Environment and development
in coastal regions and in small islands

Coastal region and small island papers 3

San Salvador, Bahamas

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San Salvador is similar in many respects to other islands of the Bahamas Archipelago, but it is unique in its position away from the Bahama Banks. The isolation of San Salvador influences its climate and ecology as well as its cultural history. The CARICOMP mangrove sites are located along the southern coast of San Salvador, and represent the only such shoreline mangroves on the island. Data collected to date reflect the stressed nature of Bahamian mangrove systems. The seagrass sites are located in embayment areas at both the southern and northern parts of San Salvador. The data reveal the importance of Thalassia at both sites, but variations exist in its biomass between the two sites. The coral reef site is located off the west shore of the island and, while not representative of the majority of Bahamian reef systems, it does meet the criteria set up by CARICOMP. Data collected to date from the coral reef site shows little change from one monitoring to the next. Daily and weekly physical measurements at all of the sites reveal the importance of seasonal fluctuations.

Introduction

San Salvador is one of the 700 islands which make up the Bahama Archipelago located along the subsiding continental margin off the coast of Florida. This archipelago extends from the Navidad Bank, 20°N, off the coast of Hispaniola, north to the Little Bahama Bank at 27.5°N. While the entire archipelago extends 1,400 km north to south, the Commonwealth of the Bahamas is 1,126.5 km, from Grand Bahama to Inagua, the southernmost island.

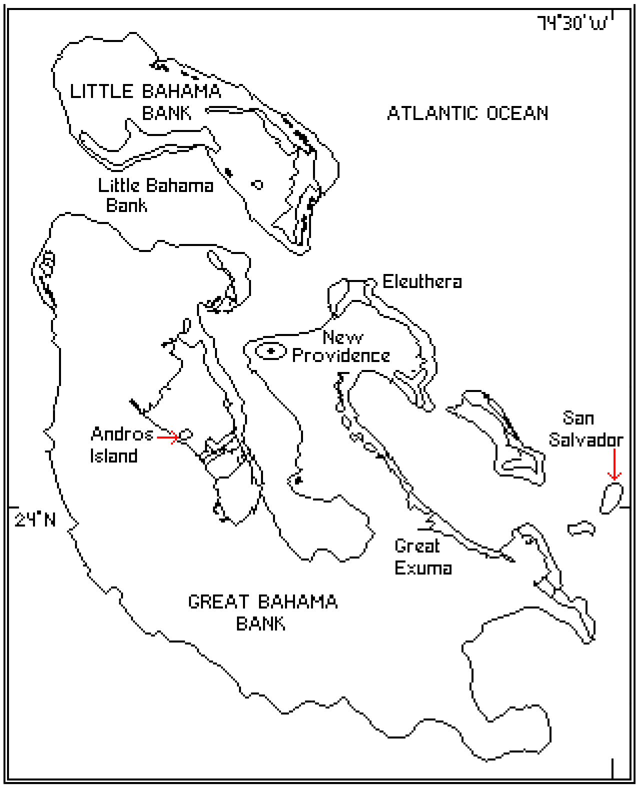


Fig. 1. Location of San Salvador, Bahamas.

Geological History

The Bahamas are low, carbonate islands that rest on two large bank systems, with water depths of less than 10 m. The Little Bahama Bank is in the northern Bahamas; the Great Bahama Bank extends from central to southwestern Bahamas. The remaining islands are isolated small platforms beginning at 24°N latitude in the eastern Bahamas and extending to Navidad Bank just north of Haiti. These shallow seas give the Bahamas its name, from the Spanish "Baja Mar." The bank systems are separated from each other by a deep water basin, with depths up to 4,000 m.

The origin of the Bahamas is still controversial. The archipelago may be the result of plate tectonics activity 200 million years ago, forming as a horst graben (Mullins and Lynts, 1977), or it may be the remnant of a much larger platform (Meyerhoff and Hatten, 1974). It is generally accepted that these banks originated at a latitude with warm, shallow waters that encouraged the growth of a variety of marine organisms whose skeletal remains were deposited as sediments. The weight of these sediments caused subsidence as deposition continued, developing carbonate deposts which, at present, reach a thickness of more than 5.4 km (Meyerhoff and Hatten, 1974). The islands are all less than 61 m above sea level; the highest elevation on San Salvador is 37.5 m, atop one of the ridges on the east side of Flamingo Pond (Shaklee, 1994).

The Bahama Platform became exposed during sea-level lowstands as a result of four major glacial advances during the Pleistocene. Winnowed eolianite dunes formed during these periods and became lithified after flooding, thus forming the islands. During the interglacial stages, weather altered the landscape into karst formations of caves, sink holes, and solution pits. These conduits honeycomb the islands. Because of the great porosity of the limestone, water from rainfall and runoff is rapidly delivered underground through these conduits, resulting in a scarcity of freshwater rivers and streams in the Bahamas.

During the last ice advance, sea level was 91.5 m lower than today, exposing the banks. This allowed plants and animals to arrive from the Greater Antilles, across the short gap from Cuba or Hispaniola. Some plants also arrived via birds and as flotsam, as is the case with mangroves. Thus, the majority of life forms are Caribbean in origin rather than North American.

