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Mid-to-late Holocene sea level influence on coastal wetland development in Trinidad

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Abstract

Understanding how Holocene sea levels influenced coastal wetland development in the Caribbean will aid wetland management in the context of predicted sea level rise. Nine radiocarbon dates from the Maracas and Nariva Swamps on wave-dominated coasts from Trinidad, show sea level was –9 m approximately 7000 yr BP, and rose gradually to –2 m by 2000 yr BP. Since then there may have been isostatic readjustment. Wetlands developed with a transgression of dry upland habitats by rising seas and the facultative halophyte *Rhizophora* colonized the new brackish water environment. A freshwater plant community gradually replaced the *Rhizophora* as the marine influence decreased. At Maracas, higher sea levels caused wetland retreat as beach and lagoon habitats migrated inland. Sand ridges in Nariva Swamp indicate that, as in Maracas Swamp, sea level rise created beaches and lagoons, but that these landforms prograded as additional nearshore sediments were deposited. Basins were also filled with sediment delivered by streams that drain the watershed, and by mangrove peat accumulation.

1. Introduction

Coastal wetlands are transitional features between terrestrial and nearshore ecosystems that support a biota that is adapted to fluctuating salinities. In the Caribbean, wetlands in coastal locations support mangrove communities where the dominant species is *Rhizophora mangle* (red mangrove) which colonizes low-energy depositional environments of mud, sand and coral rock, where it traps marine and terrestrial sediment and also deposits organic matter that becomes peat. In this way, the basins are filled to a level consistent with the forces that dominate the local environment, e.g. sea levels, freshwater inputs or nearshore hydrography. Coastal wetlands, therefore, represent the final stage in the leveling of marine delta plains, invaded canyons, embayments and other physiographic depressions along the coast, and suggest coastal stability (Frey and Basan, 1985). Because *Rhizophora* grows best in the upper half of the inter-tidal range, sea level is a key determinant of mangrove wetland form and function. Recent attempts to predict how coastal wetlands might respond to the predicted rise in sea levels from "global warming" (Warrick et al., 1996) are inconclusive. Woodroffe (1990) suggests that factors such as shoreline topography, sediment sources and rate of supply, as well as the rate of sea level rise, would determine the final response and, using data from Australia, states that in some cases, mangroves may be able to keep up with an annual short-term sea level rise of 8–10 mm. Similarly, Ellison and Stoddart (1990), reviewing the stratigraphic record of mangrove ecosystems from several Pacific island locations conclude that "low islands" would be severely vulnerable to mangrove loss if the rate of sea level rise exceeds 12 cm per century. Less optimistic are Parkinson et al. (1994), who, using data mainly from Florida and Mexico, conclude that the present stability of mangroves might only remain if historical rates of sea level rise continued into the future. Caribbean data (Digerfeldt and Hendry, 1987; Rull, 1999) suggest that these rates have been of the order of 1 mm/yr over the past several millennia.

Sea levels have risen about 130 m since the Last Glacial Maximum (LGM) (Fairbanks, 1989). The release of glacial melt-water to the global ocean caused a rapid rise in sea levels from the LGM low-stand to approximately 10 m below present at 7000 yr BP. Subsequent sea level rise has been unpredictable with

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different rates at different locations demonstrating the uncertainties of isostatic re-adjustment, tectonic processes, and physiographic and landform changes. As a result, no single sea level curve for the mid-to-late Holocene is available. In the Caribbean, data from wetland peat and coral limestone deposits from Guadeloupe (Feller et al., 1990), Jamaica (Digerfeldt and Hendry, 1987) and Venezuela's Caribbean coast (Rull, 1999), show similarities in mid-to-late Holocene sea level change with a rapid rise (5 mm/yr) occurring between 8000 and 6000 yr BP, and a low rate of increase (0.25 mm/yr) after 4000 yr BP, with an intermediate rate from 6000 to 4000 yr BP. Since coastal wetlands in the Caribbean have physiographic, hydrodynamic, and biological differences, it is likely that a "one size fits all" approach to determining the response of coastal wetlands to sea level rise cannot be applied to the region. This paper describes the development of coastal wetlands in Trinidad, and shows that geomorphology and nearshore hydrography can influence the process. A sea-level curve for the mid-to-late Holocene is also presented.

