Holocene Development of Coastal Wetland at Maracas Bay, Trinidad, West Indies

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**ABSTRACT**


Studies on Holocene sea level change along the coast of northeastern South America can assist in understanding how the region’s coastal environments might respond to future sea level change. A freshwater wetland along a wave-dominated pocket bay yielded a 980-cm-long sediment core, which records sediment and vegetation change over the past 7000 years. Above basal sand, peaty mud \(<450\)-cm depth is overlain by mangrove peat extending \(<100\) cm and dark, peaty freshwater mud \(<35\) cm. Three radiocarbon dates provide a chronological framework and estimate rates of sedimentation. Loss-on-ignition analysis shows a shift from basal silicates to organic matter at 4000 YBP that indicates a reduction in marine influences and the establishment of a mangrove habitat. *Rhizophora* dominates the fossil pollen record. Spores of the tree ferns *Cnemidaria* and *Cyathea* indicate an adjacent humid forest whereas *Polypodium*-type spores and Cyperaceae pollen in the upper part of the core indicate freshwater conditions. The reduction in the sedimentation rate from 1.99 mm y\(^{-1}\) before 4000 YBP to 1.05 mm y\(^{-1}\) after 4000 YBP reflects reduced delivery of external sediments to the wetland and the addition of autochthonous organic matter, whereas the further reduction to 0.61 mm y\(^{-1}\) after 3000 YBP suggests declining rates of peat formation and reduced sediment inputs from the forested watershed. We conclude that the stratigraphy and plant succession was the result of long-term building of a beach ridge. Brackish water peat and then freshwater peat formed behind the bar.

**ADDITIONAL INDEX WORDS:** Holocene, sea level, Caribbean, mangroves, Rhizophora.

**INTRODUCTION**

Sediments from coastal wetlands are both organic and inorganic, reflecting autochthonous (*in situ*) and allochthonous (transported) origins. Organic matter is derived from local vegetation and reflects sea level change because these sediments accumulate in the upper half of the tidal range (Ellison, 1989; Rull, Vegas-Villarubia, and Espinoza de Pernia, 1999). Waves, streams, or wind transport inorganic sediments, comprising terrigenous materials or coastal and marine sediments, to the area. Microfossils in cores from coastal wetlands have been used to describe mid- to late-Holocene sea level change (Digerfeldt and Hendry, 1987; Ellison, 1989; Woodruffe, 1981), flora history (Ramcharan, 1980), and human impact (Rull, Vegas-Villarubia, and Espinoza de Pernia, 1999). Holocene sea level curves for the Caribbean suggest that modern eustatic sea level was reached approximately 6000 years ago (Digerfeldt and Hendry, 1987; Rull, Vegas-Villarubia, and Espinoza de Pernia, 1999; Wells, 2001), but isostasy may have caused local fluctuations since then. To describe regional climatic change during the Holocene from lake sediments, Hodel et al. (1991) used oxygen isotope measurements and pollen zonation from Lake Miragoane, in southern Haiti, and insolation at 10° N, and showed drought at the beginning of the Holocene, followed by a moist climate between 8000 YBP and 3200 YBP, and later, followed by a drier climate to the present. This change in climate in Haiti at 3200 YBP coincides with a warm humid phase in Venezuela (Rull, Vegas-Villarubia, and Espinoza de Pernia, 1999) and for tropical South America, which dates approximately 4000 YBP.

Current evidence indicates that coastal wetlands in the Caribbean date from the mid-Holocene. On tide-dominated coasts, these wetlands remain open to the sea and experience unrestricted tidal flushing and freshwater flows, factors that allow for expansive development of mangroves and associated freshwater wetland habitats. *Rhizophora*, the most prolific producer of pollen and organic matter in mangroves, develops optimally in these conditions. Because sediment accumulation occurs in the upper half of the tidal range, sediments