Physical Geography

San Salvador is located at 24°3'N latitude and 74°30'W longitude, 640 km ESE of Miami, Florida. It is surrounded by 4,000-m-deep waters and is exposed to waves from the Atlantic Ocean (Fig. 1, and Fig. 2). The island is pod shaped, with a north-south orientation. It measures 11.2 km east-west and 19.25 km north-south, not including the offshore cays to the north. The island has 94.9 km^2 of surface area, most of which consists of dune ridges, with adjacent troughs forming brackish (hypersaline) lakes that constitute nearly a third of the total area (Fig. 2). A series of fringing reefs surrounds the island, with a break in the vicinity of Cockburn Town on the west coast. This breach in the reef provides access to the island for shipping, dockage, and mooring during normal weather patterns. The reefs form several protected embayments, including Grahams Harbor and Rice Bay in the north, Long Bay in the east, Snow Bay and French Bay in the south, and Fernandez Bay and Bonefish Bay in the west (Fig. 2).

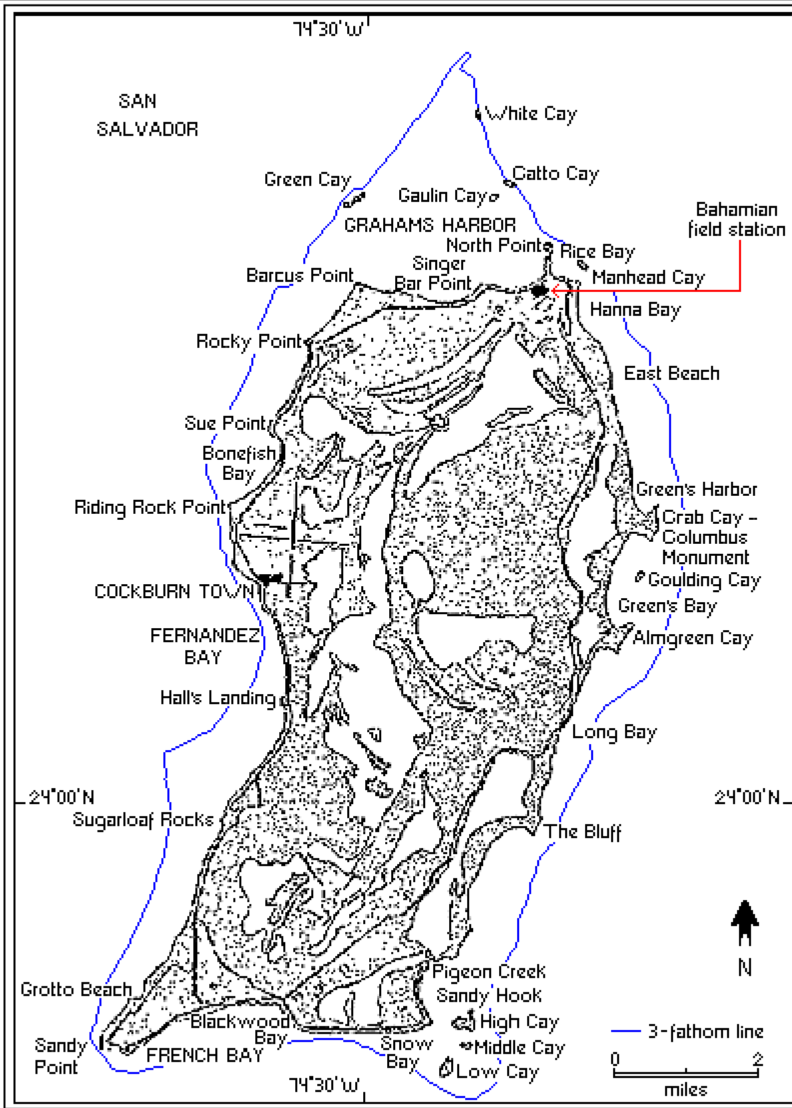
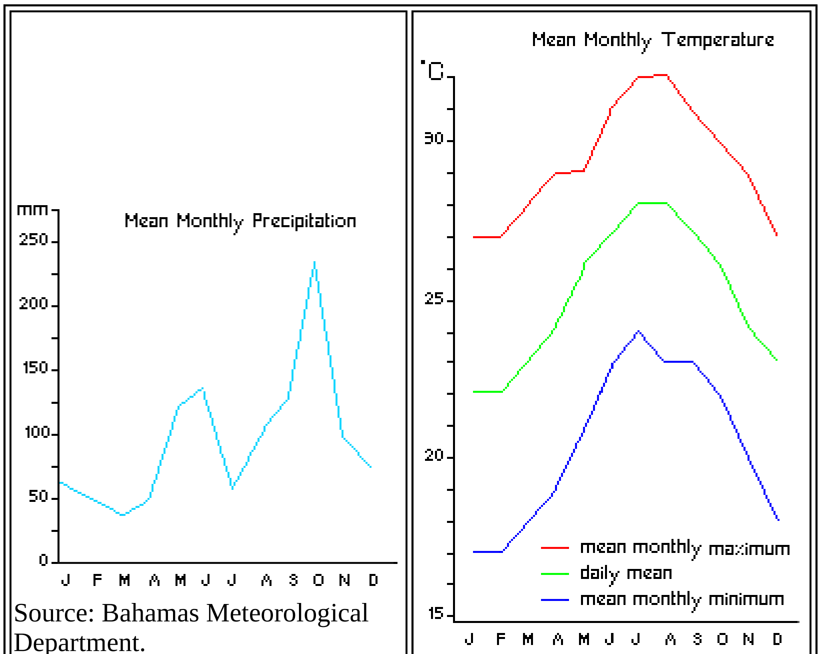


Fig. 2 Map of San Salvador, Bahamas (modified from Adams, 1980).