2. Study sites

Trinidad lies on the northeastern South American continental shelf (Fig. 1a), and its nearshore environment and hydrography is influenced by discharge from the Orinoco River and the sweep of the Guiana Current. The island has four coasts that are each physiographically different. Mountains that reach elevations of 900 m back the north coast, while the east coast fronts a gently sloping axial depression and dissected peneplain complex. A complex of lower mountains and a dissected peneplain back the south coast, while expansive lowlands grade out to the west.

Maracas Bay and Nariva Swamps occupy physiographically different basins on Trinidad's wave-dominated north and east coasts, respectively. Like the upland, offshore marine slopes are steep along the north coast and gentle along the east coast. While both coasts experience continuous wave action, the gentle bathymetry of the east coast dampens wave energy at the shoreline, while higher wave energy is experienced on the north coast.

The Maracas Bay Swamp (Fig. 1b) occurs in a watershed that is bounded by Maracas Bay, a semi-circular embayment of the Caribbean Sea, and the mountains of the Northern Range, which reach elevations of 600 m and cause orographic precipitation. The wetland has a mainly shrub and herb flora with trees scattered along the watercourses. Mangroves are absent today, having been destroyed during settlement and road construction. A fifth-order dendritic river, which forms a lagoon landwards of the beach, drains the watershed. A sandbar at the river mouth restricts freshwater discharge to periods of high river flow. Salinity levels in the lower reaches of the tidal channel are seasonally variable, and during the rainy season when the sandbar is breached, it ranges between 2 ppt at low tide and 18 ppt at high tide (Ramcharan, 1981). The wetland is delimited from the sea by a sandy beach that rises approximately 2 m above mean sea level. Beach sediments are comprised of quartz particles with no discernible silt fraction. The Antilles Current and northerly winter swells influences the nearshore marine environment. Winds are mainly from the northeast, producing a northeast to southwest wave train that creates longshore drift. Sustained high winds and northerly swells during the Northern Hemispheric winter pile water onshore and move sediments offshore. The bay descends to 40 m at the entrance. A steep gradient change at 18 m suggests an early Holocene beach ridge. Suspended sediment levels in the bay are low, and reflect the steep offshore physiography, strong oceanic influence on nearshore waters and the resistance of parent rocks to rapid erosion.

Nariva Swamp (Fig. 1c) is an area of gentle, almost flat, topography that occupies an axial depression. Inland, a dissected peneplain borders the swamp and the highest hills (270 and 210 m high) lie some distance away to the northwest and north, respectively. More than 90% of the area lies below 5 m elevation, but several areas of higher ground are remnants of a shore-parallel sand bar that now lies inland from the present beach, while others are structurally part of the bordering peneplain. A belt of sand at the lower margins of the peneplain suggests a mid Holocene marine beach deposit. Several rivers discharge into the wetland to produce flooding during the wet season. Outflow from the swamp is via the Nariva River, which flows along a shore-parallel depression between sand bars. However, during heavy rains, floodwaters create another discharge point that is several kilometers north of the Nariva River mouth. The wetland flora is diverse and contains several distinct plant communities distributed along a salinity gradient. A mangrove fringe dominated by *Rhizophora mangle* is present along the coast, while inland areas support freshwater communities of herbs, shrubs and trees. The Guiana Current that transports sediments from the northeast South America continental shelf to the eastern Caribbean island arc influences the nearshore. As a result, suspended sediment levels in the nearshore waters are high and are due both to re-suspension of sediments from the shallow nearshore zone by breaking waves, and the delivery of new material (mainly silts and plant detritus). Dominant winds are from the east to northeast, and drive a wave train that is often parallel to the coast.

