchs
Land Use Classification of the South West of Puerto Rico	2001	1365	Prof. Linda L. Vélez
The Natural History of Jobos Bay, Puerto Rico.	2001	1397	Dr. Eddie N. Laboy
Developing the required database to run the better assesment science integrating point and nonpoint	2001	1489	Adneris I. Picón
Evaluación de fuentes de contaminación en la cuenca hidrográfica de la reserva estuarina de Bahía de Jobos y su posible asociación con los altos niveles de nitratos en sus aguas subterráneas	2001		Mayra Rupert
Hurricane impacts on the growth of mangrove ferns *Acrostichum danaefolium*	2001		Joanne Sharp
Presencia de especies Vibrio en la Reserva Bahía de Jobos	2002		Felix Badillo
Estudio sobre las condiciones socioambientales de las comunidades aledañas a la reserva nacional de investigación estuarina de Bahia de Jobos (JOBANERR)	2003		Melina M. Unpierre

Apendix H. Ongoing Research in Jobos Bay National Estuarine Research Reserve

Title	Year	Status	Author
Recolonization and succession of mangrove fauna following natural and antropogenic disturbance	2001	writing final report	Amanda Jones
Estudios Geomorfológicos de Cayo Caribe, Guayama (1932-2002)	2001	writing final report	Roxana Grafals
Evaluación para el desarrollo de un Plan de Restauración en el área de Mar Negro, Bahía de Jobos	2001	writing final report	Dr. José Seguinot
Well and instertitial water crop protection chemicals study on the Salina Fan Delta Aquifer	2002	writing final report	Dr. José A. Dumas
Uso de dos modelos de computadoras para predecir la carga y la concentración de nitrógeno en el estuario de Bahía de Jobos	2001	on going	Jeniffer Bowen
Development and implementation of management plan to reduce non point pollution of the coastal waters of the National Estuarine Reserve of Jobos Bay	2001	on going	Dr. Wilfredo Colón
Evaluación de la contaminación con Nitratos en el area de Salinas, Puerto Rico	2001	on going	José Rodríguez
Determinación de la condición de los suelos en área afectada por cambios hidrológicos en Bahía de Jobos	2002	on going	Rosael Ferrer
Plan de contingencia para derrames de petroleo en los manglares de la reserva nacional de investigación estuarina de Bahía de Jobos	2002	on going	Ivie A. Martínez
Inventario GIS de uso de terrenos en la cuenca de la Bahía de Jobos	2002	on going	Dr. Luis Olivieri
Heavy metal evaluation in airbone PM10 from the Jobos Bay National Estuarine Reserve	2002	on going	Dr. Braulio Jiménez
Exposure assessment of heavy metals from edible sport fish in Jobos Bay National Estuarine Research Reserve	2003	on going	Dr. Carlos Rodríguez
Heavy metals and biomarkers toxicity assays in Jobos Bay National Estuarine Research Reserve	2003	on going	Dr. Carlos Rodríguez
Ecological Knowledge and success in a Puerto rico small-scale fishery	2003	on going	Carlos García Quijano
Relationships between the distribution of the bottlenose dolphin (tursiops truncatus) and the abundance of their prey in Jobos Bay	2003	on going	Verónica Acevedo Soto
Estudio piloto para la propagación y establecimiento de plántulas de *Avicenia germinans* en JBNERR	2003	on going	Luisa Ramírez

APPENDIX I. Regulation for the Use and Protection of Resources of the Jobos bay National Estuarine Research Reserve.

GENERAL RULES

1. This Regulation supplements the Reserve's Resource Protection Guidelines incorporated in this Management Plan. By reference, it also incorporates regulations currently in force in all Commonwealth forests. These latter regulations have, in some cases, been made more stingent, because of the particular management needs poised by the fragile ecology of the Estuarine Research Reserve.

2. Amendments and/or additions to this Regulation shall be considered by the Reserve Manager in consultation with the Research Advisory Committee, Education Advisory Committee, and the Citizen Advisory Council for JBNERR.

B. HUNTING AND FISHING

1. Traditional hook and line fishing is, at all times, permitted in the Reserve's designated Conservation Sectors. Catch and release practices will be encouraged for small or immature specimens. Pot fishing, using a mesh size of no smaller than 3 inches, will be allowed in reef areas. Pot fishing will be prohibited in the waters of Mar Negro.

2. Traditional shellfish harvesting of mangrove oysters is permitted within the Reserve. Fishermen will be encouraged to provide information on the amount of oysters harvested, the areas from which they were gathered, and other pertinent information bearing on maintaining a sustainable yield.

3. Hunting of birds and animals is prohibited within the Reserve at all times.

C. OPERATIONS AND USE RESTRICTIONS

1. Hours of Operation

    a. The Reserve shall be open to visitors throughout the year from 9:00 AM to 4:00 PM.

    b. The visitor's center, offices, and laboratory shall be open from 7:30 AM to 4:00 PM, Monday through Friday, and on Saturdays from 10:00 AM to 2:00 PM.

    c. Within Conservation and Limited Use Sectors, areas have been designated for education and passive recreation activities. There are no designated areas for camping or picnics in the Reserve.

2. Access to the Reserve

    a. Individuals and small groups (fewer than 8 persons) are requested to register at the visitor's center.

    b. Groups of 8 or more persons, including student groups, are requested to make advance reservations to visit the Reserve so as to allow for the scheduling of guides and lecturers.

    c. All visitors must provide their own transportation to the Reserve. The Reserve will coordinate transportation only for education and research activities.

d. Water access to the Reserve will be encouraged through the use of charter boats made available from the local fishing community.