Weather and Climate

The moderating effect of the Antilles Current, part of the North Atlantic Gyre flowing past San Salvador, cools in the summer when temperatures range from 22 to 32°C, and warms in the winter when temperatures range from 17 to 27°C (Fig. 3). Annual rainfall in the Bahamas ranges from 140 cm on the northern islands to 70 cm on the southern; San Salvador, in the center, averages 100 cm. Cold fronts from the north bring winter rains; as front systems progress southward across warm waters of the banks, winds moderate and it rains in the northern Bahamas. The summer rains (May-September) result from convection; the larger northern islands create more convection currents and receive more rain in the summer. The second rainy season is from September to November; it is caused by tropical depressions, tropical storms, and hurricanes and may account for up to one quarter of the total annual rainfall. All these weather conditions are unpredictable and produce years either with less than average rainfall on San Salvador or heavy rains that wash away exposed soils. Bahamian soils generally are shallow, poorly developed, and retain very little water. Land disturbed by cultivation erodes very quickly, and the lightweight humus occasionally present washes away even more easily.



Source: Bahamas Meteorological Department.

Fig. 3. Precipitation and temperatures in the Bahamas (Shaklee, 1994).

Vegetation

San Salvador hosts only those species which can survive the hardships of poor soils, full sun, and periods of drought. Salt winds have led to 6 to 8% endemism in the plant communities. The vegetation of San Salvador is generally "scrub," with approximately 524 species of vascular plants in 265 genera, representing 96 families. Of these, about 60% are of Caribbean origin, approximately 30% are exotic Florida imports, and the rest are the 6 to 8% endemics (Smith, 1993).

As defined by Smith (1993), the vegetation of San Salvador can be categorized into three broad zones: coastal, nearshore, and inland. Coastal vegetation, in beach soil locations, is defined as the sea strand/sea oats community, consisting of sea oats (*Uniola*), sea grapes, and railroad vine, all of which assist in stabilization of the dunes. In rocky shore locations, the vegetation is 1 m high and includes *Mallotonia gnaphalodes* (bay lavender), *Erithalis diffusa* (black torch), *Scaevola plumieri* (ink berry), and

Gundlachia corymbosa (horse bush). The nearshore vegetation is located farther inland and is more protected from salt spray. This "coastal coppice" community consists of thicket and silverthatch or *Cocothrinax* shrub. The inland vegetation includes the mangrove community, the freshwater forests, the whiteland community, and the blackland community.

Mangrove swamps line the inland brackish lakes and are also found in protected basins such as Pigeon Creek and French Bay; the average height of the trees is 4 m. Vegetation is sparse in the mangrove flats; plants grow out of cracks in the rocks or in pits where soil has collected; average tree height is less than 0.3 m.

The blackland community is the most extensive plant community on the island. The soils are fertile light and dark loams. This community is characterized by dense vegetation with great species diversity but no dominant species.

Cultural History

It was probably San Salvador upon which Europeans (Columbus and his crew) first set foot in the New World. As described by Columbus in his log, the local Indians, called Lucayans, named the island Guanahani. These islands were completely depopulated by 1513 when Ponce de Leon passed through on his expedition to Florida. The Indians either were the victims of European diseases or were deported to the Greater Antilles as slaves. While the Spanish by-passed the Bahamas for more lucrative locations in their quest for gold and fertile lands, the British slowly took possession of this region, initially because of its strategic position on the perimeter of the Spanish colonies, and finally declared it a crown possession in 1629.

San Salvador was virtually unaffected by the encroachment of Europeans until American colonists loyal to Britain were forced from the United States and migrated to the Bahamas in 1783. They built impressive estates, using African slaves as a labor force. The "Loyalist Period" ended in 1834, when the Crown abolished slavery, capping an era that included many unsuccessful years for the planters because of drought, insect infestations, and soil depletion.

The descendants of San Salvador’s slaves continued experimenting with agriculture under a sharecropping system throughout the 1800s, raising first citrus and livestock, then pineapples, and finally sisal. All of these large-scale agricultural enterprises apparently came to the same end as those of the Loyalists. Records show that just prior to and after World War I, the lifestyle of San Salvador’s inhabitants was very poor, with everyone existing on subsistence farming.

Prosperity returned in 1951, with the establishment by the United States of a down-range missile-tracking base, a Coast Guard station, and a submarine tracking facility, all located on San Salvador. The majority of the US military departed the island in the late 1960s, leaving an infrastructure of well-constructed buildings, an electrical power station, and a 1,500 m paved airstrip. These facilities have all been put to good use by the Bahamas Government, now housing a Teachers’ Training College, a high school, and the Bahamian Field Station. Prosperity has continued for San Salvador with a short-lived land development company in the 1970s and now a recently opened Club Med resort.

The local resident population of less than 800 persons lives in several small communities around the perimeter of the island. The capital is Cockburn Town, on the west coast of San Salvador, which houses the local government offices of the Commissioner and police, the post office, a telecommunications center, a government clinic, and electrical utilities company. Electricity is available for all but the smallest of communities on the rural southeastern side of the island; telephone service extends only along the west and north coasts. United Estates, located on the northeastern side of San Salvador, is home to the majority of the island's population and is also the site of the Dixon Hill Lighthouse, a major navigation aid in this section of the Atlantic.