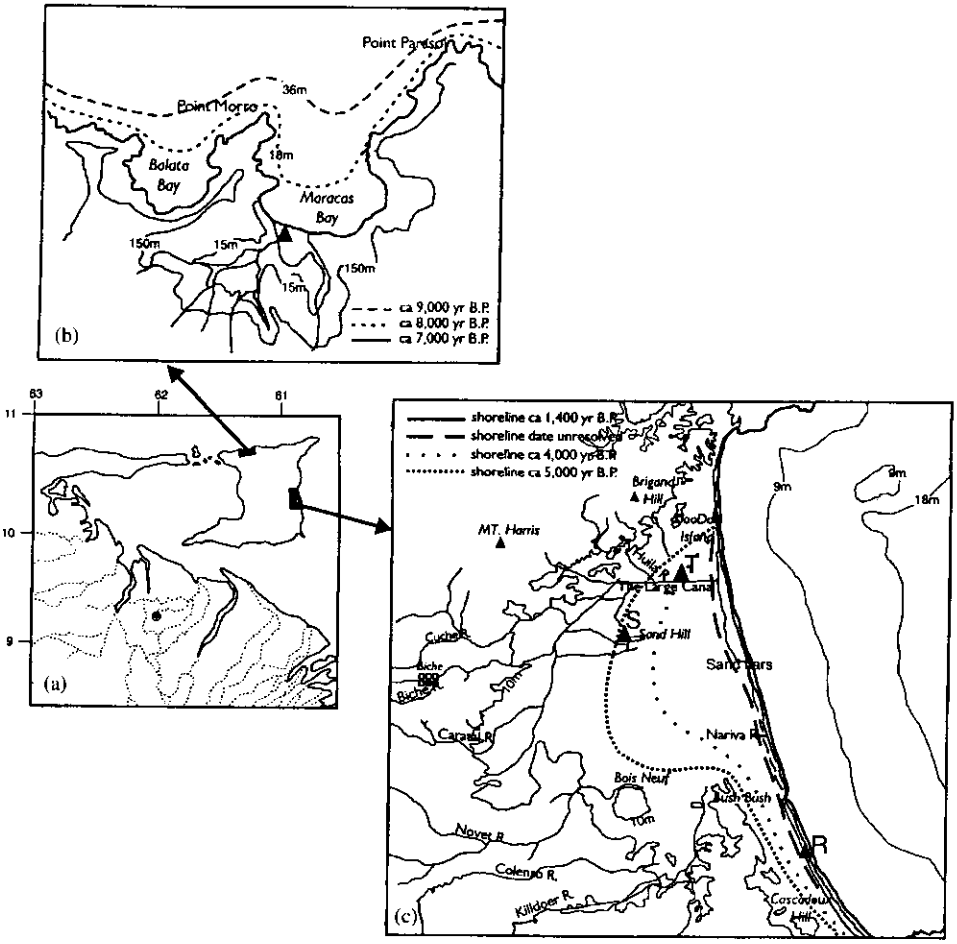

Fig. 1. Map of Trinidad showing its general location northeast of the Orinoco River delta (a), the locations of the Maracas (b) and Nariva swamps (c), and the positions of the cores taken from Maracas (designated by a star) and Nariva (designated by triangles). (Scale: Maracas 1:100,000, Nariva 1:200,000)

3. Methods

Four sediment cores were taken, one from the Maracas Swamp and three from Nariva Swamp with a modified Dachnowsky corer. The Maracas core (930 cm long) was lifted in 31 sections, while the Nariva cores (Sand Hill West– 780 cm), (Trough—630 cm), and (Raphael—170 cm) were lifted in 26, 21, and 6 sections, respectively. The Maracas core and the two longer Nariva cores were lifted from sites that experience seasonal flooding while the Nariva (Raphael) core does not. Fossil pollen concentrations follow Cwynar et al. (1979), and a minimum count of 200 grains was counted per sample. Pollen and spore identifications follow Huang (1971), Bartlett and Barghoorn (1973), and Roubik and Moreno (1991), and were verified with pollen reference collections at the Royal Ontario Museum (ROM), Toronto, and the University of the West Indies (UWI), in Trinidad. Beta Analytical (Beta) of Florida, the Rijksuniversiteit, Groningen (GRN), Netherlands, and the Department of Earth Sciences (BGS), Brock University, St. Catharines, Ontario, radiocarbon dated the core samples. Calibration of the radiocarbon dates follows Stuiver and Reimer (1993).

4. Results and discussion

4.1. Radiocarbon dating

Nine radiocarbon dates (six from Nariva and three from Maracas) (Table 1) time the physiographic development of the wetlands and the vegetation succession inferred in the summary pollen diagrams. The Maracas Swamp dates from 6700 yr BP and the Nariva from 5991 yr BP. The dates confirm the sequential deposition of the peat and organic sediments, and permit calculation of sediment deposition rates over time. These were variable, illustrating the effects of geomorphic, hydrographic and biological factors. In