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taken from mangroves that are open to tidal flushing are good indicators of sea level changes. Conversely, mangrove sediments that are deposited under nontidal conditions reflect changes other than those caused by sea levels. Wetlands that occur on wave-dominated coasts present different features such as restrictions on tidal exchange, clear physical delimitation from the sea, the restriction of mangroves to the riverbanks and flood areas, and the establishment of expansive herbaceous marshes in the interfluve areas (OERTEL et al., 1992). Sediments taken from these areas allow for an understanding of sea level change that is generally restricted to the period when there were open connections between the land and sea. On the other hand, these areas illustrate the role that coastal processes can play in wetland formation, and provide good evidence for vegetation succession resulting from influences such as human settlement and paleoclimatic change. Tide-dominated wetlands are subject to advance and retreat as sea levels change or as sediment input to the habitat increases; however, wave-dominated wetlands are less vulnerable to erosion as they are protected by beaches or beach ridges.

Coastal wetlands in Jamaica date from the mid-Holocene and reflect local changes in sea levels (DIERGELIDT and HENDRY, 1987). However, sedimentation rates are variable and are influenced by factors such as tectonic movement, rates of sea level change, richness of a sediment source, degree of tidal flushing, basin physiography, precipitation levels, and net primary production. Given the physiographic diversity that now exists in the Caribbean, it is important to study different sites and a range of different environmental conditions before attempting to develop regional scenarios of wetland development and to predict possible responses to future sea level change. In this article, we present evidence of floristic and habitat change from the north coast of Trinidad, West Indies, and their changes in coastal geomorphology based on pollen analysis, lithology, and sedimentation rates. We suggest that, in the context of near-stable sea levels, coastal processes may be more influential in determining modern wetland features in the Caribbean. A mid- to late-Holocene sea level curve developed for Venezuela’s Caribbean coast (RULL, VEGAS-VILARUBIA, and ESPINOZA DE FERNIA, 1999) is applied to the site. This curve was developed using radiocarbon data that was obtained from a mix of sediments, including mangrove and other coastal peats and coral or massive carbonates, and shows a rapid rise in sea levels up to 8000 YBP, with a slower rate between 8000 and 4000 YBP, and stable levels after 3000 YBP. This article is part of a broader study on the response of coastal environments in the southern Caribbean to mid- to late-Holocene changes in sea level.

THE STUDY SITE

The Maracas Bay swamp occupies an enclosed basin on Trinidad’s north coast at latitude 10°45’ and longitude 60°25’ (Figure 1). The Maracas watershed is bounded by Maracas Bay, a semicircular embayment of the Caribbean Sea on the north, and the mountains of the Northern Range on the south. Similar embayments along the north coast do not support wetlands today. The beach berm at Maracas Bay is approximately 1 m above the wetland surface and restricts marine influences to the wetlands except in times of wave overtopping and tidal extremes. Landward, higher elevations that reach <900 m, influence orographic precipitation. These steep mountain slopes support dense lower montane forest communities at the higher elevations, old growth plantations of coffee and cocoa at mid to lower elevations, and weeds and shrubby regrowth at the lower elevations adjacent to the wetland.

The forest community on the mountain slopes is diverse, with Carapa guianensis, Guarea glabra, Sterculia pruriens, Cordia alliodora, Byssonima spicata, Pouteria guianensis, Ficus nympheifolia, Ficus trigonata, Eschweileria sublandulosa, and Tapirira guianensis being the most common species (SINGH, 2000). The wetland zone of the watershed has an expansive shrub and herb flora with trees scattered along the watercourses. The vegetation generally reflects freshwater conditions, and the most common trees, which are also known to tolerate brackish water habitats, are Crudia glaberrima, Pterocarpus officinalis, Thespesia populnea, Terminalia catappa, and Erythrina fusca. Shrubs include Montrichardia arboreascens, Acrostichum aureum, and Ludwigia sp. and are associated with several species of grasses and sedges. Mangroves are absent today, probably because of the restricted tidal flushing and the absence of substrates that facilitate the establishment of Rhizophora propagules. Other mangrove species, such as Laguncularia racemosa and Avicennia germinans, that commonly occur in other wetlands in Trinidad are absent from the north coast.