Nearshore Waters

The Antilles Current, as part of the North Atlantic Gyre, brings warm waters as well as flotsam to the coast of San Salvador. However, the strongest current affecting the nearshore waters of the island is the long-shore current running north-south along the western shore. This current is strongest in the winter months when waves are forced around the island by the northeasterly winds. In summer, winds shift to predominantly southeasterly, resulting in the progradation of many beaches. Although long-term data on nearshore water conditions are not available, various measurements have been collected since 1992 by Thomas McGrath as part of a nearshore coral monitoring project. Table 1 shows the 1993 mean values at different times of the year for air and water temperatures, pH, salinity, and dissolved oxygen at different sites around San Salvador. Secchi disk depth varied from 21 m in July 1993 to less than 11 m in November 1993.

Table 1. Mean values for nearshore waters (McGrath, 1993).

		Temperature (°C)			Salinity	Dissolved Oxygen
Reef Site		Air	Water	pH	‰	%
Rocky Point	March	23	24	8.3	3.5	6.0
	August	29	30	8.3	3.5	—
	November	26	25	8.3	3.5	6.0
Linday's Reef	March	24	24	8.3	3.5	6.0
	August	29	30	8.3	3.5	—
	November	26	25	8.3	3.5	6.0
Rice Bay	Site not established until August team					
	August	29	30	8.3	3.5	—
	November	26	25	8.3	3.5	6.0

Physical Measurements

The mangrove wetlands station is located in Blackwood Bay (Fig. 4); salinity and temperature measurements are taken 5 m offshore in order to obtain proper depth, interstitial water is measured 5 m landward of Quadrant 1. Seagrasses are sampled at two stations, the southern one in French Bay (Fig. 4), and the northern one in Grahams Harbor (Fig. 6), which also contains the climate sampling station. The coral reef station is located in Fernandez Bay (Fig. 8).

Mangrove Site

The mangrove site is located in an area called Blackwood Bay, part of a large embayment known as French Bay on the southern shore of San Salvador (Fig. 4).

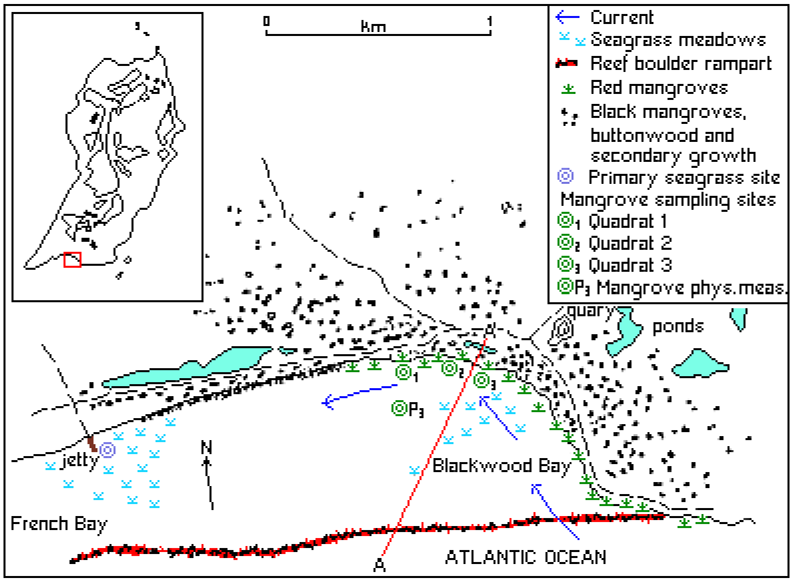
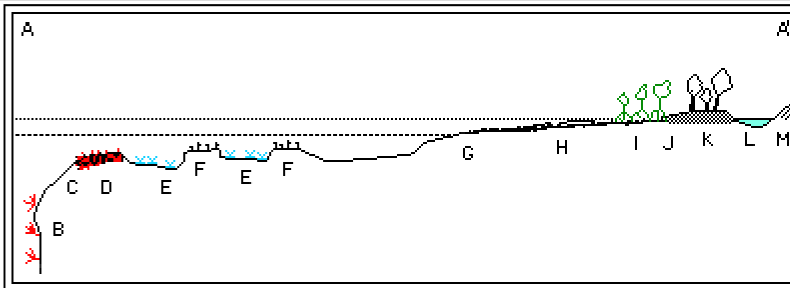


Fig. 4. Seagrass and mangrove sampling sites in southern San Salvador. Section A-A' is displayed in Fig. 5.

Blackwood Bay has a low-energy shoreline, due to the fringing reef to the south which dampens waves coming from the Atlantic. Seaward of the reef, as described by Pace (1986), the bay platform passes through spur and groove topography and plunges almost vertically to abyssal depths (Fig. 5). The reef is a boulder rampart composed of coral rubble, bound by encrusting *Millepora*. The quiet lagoon located landward of the reef is a shallow platform of bedrock with mud mounds upon which *Thalassia* is growing on the lower mounds, *Halodule* on the higher. *Thalassia* traps sediments, causing the mounds to grow taller until they are exposed at low tides. *Thalassia*, having a low tolerance for aerial exposure, is then replaced by *Halodule*.



