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Commentary

The Oldest Holocene Caribbean Mangroves and Postglacial Sea Level Rise: Biogeographical Implications

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Abstract: This commentary underscores the importance of the recent discovery of the oldest in situ Holocene mangrove sediments found to date in the Caribbean region. It also emphasizes the implications of this finding for understanding postglacial sea level rise and the subsequent recolonization of current Caribbean coasts by mangrove communities. These communities likely survived the last glaciation in small microrefugia located beyond the present continental shelf, from where they expanded to form the present-day mangrove biogeographical patterns.

Keywords: mangroves; pollen; Caribbean; sea level; Holocene; biogeography

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1. Introduction

Sediments deposited in situ on intertidal tropical/subtropical mangrove communities are among the best-suited indicators of past sea levels [1]. These sediments are often organic in nature (mangrove peats) and may contain remains of aerial roots typical of mangrove trees and organisms living on them (e.g., oyster shells). Unequivocal proof that peats and similar sediments were deposited within a mangrove community is the finding of pollen assemblages qualitatively and quantitatively similar to modern mangrove sediments [2]. In the Caribbean region, mangrove pollen assemblages in in situ sediments are dominated by mangrove-forming trees of the genera *Rhizophora* and *Avicennia*, with *Rhizophora* values reaching up to 80% in the source area and declining quickly landward and offshore [3]. The combination of macroscopic sedimentary features and pollen analysis provides the best estimates of past sea levels for a given locality. This commentary highlights the recent finding of the oldest mangrove sediments documented to date for the Holocene in the Caribbean region [4] and discusses their potential impact on the reconstruction of postglacial sea level rise, with emphasis on the Early Holocene.

2. The Caribbean Mangroves

The Neotropical mangroves originated in the southern Caribbean region, around the Maracaibo Basin (Figure 1), during the Eocene (50–40 Ma), underwent a major evolutionary turnover in the Eocene/Oligocene transition (~34 Ma), and diversified during the Neogene (~23 to 2.6 Ma) to attain their present biogeographical and taxonomic configuration in the Quaternary [5]. During the Pleistocene (the last 2.6 Ma), Caribbean mangrove distribution is thought to have been strongly influenced by glacial (lowstand)/interglacial (highstand) cycles, although the earliest record documented corresponds to the onset of the last glaciation (130 kyr BP) [6]. Mangroves are expected to be significantly affected by the predicted future sea level rise that, in combination with anthropogenic deforestation, is the main threat to these unique tropical/subtropical coastal forests. In the Caribbean region, it has been estimated that under current deforestation rates, what has taken evolution ~50 million years to build could disappear in barely three centuries [7].