Annual rainfall of 1500- to 3000-mm per year (1976–1998) is distributed over a long wet season (May to December) and a short dry season (January to April). Precipitation is influenced by local mountains, the Intertropical Convergence, and tropical waves, which are frequent between June and October. A fifth-order dendritic stream, the Grand Fond River, which forms a lagoon landwards of the beach, drains the watershed. Sandbars at the river mouth restrict 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, salinity ranges between 2 ppt at low tide and 18 ppt at high tide (RAMCHARAN, 1981).

Winds are mainly from the northeast, producing a northeast to southwest wave train that creates a marked longshore drift. Sustained high winds and northerly swells during the northern hemispheric winter pile water onshore and move sediments offshore. The bay is deep to approximately 40 m at the entrance. A steep gradient change at 18 m suggests an early to mid-Holocene beach ridge.

MATERIALS AND METHODS

A 980-cm long sediment core was retrieved with a Dachowsky sampler. Sediments graded upward from sand to silt to peat. The lowest 15 cm of sand represents marine beach before wetland formation. This was overlaid by peaty mud <450 cm, with peat extending <100 cm; dark peaty mud, presumably freshwater in origin, extends <35 cm. The top 35 cm contained nonwetland sediments, probably from road
building. Wood fragments were scattered throughout the core.

Twenty-six samples were analyzed by loss on ignition (LOI) following Dean (1974) and by fossil pollen analysis following the preparation technique of Cwynar, Burden, and McAndrews (1979). The pollen concentrate was mounted in silicone oil, and pollen analysis was done with a compound microscope at 300× or 500× magnification. Fossil pollen was compared with reference pollen at the Royal Ontario Museum and to Rouh and Moreno (1991). At least 200 pollen grains and fern spores were identified in each sample. Sediment from three levels was radiocarbon dated and rates of

Figure 1. Map of Trinidad showing its general location within the Caribbean (a), northeast of the Orinoco River delta (b), the location of the Maracas Swamp, and (c) the position of the core taken from Maracas (designated by a star). Dashed lines infer past shorelines.
Table 1. Radiocarbon dates of Maracas Swamp sediments. These were provided by Beta Analytical (Beta) of Miami, Florida, and the Department of Geochronological Sciences (DGS) at Brock University in St. Catharines, Ontario, Canada. These were calibrated to arrive at chronological dates.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Radiocarbon Date BP</th>
<th>Calibrated Age BP</th>
<th>Lab No.</th>
<th>Sedimentation Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–35</td>
<td>Assumed to be zero</td>
<td>Assumed to be zero</td>
<td>None</td>
<td>0.61 mm/y</td>
</tr>
<tr>
<td>210–225</td>
<td>2980 ± 80</td>
<td>2980 ± 80</td>
<td>BGS 2396</td>
<td>1.05 mm/y</td>
</tr>
<tr>
<td>350–385</td>
<td>3960 ± 60</td>
<td>4417 + 102, −114</td>
<td>Beta 124614</td>
<td>1.99 mm/y</td>
</tr>
<tr>
<td>805–840</td>
<td>5880 ± 60</td>
<td>6700 + 77, −59</td>
<td>Beta 124615</td>
<td>Not calculated</td>
</tr>
</tbody>
</table>

sedimentation calculated between the dates; the sediment surface was assumed to be zero YBP.

RESULTS

Radiocarbon dates establish a chronology for sedimentation, vegetation history, and sea level change (Table 1, Figure 2) over the past 7000 years. Loss on ignition shows peak silicate percentages at the base, but these decline after 4000 YBP (Figure 2). This indicates that marine allochthonous sedimentation dominated at the site between 4000 and 7000 YBP, implying a strong connection with the bay, and that coastal processes strongly influenced wetland conditions. The sand in the lower section of the core was deposited under marine conditions in which wind and wave move materials through both shore normal and shore parallel gradients. This high level of silicate contrasts with the high organic matter percentages after 4000 YBP, which suggest a more enclosed habitat with reduced marine influence and greater production and retention of organic matter. In this low-energy environment, a more stable community developed, probably behind a sand barrier that separated the newly formed wetland from the bay. Terrestrial influences would have increased. Carbonate levels are consistently low, but small peaks between 6000 and 4000 YBP suggest either marine molluscs, such as Donax, that are now common on Trinidad’s beaches, or the precipitation of carbonates from marine waters in the intertidal zone. The high silicate in the upper samples may suggest a combination of factors including land clearance for settlement and agriculture and infrastructure development.