B Vertical well with abundant coral
C Fore-reef slope - smooth spur - and - groove structure
D Reef crest - encrusting *Millepore* boulder rampart
E Sandy intermound area with *Thalassia*
F Halodule
G Intertidal zone
H Pleistocene bedrock with paleosol
I Red mangrove
J Coarse sand beach back berm
K Coral rubble - black mangrove and buttonwood
L Pond
M Pleistocene dune

Fig. 5. Subenvironments of Blackwood Bay (not to scale); location of section A to A' is shown in Fig. 4.

The platform shallows upward into an intertidal zone and continues to the mangroves of the upper intertidal zone. Red (*Rhizophora mangle*) and black (*Avicennia germinans*) mangroves are interspersed here, and the progression continues landward into white mangroves (*Laguncularia racemosa*) and buttonwood (*Conocarpus erectus*). Tree growth ends abruptly along a sandy beach ridge, or berm, which is basically treeless and covered primarily with dried *Thalassia* wrack along with *Sargassum* and swash debris. The berm parallels the shore and has all the appearance of an abandoned road; it represents the spring high tide and is marked with human detritus: bottles, styrofoam cups, plastic jugs, etc.

The sand beach extends 5 m inland to a gravel ridge of reef rubble and rock fragments. This ridge also parallels the coast and dips landward into several shallow ponds. Some of these ponds were dry in early April 1994, but there was evidence of flooding during the previous rainy season. The sand ridges probably represent successive storm beaches that were rapidly stabilized by mangroves (Kramer and Caputo, 1988). This may have been accelerated by tropical storms transporting materials to the gravel ridge and the shoreward sand berm.

The coastal red mangrove forest in Blackwood Bay is one of two habitats in which coastal mangroves exist on San Salvador; the other is in a lagoon/tidal flat complex in Snow Bay. The mangroves on San Salvador are typical of those on many of Bahamian islands. Mangroves are vulnerable to wave activity (Davies, 1980), which accounts for their absence on most of the coast, with the exception of these two low-energy environments. Lugo (1993) described the coastal mangroves of San Salvador as good examples of an ecosystem under stress. As he stated: "Short tree structure, small and rigid leaves, abundance of senescent leaves, vertical leaf orientation, thinned canopy, and high rates of albino seedlings are indicators of stress." Most of San Salvador’s mangrove communities would be classified as "scrub" or "dwarf" as a result of scarce fresh water from rainfall and runoff, low nutrient availability, generally poor tidal exchange, lack of good substrate, and exposure to strong winds.

The mangrove sampling quadrants in Blackwood Bay consist of three 10 x 10 m plots located parallel to the shoreline, entirely within the intertidal zone. The substrate consists of calcium carbonate gravels and sands, with concentrations of organic-rich mud as the density of the mangrove prop roots increase. This site supports the growth of taller and greater diameter-at-breast-height (dbh) red mangroves than are typically found at other coastal communities on San Salvador. This may be due to seepage from the freshwater ponds located just landward of the sandy beach ridge, and/or to protection from prevailing winds.

Mangrove Quadrant 1 is located at 74°31'36"W, 23°57'12"N, entirely within the intertidal zone, and consists solely of red mangroves. The quadrant contains trees with maximum heights of 4.5 m and 4 with diameters greater than 2.5 cm just above the top prop roots. Numerous seedlings (diameter less than 2.5 cm) are dispersed throughout the quadrant.

Quadrant 2 is located 250 m east of Quadrant 1 and contains 22 trees more than 2.5 cm in diameter. The tallest mangrove reaches 4.5 m. This quadrant of red mangroves contains one large buttonwood tree, which may be a leftover from a lower sea-level stand.

Quadrant 3 is adjacent to the eastern side of Quadrant 2 and also parallels the shoreline. It contains 5 massive red mangrove trees whose prolific prop roots cover the entire 10 m^2 quadrant. The circumference at the top of the last prop root averages 22 cm. There are no seedlings in this quadrant, although it has the densest growth of the three. Tree heights reach 5.5 m.

Seagrass Sites

Seagrass meadows occur in many marine coastal areas throughout the world (den Hartog, 1970). The diverse ecological roles played by seagrass in the marine environment have been well documented (Zieman, 1982; Thayer *et al*., 1984). These plants provide fixed carbon to other trophic levels through direct herbivory and microbially transformed detritus (Ogden, 1976; Lewis, 1986; Kenworthy *et al*., 1989). Seagrass also stabilizes marine sediments (Fonseca and Fisher, 1986; Fonseca, 1989) and provides a habitat for a variety of other organisms (Kenworthy *et al*., 1988).