Table 1
Radiocarbon dates of Maracas (M) and Nariva (N) Swamp sediments

Core and depth	C^{14} date (BP)	Calibrated age (BP)	Laboratory number	Sedimentation rate (mm/yr)
M 210–225	2930 +/−80	2980 +/− 80	BGS 2396	0.73
M 350–385	3960 +/− 60	4417 +/− 108	Beta 124614	1.04
M 805–840	5880 +/− 60	6700 +/− 68	Beta 124615	1.99
N(SHW) 200–225	2720 +/− 55	2815 +/− 50	GRN 9094	0.75
N(SHW) 475–525	4790 +/− 70	5532 +/− 64	GRN 9326	1.06
N(SHW) 638–693	5260 +/− 70	5991 +/− 59	GRN 9095	3.61
N(T) 160–180	555 +/− 45	546 +/− 30	GRN 9327	3.11
N(T) 525–590	4250 +/− 70	4832 +/− 71	GRN 9096	0.90
N(R) 125–145	1360 +/− 50	1288 +/− 25	GRN 9097	1.01

Note: M—Maracas, N—Nariva, SHW—Sand Hill West, T—Trough, R—Raphael.

Nariva, the data shows a seaward migration of mangroves with the basal dates of mangrove peat in the Trough (4832 yr BP) and Raphael (1288 yr BP) cores following the peak mangrove presence in the Sand Hill West core (5532 yr BP).

4.2. Sedimentation

Sediments in the cores include sand, muds and peat (Fig. 2). Loss-on-Ignition analysis of the Maracas core (Ramcharan and McAndrews, 2003) shows basal sand and high silicate levels up to 4 m (4000 yr BP) that was followed by high levels of organic matter. This suggests that the silicate was deposited under high-energy marine conditions while the organic matter was deposited under low-energy fluvial and wetland conditions. This change in sediment type suggests the building of a beach barrier at the shoreface to delimit the wetland. The Nariva cores show different sediment compositions. The Sand Hill West core shows basal clay followed by mangrove peat and mud, while both the Trough and Raphael cores show basal sand. In the Trough core this is followed by peat and mud while the Raphael core contains peat. Mud in the Sand Hill West and Trough cores confirm deposition under fluvial conditions that still exist at present, while the dominance of peat in the Raphael core suggests a low energy, high water table, environment.

Overall sedimentation rates in the two wetlands are close (Table 1), 1.23 mm/yr at Maracas and 1.11 mm/yr at Nariva. However, several intervals of variable rates can be recognized. Over the past 3000 yr, rates averaged 0.74 mm/yr in the upper levels of the Maracas and Sand Hill West cores, while the rate observed during the period 7000–3000 yr. BP was higher (1.62 mm/yr at Maracas and 1.32 mm/yr at Sand Hill West). Several anomalies to this overall rate are shown. The high (3.61 mm/yr) rate in the lower levels of the Sand Hill West core suggests high fluvial and sediment influx from the adjacent watershed combined with mangrove peat deposition, while the rapid sedimentation observed in the upper levels of the Trough core (3.11 mm/yr) may be associated with disturbance for agriculture. The rate of peat formation in the Raphael core suggests that sea level rose at an average rate of approximately 1 mm/yr during the past millennium.

4.3. Fossil pollen record

Summary fossil pollen diagrams (Fig. 2) describe the sequence of floristic change in the wetlands. In the Maracas Swamp (Fig. 2a), *Rhizophora* dominated the fossil pollen record over the past 7000 yr, thereby indicating continuous presence at the site. Tree fern spores (*Cyathea* and *Cnemidaria*) indicate the proximity of a humid forest, and Cyperaceae and *Polypodium* spores in the upper levels indicate the recent establishment of freshwater conditions.

Conversely, the Nariva cores illustrate a different sequence of vegetation change (Figs. 2b–d). The Sand Hill West core (Fig. 1c) shows the early displacement of the terrestrial flora by *Rhizophora* at 6000 yr BP with a peak presence at 4700 yr BP followed by a significant decline at 4000 yr BP. A brackish water-tolerant plant community with *Pterocarpus officinalis* followed the *Rhizophora* decline, and later succession by a shrubby/herbaceous freshwater flora at 2700 yr BP completes the transition from a marine influenced brackish water habitat to freshwater habitat.

A pollen diagram from the core "Trough" (Fig. 2c) shows *Rhizophora* dominating the fossil record from 4800 yr BP and continuing until 550 yr BP when a freshwater flora dominated by grasses, sedges, and ferns, abruptly replaces it. A third pollen diagram from the core "Raphael" (Fig. 2d) contains a 1300 yr record and shows continuous dominance by *Rhizophora*.