The radiocarbon analysis shows variable sedimentation rates (Table 1), whereas the LOI analyses illustrate sediment types at different stages in the wetland’s development. Because the base of the core could not be dated, we estimate the date of initial sand deposition and subsequent wetland formation to have occurred approximately 7000 years ago. The sedimentation rate varies with the sediment type and parallels the change from dark-brown, peaty mud before 4000 YBP to peat afterwards. The deposition rate between 6700

![Maracas Bay](image)

Figure 2. A percentage diagram showing loss on ignition and pollen analysis results. They were drawn using CANPLOT (Campbell and McAndrews, 1992).
YBP and 4410 YBP is 1.99 mm y⁻¹. Between 4410 YBP and 2980 YBP, the rate decreases to 1.05 mm y⁻¹, and for the period 2980 YBP until the present, 0.61 mm y⁻¹. This indicates a reduction in the input of marine sediment and the addition of terrigenous mineral sediment and organic matter to the sediment. The reduced sedimentation rate after 2980 YBP indicates lower precipitation and sediment transport in the watershed and the decline of mangrove peat formation.

Palyngmorphs were well preserved in the core. The fossil pollen record is dominated by *Rhizophora*, which ranges between 95% and 60%. At the top of the core, *Rhizophora* contributes only 40% of the pollen sum. There are ferns and unidentified dicots throughout, suggesting a rainforest source and water transport. *Rhizophora* is a prolific pollen producer and is always overrepresented in the fossil record. Pollen over 45% derives from *in situ* *Rhizophora* communities whereas values less than 45% are thought to represent habitats that fringe the *Rhizophora* zone (van der Hammen, 1963). Tropical rainforest trees tend to be underrepresented in the fossil pollen record because species flower intermittently (Richard, 1996); prolific flowering does not occur annually and most species are insect pollinated.

Despite this dominance by *Rhizophora*, the fossil record displays four zones (Figure 2). Zone 1 occupies the basal sand and silty mud and has relatively low *Rhizophora*, with abundant dicots (probably trees), and ferns (*Cnemidaria, Cyatheae, Polypodium*). This assemblage indicates that the habitat was a cayon, with *Rhizophora* as a fringe community, and that the forest communities were contributing relatively more pollen and spores. Mangroves are excluded from the site today, probably because of the slight tidal flushing and the absence of mud flats.

Zone 2, from approximately 6000 to 3000 YBP, occupies peaty mud sediments. It shows high and fluctuating *Rhizophora*, lower dicots, and abundant fern spores from the genera *Cnemidaria, Cyatheae*, and *Polypodium*. The assemblage suggests that this was a *Rhizophora* community near forest and herbaceous communities. *Rhizophora* would have been concentrated along the tidal reaches of the waterways and newly emergent mudflats and sandbars. Its prolific pollen production would have masked that from the forest flora. The absence of other common wetland plants from the fossil record suggests that the freshwater wetland was sparse, whereas the occasional occurrences of *Acrostichum* indicate disturbance, possibly from mangrove “dieback.” High levels of siltate until 4000 YBP suggest that the habitat was open to the sea and that both terrigenous and marine sediment were being deposited.

The period 3000–1000 YBP (Zone 3) began with reduced *Rhizophora*, which was followed by a peak (90%) at 1500 YBP. *Cnemidaria* and *Cyatheae* spores are present with sustained levels of *Polypodium* spores and other taxa such as Cyperaceae, *Acrostichum*, and a “monolete reticulate” spore type. Cyperaceae pollen indicates a freshwater herbaceous wetland habitat, which would have also supported grasses, shrubs, and herbs that remain unidentified in the record. *Acrostichum* suggests a disturbance in the mangrove habitat, possibly through the onset of reduced water levels and the absence of habitats that are suitable for mangrove regeneration. The sudden decline of *Rhizophora* at 3000 YBP was complemented by increased dicot pollen, suggesting an episodic event that might have damaged the forest, which later experienced a resurgence of the community. The change in sediment type from peaty mud to peat indicates reduced amounts of sediments transported from the adjacent areas as well as increased peat formation in a low-energy environment.