A number of environmental factors can have a profound influence on the growth and distribution of seagrass species in general. Among these are light intensity and quality (Dennison, 1987), temperature (Bulthuis, 1987), sediment nutrient status (Short, 1987), current velocity (Fonseca and Kenworthy, 1987), and microbial interactions (Smith, 1987). One or a combination of these factors may also account for seagrass declines in various geographical regions (den Hartog, 1987; Short *et al*., 1987; Shepherd *et al*., 1989). Although some decline may be attributed to point-source pollution, it is difficult to determine if they are local or widespread due to the lack of long-term, coordinated monitoring studies at key locations. Seagrass meadows occur off the northern, southern, and eastern coasts of San Salvador. They are particularly extensive in somewhat protected areas in the south (French Bay) and in Grahams Harbor in the north. French Bay was selected as a primary CARICOMP site because it has the highest potential growth rates for *Thalassia*, caused by the winds and currents providing high levels of nutrients (Fig. 4). The French Bay site is located 10 m east of and parallel to the French Bay jetty, which runs at 337° to the shore. The seagrass meadows near the mangrove sites are often exposed during low tides, while those chosen as CARICOMP studies are never exposed. Grahams Harbor was selected as the secondary site since it is most typical of the seagrass meadows around San Salvador. Grahams Harbor is a windward, high-energy lagoon located on the northeastern coast of San Salvador at 24°07' 24"N, 74° 27'30"W (Fig. 6). This shallow basin is bounded by San Salvador to the south and North Point to the east. A barrier reef protects the lagoon along its northern margin; it is open to deeper waters to the west (Armstrong and Miller, 1988). Protected by fringing reefs, Grahams Harbor contains the most stable and the most extensive seagrass meadow around the island. It is buffered against extremes in water current velocity and is approximately 3 m deep at mean low tide. Beginning in 1988, samples of the seagrass beds in both French Bay and Grahams Harbor have been collected semiannually (mostly in July and December). The sampling protocol is given in Table 2 and resulting data are shown in Fig. 7.

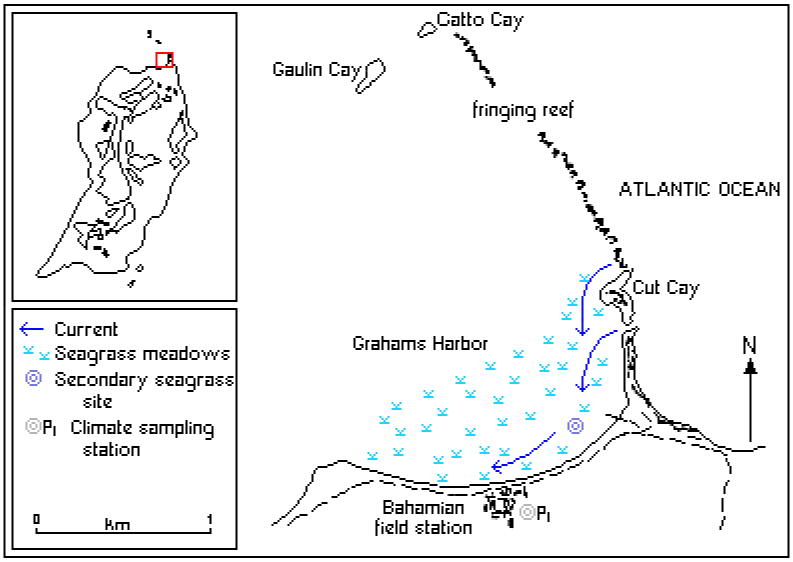
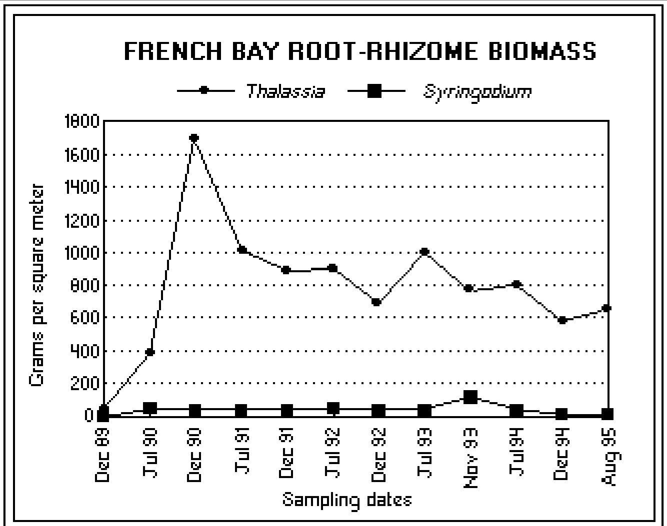


Fig. 6. Seagrass sampling site in Grahams Harbor, northern San Salvador, Bahamas.

Table 2. Six year seagrass sampling protocol, 1988-1993.				
Site		Dates Sampled	Number of Cores	Species Present
French Bay		1, 4-12	285	T, S
Grahams Harbor		1-12	930	T, S, H
Sampling Dates				Seagrasses
1 = 07/88	4 = 12/89	7 = 07/91	10 = 12/92	T = *Thalassia*
2 = 12/88	5 = 07/90	8 = 12/91	11 = 07/93	S = *Syringodium*
3 = 07/89	6 = 12/90	9 = 07/92	12 = 11/93	H = *Halodule*