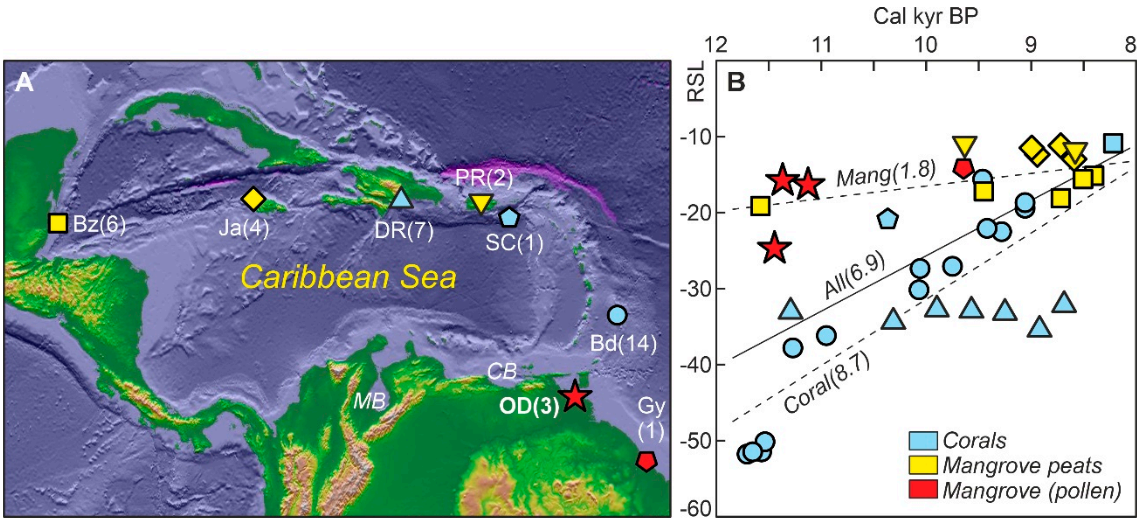

Figure 1. The location map and Early Holocene sea level trends. (**A**) A map of the Caribbean region indicating the locations used for reconstructing the relative sea level (RSL) and the number of dates measured in parenthesis (Bd, Barbados; Bz, Belize; DR, Dominican Republic; Gy, Guyana; Ja, Jamaica; OD, Orinoco Delta; PR, Puerto Rico; SC, St Croix). Flat light blue areas indicate the continental shelf, which marks the approximate sea level position during the Last Glacial Maximum (LGM; ~21 cal kyr BP). Other localities mentioned in the text are CB, Cariaco Basin, and Maracaibo Basin. (**B**) RSL trends, in m below the present level, correspond to the Early Holocene. The raw data have been taken from Khan et al. [1], except for the OD data (red stars), which are from Pocknall and Jarzen [4] (see Table 1). Linear regression lines and RSL rates (in m/1000 yr) are also indicated for the totality of records (All), the coral records (Coral), and the mangrove records (Mang).

3. The Early Holocene

At the beginning of the Quaternary (the last ~2.6 Ma), the Caribbean mangrove forests had already attained their present-day plant composition and dominance patterns [5]. Therefore, Quaternary records of mangrove responses to natural and anthropogenic drivers of ecological change are often utilized as past analogs for predictive purposes in the face of future global change. The incompleteness of Quaternary pollen records, however, is barrier to a thorough appreciation of these changes and their biogeographical expression. Indeed, Pleistocene mangrove records are almost lacking, and most reconstructions using pollen correspond to the Holocene (the last 11.7 kcal yr BP). The Holocene mangrove record is also incomplete, as the only continuous sequences correspond to the Mid–Late Holocene (~8 cal kyr BP onward), and the Early Holocene is virtually absent [5]. Indeed, only a single Early Holocene mangrove date (8590 ± 65 ^{14}C BP; 9465–9715 cal yr BP) from Guyana is available [8,9], which prevents the assembly of a reliable chronostratigraphic model for Early Holocene Caribbean mangroves.

4. The Oldest Holocene Mangroves

A palynological reconstruction that has just been published provides additional dates that extend the Holocene Caribbean mangrove record to around the Pleistocene/Holocene (P/H) boundary, which marks the end of the last glaciation [4]. These dates are provided in ^{14}C years BP and have been calibrated here (Table 1) for homogeneity with the available Caribbean-wide mangrove review [5]. Another date (11,090 ± 50 ^{14}C yr BP at 7.62 cm depth) was considered anomalous by these authors, possibly due to the presence of reworked material from older sediments. Pollen analysis revealed that samples corresponding to the 50.90–60.05 m sampling interval (Pollen Zone II), which include the dated samples of Table 1, were deposited within a mangrove environment dominated by *Rhizophora* and *Avicennia*, the two major mangrove trees of the Caribbean region.

Table 1. Sample depths (SDs) and radiocarbon ages (RAs) were provided by Pocknall and Jarzen [4] for the borehole BH-1 at Punta Pescador (first two columns). Here, SDs have been corrected for water depth at the boring site (3.66 m ± 2) (SD_w) and these new depths have been corrected by subsidence rates estimated for Punta Pescador (2.8 mm/yr; [10]) (CD_{ws}). TS is total subsidence. RAs have been calibrated here (RA_c) with IntCal20 [11] using CALIB 8.20 (http://calib.org/calib/, accessed on 14 May 2024).

SD (m)	RA (^{14}C yr BP)	SD_w (m)	TS (m)	SD_{ws} (m)	RA_c (2σ cal yr BP)	Median
50.90	9690 ± 50	47.24 ± 2	31.12	16.12 ± 2	10,797–11,228	11,114
51.05	9950 ± 50	47.39 ± 2	31.86	15.53 ± 2	11,242–11,686	11,378
60.05	9920 ± 230	56.39 ± 2	32.08	24.31 ± 2	10,699–12,447	11,457

To estimate the corresponding sea level position from these mangrove age–depth data, the sample depths still need some corrections. First, the core was drilled at 12′ (3.66 m) of water depth (Pocknall, pers. comm.); however, it is not known at which tide situation the core was drilled, which in the delta coasts has a diurnal amplitude of 2 m [10]. Therefore, 3.66 ± 2 m should be subtracted from the original sample depths (SDs) to obtain the water-corrected sample depths (SD_ws). Second, according to [2], local tectonics and subsidence—i.e., the lowering of the land surface relative to a topographic datum—due to sediment compaction and dewatering may be important in the Orinoco delta. No corrections for local tectonics are needed, as the delta is seismically quiescent. However, at Punta Pescador, near the coring site, subsidence rates are 2.88 mm/y [10]. Therefore, the depth of the sample should be multiplied by this rate to obtain the total subsidence (TS), which should be subtracted from the SD_w to obtain the actual sea level corrected by water depth and subsidence (SD_{ws}). No corrections for the marine reservoir effect are needed, as all samples discussed here are of terrestrial origin (plant remains) [4]. Table 1 shows the calculations.