The upper-sediment unit records the past 1000 years (Zone 4) and shows a reduction in *Rhizophora* pollen that is associated with a rise in other angiosperm pollen, as well as increases in the presence of spores from shrub-herbaceous ferns. This suggests the continued presence of freshwater conditions that support common wetland plants such as grasses, sedges, *Typha*, and ferns. *Cyatheae* indicates that forest is near, whereas *Hippomane* pollen indicates a coastal woodland. In the Caribbean, *Hippomane mancinella* is a common tree, which, together with *Coccoloba uvifera*, *Chrysobalanus icaco*, *Terminalia catappa*, and several others, form woodlands in dry coastal areas.

**DISCUSSION AND CONCLUSION**

The combined results of LOI, pollen, and radiocarbon analysis document the physical and biological change that began at lower elevations as the Maracas Bay watershed was inundated by coastal flooding from sea level rise. This 7000-year record began with the rapid deposition of marine sediments that continued until 4000 YBP and was followed by the establishment of brackish and freshwater habitat. This is consistent with data from the Unare delta in Venezuela (Bejarano, 1993 in Rull, Vegas-Villarubia, and Espinoza de Pernia, 1999; Roa, 1991).

Marine invasion of the watershed facilitated the establishment of a *Rhizophora*-dominated mangrove community. However, shore-normal and shore-parallel littoral conditions would have stabilized the shoreline and allowed a beach to be formed even as sea levels were changing. The sharp reduction in silicates at 4000 YBP indicates the most likely time of beach closure and the beginning of increased freshwater influences at the site, which would lead to the present herbaceous marsh. Following Oertel et al. (1992), *Rhizophora* would have occupied the channel banks and other wet areas, whereas shrubs, herbs, graminoids, and others would have occupied the interfluve areas.

Because *Rhizophora* occupies the upper half of the intertidal range, it could be used to indicate sea level. However, *Rhizophora mangle*, the most widespread species in the Caribbean, and *Rhizophora racemosa* are known to form extensive communities in nontidal freshwater habitats, e.g., Graeme Hall Swamp in Barbados, Levera Pond in Grenada, and the lower reaches of the San Juan River system in eastern Venezuela. Nevertheless, its presence in the Maracas fossil record can be used to determine sea level change during the mid-Holocene because it clearly inhabited a marine-influenced habitat at that time. The change in sedimentation rate from an initial 1.99 mm y⁻¹ to 1.05 mm y⁻¹ after 4410 YBP, when combined with the change in dominant sediment type.
from silicate to organic matter, dates the end of the marine influence on the wetland.

In the Maracas watershed 6700 years ago, the presence of a mangrove community at 830 cm confirms sea levels at that time. This is generally consistent with a date of 6970 YBP at 940 cm for Playa Medina, Venezuela (Rull, Vegas-Villarubia, and Espinoza de Pernia, 1999) and 6960 YBP for 880 cm at Negril, Jamaica (Digerfeldt and Hendry, 1987). Compaction of sediments and differences in surface elevations could account for the depth differences observed at those sites. The other two Maracas dates, however, are inconsistent with the sea level curves proposed for Venezuela (Rull, Vegas-Villarubia, and Espinoza de Pernia, 1999) and Jamaica (Digerfeldt and Hendry, 1987), and contradict mid- to late-Holocene sea level curve for the north coast of Trinidad (Ramcharan, 2004). The reduced sedimentation rate after 3000 YBP indicates reduced precipitation and erosion in the watershed and the onset of drier conditions. This is consistent with results from Haiti, which document the onset of drier conditions in the region after 3200 YBP (Hodell et al., 1987).

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LITERATURE CITED