Collectively, these results illustrate the seaward migration of the brackishwater coastal environment (represented by *Rhizophora*) and the development of a freshwater habitat landwards. Considering the importance of salinity to the optimum development of *Rhizophora*, it is suggested that the decline of

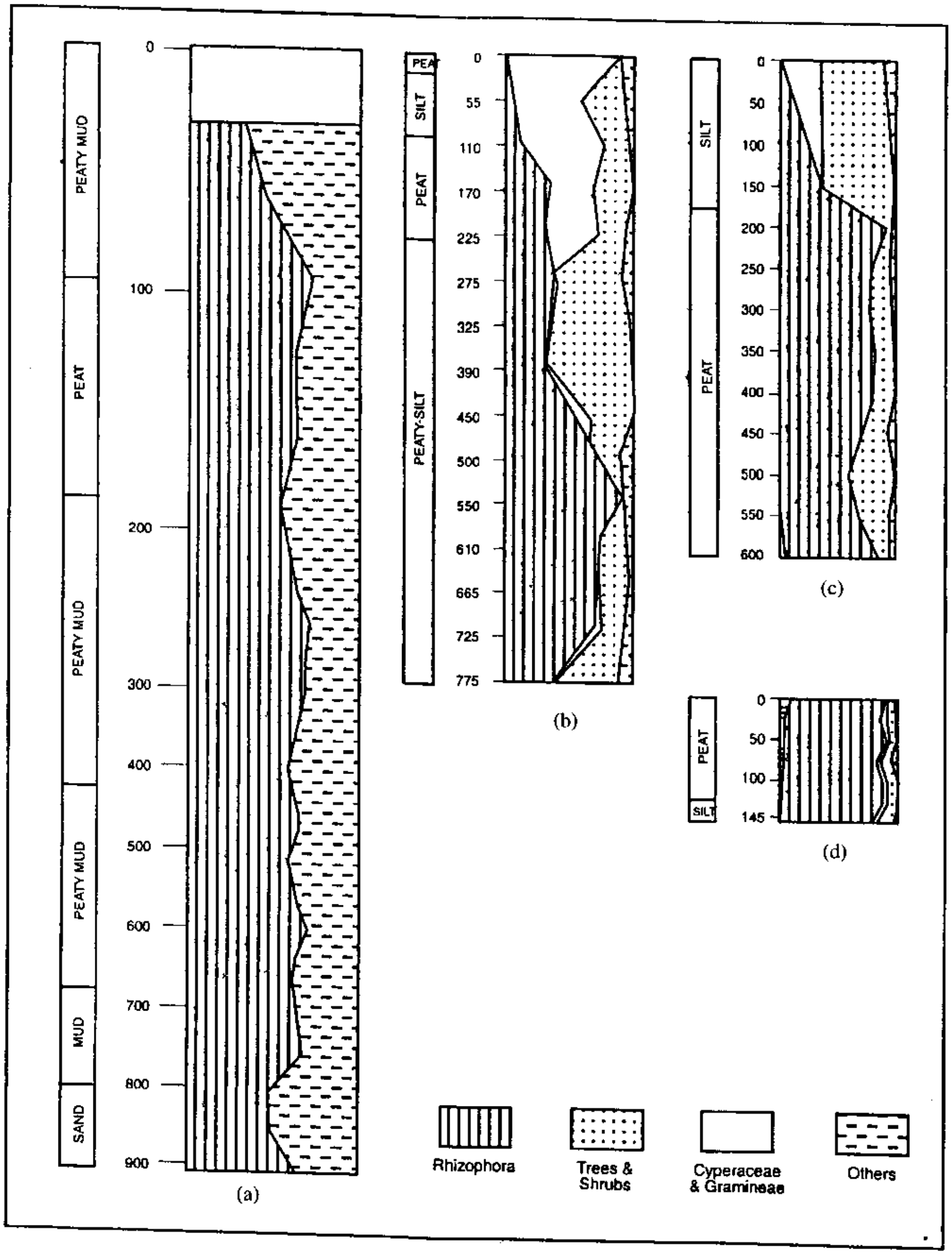

Fig. 2. Summary fossil pollen diagrams of the cores Maracas (a), Sand Hill West (b), Trough (c), and Raphael (d). Depths are in centimeters and "X" axis represents percentage representation of the different plant groups.

Rhizophora in the landward areas was due to tidal and salinity limitations in the wetland basin that were caused by the development of new geomorphic features in the nearshore.