3. Use of Vehicles

a. Motor vehicles are prohibited within the Reserve, except for Ranger patrol vehicles and maintenance units.

b. Parking is provided at the visitor's center and at other designated points from which visitors may proceed into the Reserve on foot or by boat.

4. Use of Vessels

a. Privately owned boats may dock at piers within the Reserve for no more that three (3) hours without a permit. Anchorages will be limited, as designated by signage.

b. Privately owned boats may tie up to a mooring buoy within the Reserve for not more than two (3) hours without a permit.

c. Privately owned boats used for research activities sponsored by the Reserve will receive special permits for that purpose.

d. No anchoring will be permitted on mangrove roots in water areas of the Reserve. All boats using anchors will be restricted to areas specifically designated for that purpose.

e. Vessels with a maximum size of 22 feet are permitted to transit in Conservation Sectors and Limited Use Sectors. No motor vessels will be allowed in Preservation Sectors, with the exception of researchers and shellfish fishermen.

f. Jet Ski's will not be permitted in any of the Reserve Sectors.

5. Waste Disposal

a. Visiors to the Reserve shall carry out any garbage or other waste which they may generate, or shall deposit waste materials in recycling receptacles provided in the Reserve.

b. Limited sanitary facilities will be provided for visitors only in Cayos Caribe.

6. Fire

a. No cooking or camp fires are permitted within the Reserve. Visitors using Limited Use Sectors will be encouraged to carry only snack bags. Designated rest areas should be used for eating.

b. The cutting or taking of fuel wood within the Reserve is prohibited. Collection of specimens for research and education purposes must request a permit from the Reserve Manager.

7. Pets

a. No pets are permitted within the Reserve.

b. Seeing-eye dogs guiding blind individuals may enter the Reserve with a permit from the Reserve Manager.

8. Research

Research activities related to a project sponsored or authorized by the Reserve may be conducted within the Reserve. Individuals involved in such research activities will be issued special identification which must be carried at all times within the Reserve.

9. Camping

Camping is not permitted within the Reserve.

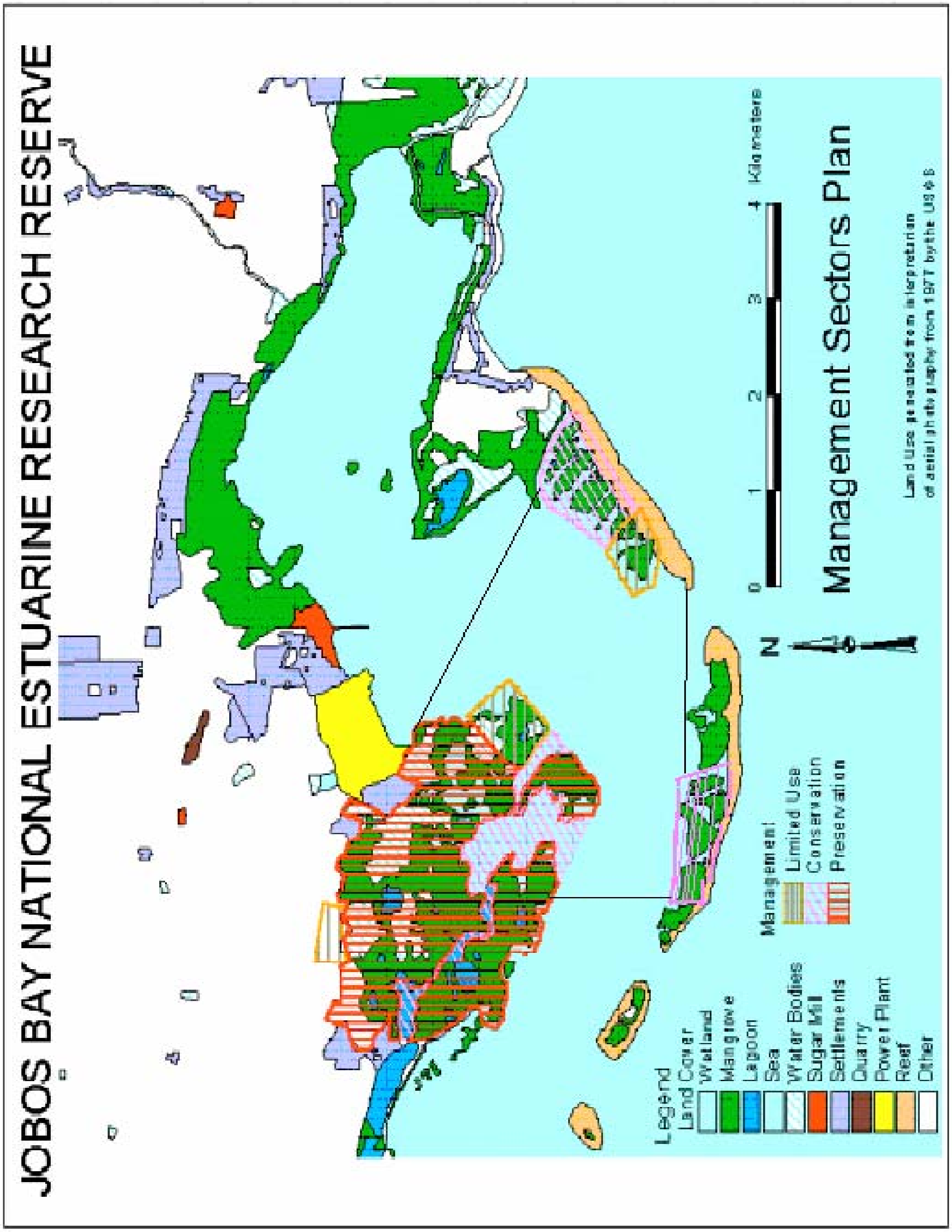

Figure 6. Jobos Bay National Estuarine Research Reserve