5. Comparisons with Previous Records

The resulting age–depth points for mangroves, deduced from the pollen analysis, were compared with the available Early Holocene relative sea level (RSL) trends for the Caribbean region (sensu lato). The most complete RSL curve available, with almost 500 index points and 240 limiting dates, estimated rising rates between approximately 7.5 and 11 m/millennium [1] for sea levels between ~50 and ~10 m below the present level (Figure 1). The majority of dates for this reconstruction were obtained in coral reefs (~60%), with the rest derived from organic sediments identified as mangrove peats based on sedimentary features. Only one of these peats, from the above-mentioned Guyana record [9], was positively identified as a mangrove peat using the pollen analysis. The new Orinoco delta samples represent the oldest mangrove samples analyzed and palynologically available for the Early Holocene and the Lateglacial, up to 14 cal kyr BP, as all samples previously analyzed correspond to corals [1].

6. Biogeographical Implications

From a biogeographical perspective, the work by Pocknall and Jarzen [4] not only contributes to the reconstruction of past sea levels, but it also aids in the geographical delimitation and expansion of Caribbean mangroves during the Early Holocene, when sea levels were rising fast after the ~120-m lowstand of the Last Glacial Maximum, reaching ~20 cal kyr BP [5]. During the LGM, the continental shelf was fully exposed, and the coasts were close to the continental slope, which is less favorable for mangrove development due to the steep topography. Indeed, these ecosystems require shallow waters and protection from strong waves, which is usually provided by coral reefs. Therefore, the most suitable environments for mangrove growth occur in highstand conditions, when the flooded continental shelf provides flat, shallow, and quiet tidal environments and favors the development of corals in front of the coasts. During the LGM, mangroves were likely restricted to small favorable refugia from where they expanded progressively until reaching their present extent. This is supported by the small amounts of mangrove pollen (<4%) recovered in the Cariaco Basin (Figure 1) sediments corresponding to the last glaciation (68 to 28 cal kyr BP), just before the LGM, when sea levels were falling [12]. These microrefugia were located offshore of present coasts, where the sea level was situated at those times.

Prior to the publication of the Early Holocene Orinoco delta record, the Guyana record suggested that mangroves would have begun to colonize coasts situated ~14 m below the present sea level by 9.7–9.5 cal kyr BP (Figure 1). The Orinoco data suggest that this colonization occurred before that, by 11.5 cal kyr BP, when mangroves were established at sea levels ~25 m below the present level. Interestingly, mangrove records, either confirmed palynologically or inferred sedimentologically, are as old as coral records, but they are present at significantly shallower depths and define different RSL rates. Indeed, the overall RSL rising rates (6.9 mm/yr) are similar to the rates estimated using only corals (8.7 mm/yr), and both fit with the Khan et al. [1] rates for the Early Holocene mentioned above. However, using only mangrove samples, the RSL rising rates are significantly lower (1.8 mm/yr). Notably, the differences in depth between corals and mangroves of similar ages are maximal at the beginning and minimized with time. This could be linked to differences in habitat requirements and colonization patterns between these two ecosystems.

On one hand, corals are submerged marine organisms, whereas mangroves are restricted to the tidal coastal fringe, essentially at the sea level itself. The preferred corals used in the Caribbean-wide reconstruction are *Acropora palmata*, which live between depths of 0 and 5 m, but also include other taxa that can live up to a depth of 30 m [1]. This is more or less the difference that exists between coral and mangrove samples at the beginning of the Holocene, between 12 and 11 cal kyr BP (Figure 1). This coexistence of mangroves and corals at different water depths under the same eustatic conditions is not surprising and is common in the present-day Caribbean and many other coasts worldwide. This does not mean that corals are not suitable indicators of sea level position, but in multiproxy reconstructions of this type, the particular biological features of each proxy should be considered with care and in combination with others.

On the other hand, the absence of mangrove samples during the Lateglacial and their first appearance in the Early Holocene, as seen in the Orinoco delta record commented on here, may be partly due to a delay in the colonization of Caribbean coasts under rising sea levels. It is possible that the postglacial colonization of the Caribbean coasts by mangroves from the small and restricted LGM microrefugia, which were living approximately 120 m below present sea levels, was not a quick process, especially under relatively rapid RSL rising trends. The Early Holocene mangroves recorded in the Orinoco delta by the P/H boundary could constitute a critical point beyond which mangroves initiated the full colonization of the coasts of the Caribbean region and surrounding areas. This would have been favored by slower RSL rising rates, as compared to former times [1]. In summary, the work by Pocknall and Jarzen [4] not only provides new data to improve our understanding of Caribbean mangroves in eustatic and biogeographical contexts but also reinforces the utility of palynological records of mangroves as the best suited proxies for reconstructing sea level trends over time and space.

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