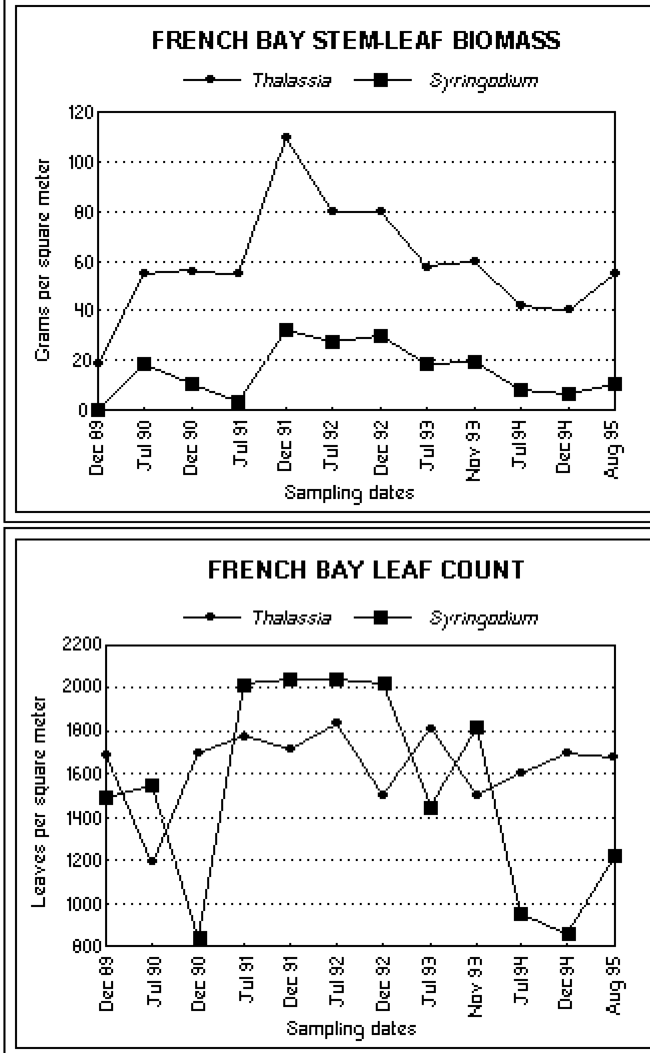
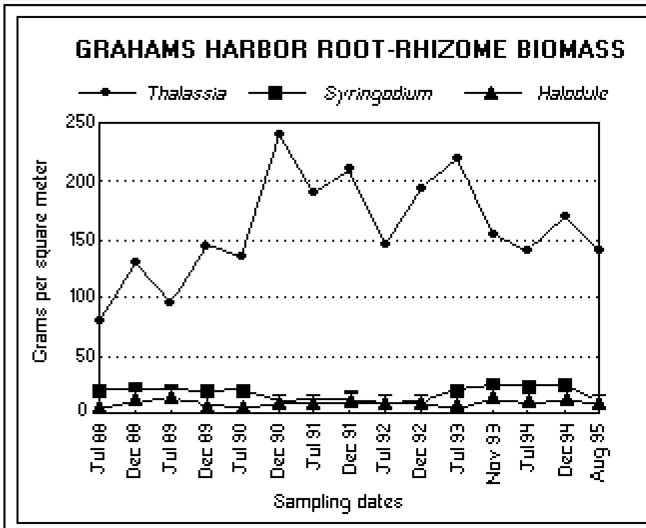


Fig. 7A. Seagrass analyses from the French Bay site, San Salvador, Bahamas.



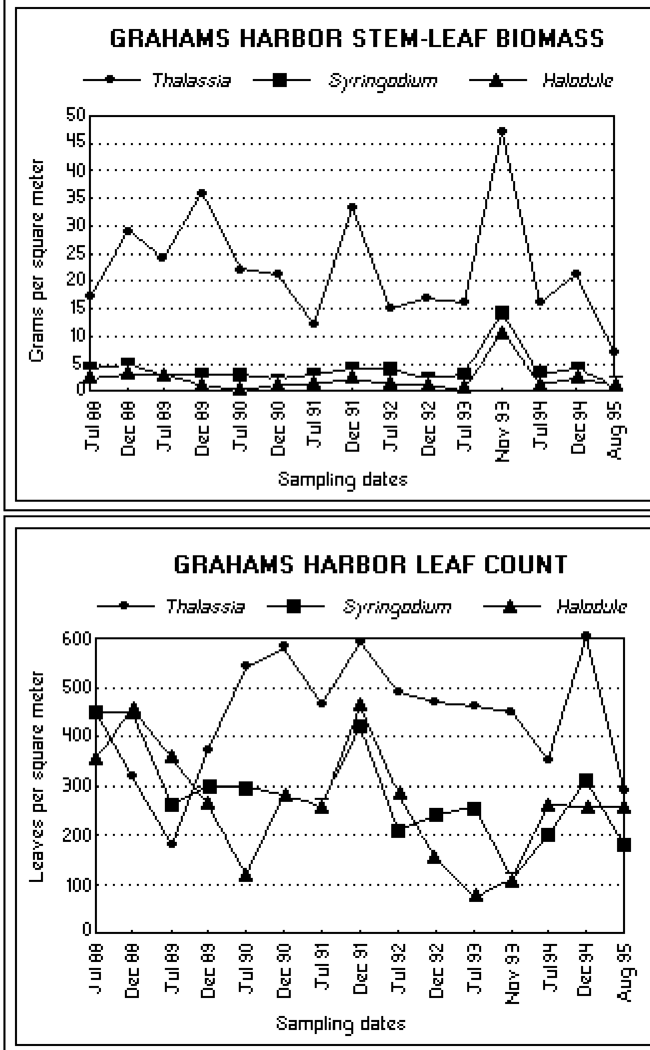


Fig. 7B. Seagrass analyses from the Graham Harbor site, San Salvador, Bahamas.