4.4. Sea-level change

As radiocarbon dates obtained from mangrove peat and muds provide a good indication of sea level at the time of deposition (Ellison, 1986) the radiocarbon data presented here provide a basis for developing a mid-to-late Holocene sea-level curve for Trinidad (Fig. 3). The main features of this curve are the slow rate of sea-level rise over the past 3000 yr that followed a more rapid rate of rise before 5000 yr, and a transitional period at around 4000 yr BP. This curve is similar to curves for Venezuela (Rull, 1999) and Jamaica (Digerfeldt and Hendry, 1987), which show a decrease in the rate of sea level rise after 7000 yr BP. Collectively, these data suggest that the wider Caribbean may have experienced similar sea-level change conditions over the mid-to-late Holocene.

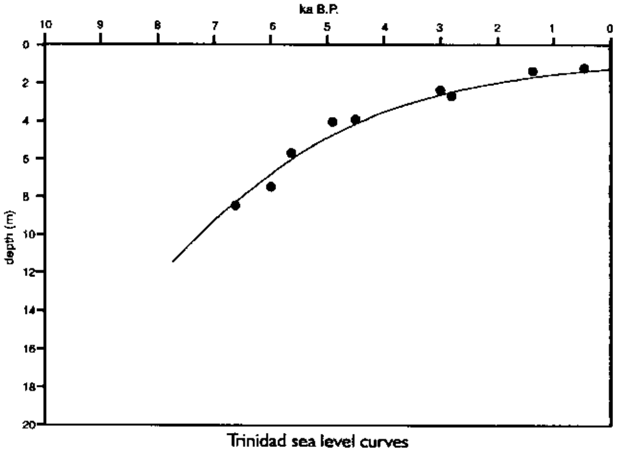

Fig. 3. Mid-to-late Holocene sea level curve for Trinidad, West Indies using data from mangrove peat and muds. Dates were calibrated (Stuiver and Reimer, 1993).

5. Conclusion

The combined results of sediment, radiocarbon and fossil pollen analysis document the physical and biological change that began at inland locations as sea level rose during the mid-Holocene and altered near-shore hydrodynamics to facilitate the development of wetlands at coastal sites. This is consistent with results from other Caribbean sites (Jamaica, Digerfeldt and Hendry, 1987) and Venezuela (Rull, 1999) that show coastal wetlands being established at around 7000 yr BP. However, both sites in this study illustrate differences in the development sequence.

At Maracas, the rapid deposition of marine sediments (Ramcharan and McAndrews, 2003) between 7000 yr BP and 4000 yr BP was followed by a slower rate of deposition of organic mud and peat mixed with silicates and carbonates under gentler wave or fluvial conditions. The low pollen counts of *Rhizophora* during the period 7000 to 4000 yr BP suggests that the species occurred as a fringe community (van der Hammen, 1963) that became more expansive and produced greater amounts of pollen. This suggests that as sea levels rose, shore-normal and shore-parallel currents combined with bay physiography and the sediment budget to restrict the marine influence at the site and establish a more stable brackish water habitat that allowed the species to form an expansive community.

The record from Nariva also shows the transgression of dryland habitats as sea levels rose, and the establishment of a *Rhizophora* community. The sequential decline in the basal ages of the *Rhizophora* communities in the Nariva cores indicates shoreline progradation accompanied by migration of the *Rhizophora* community. Today, *Rhizophora* only occurs as a narrow fringe along the banks of the Nariva River and the basal date of 1288 yr BP in the Raphael core confirms the spatial movement of the shoreline of a distance of approximately 4 km over a 4000 yr period.

Shore parallel and shore normal currents work to regulate sediment distribution in the nearshore coastal area. On sediment-starved coasts, these processes result in shoreline erosion as wave energy is expended mainly on the hard surfaces fronting the shoreline rather than on expansive beach deposits or shallow bathymetry. However, where sufficient sediments occur in nearshore waters, the processes allow for sediment deposition in the form of sand bars and beaches, features that would reduce marine flooding as sea levels rose, and allow freshwater to accumulate landwards. The Maracas and Nariva sites illustrate these two features. As the rate of sea level rise in the mid-to-late Holocene was slower than in the early Holocene, and because the gentle physiographic gradient of the axial depression that contains the Nariva Swamp extends some distance offshore, the sustained action of these coastal processes would continue to create new shorelines even further offshore, thereby extending the wetland and creating a larger freshwater habitat that could then be colonized by a wider range of wetland plant species. Conversely, at Maracas, the different hydrographic features have allowed for shoreline retreat.

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