Seagrass cores were taken along 15 to 60 m transect lines at 2 m intervals with a 0.02 m^2 corer to a depth of 20 cm. Cores were placed in plastic bags upon removal from the substratum and washed free of adhering sediment on shore. Plants were then taken to the laboratory and washed in 0.1 N HCl, sorted by species and plant part, and leaf counts made. Contents of these cores were analyzed for seagrass species, above and below sediment biomass, and leaf count. The highest growth rates for *Thalassia* were observed at the French Bay site. Both *Thalassia* and *Syringodium* were found in more or less equal population densities (based on leaf counts), but biomass was much greater for *Thalassia*. Most of these measurements have remained stable over the past few years. At French Bay, huge mounds of seagrass wrack can be found on shore after heavy storms. At the Grahams Harbor site, population levels of *Syringodium* and *Halodule* were similar and relatively consistent until November 1993, when a significant increase was observed. Biomass measurements of *Thalassia* showed distinct seasonal fluctuations, with increases during the winter months.

Coral Reef Site

The coral reef site is located at 24°02'12"N, 74°31'57"W in Fernandez Bay, a gently curving shallow embayment along the west coast of San Salvador (Fig. 8). The bay is 4-5 km wide and extends from

Cockburn Town in the north to the Sugar Loaf Rocks in the south, a distance of 6-8 km. The dominant feature of the irregularly shaped shoreline is the presence of large blocks of lithified beach sand which extend from the upper reaches of the intertidal zone (splash zone) through the lower intertidal zone and into the sandy bottom of the bay. The intertidal extends approximately 25 m into Fernandez Bay, with a mean depth of 1.5 m at high tide. The beach rock shoreline of Fernandez Bay grades into a predominantly calcium carbonate sand and extends outward from the shore 400-1,500 m to the "dropoff" or "wall," with a gradual downward slope such that the water reaches a maximum depth of 15-25 m at the top of the wall (Fig. 9). Numerous patch reefs of considerable size (>5,000 m^2, 3-5 m high) appear randomly on the floor of the bay. Water visibility remains good most of the year, with an average Secchi depth of 60 m. The mean water temperature is 28°C.

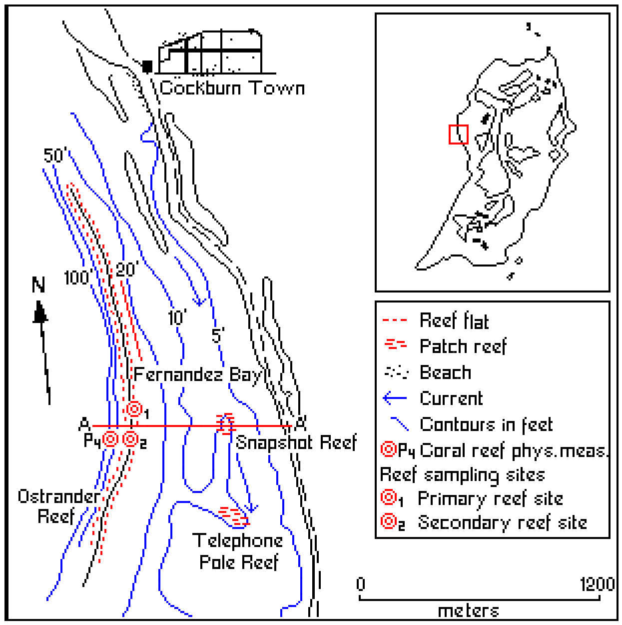
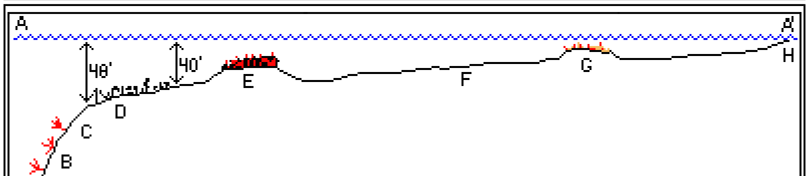


Fig. 8. Coral reef sampling site in Fernandez Bay, western coast of San Salvador, Bahamas. Section A-A' is displayed in Fig. 9.



B Vertical wall with coral

C Foreshore

D Reef flat or crest - *Montastraea* dominant species

E Reef with high percentage of *Millipora* and sponges interspersed with soft corals

F Sandy bottom

G Snapshot Reef with *Acropora cervicornis* and *Millepora*

H Rock shore dominated by *Echinometra viridis*

Fig. 9. Cross-section of Fernandez Bay (not to scale); location of section A-A' is shown in Fig. 8.

The wall is the predominant geological feature along the west coast of San Salvador Island; it has a near-vertical drop to 2,000-3,000 m. Running parallel to the shoreline and about 1,000 m from shore is a minor secondary dropoff that descends toward the top of the wall. The sampling site at Ostrander Reef is located within a band of coral reefs situated on top of the wall and extending a considerable distance both north and south of the site.

The patch reefs scattered across the sandy bottom of the bay contain at least 100 species of fish and many more species of invertebrates. Hard corals include *Acropora cervicornis, Porites astreoides, P. porites*, *Monastrea annularis*, *M. cavernosa*, and *Dichocoenia stokesii*. The same soft coral species as described above predominate. In addition, significant numbers of colonies of *Millepora* sp. occur at a higher density on these reefs than on the surrounding substrate. The predominant algal species on the patch reefs include *Padina* and *Turbinaria.*

Primary anthropogenic activities in the vicinity of the coral reef site include occasional recreational divers and fishermen that visit the wall. However, this site is not in close proximity to any regular dive sites or fishing spots. Consequently, little human impact on any aspect of this coral reef ecosystem is anticipated over the course of these studies. The coral reef site is located a considerable distance from the seagrass and mangrove sites, and little interaction between the three ecosystems can be expected.

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