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Modern pollen rain in mangroves from San Andres Island, Colombian Caribbean

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ABSTRACT

The precise characterisation of present-day mangrove ecosystems from modern pollen rain facilitates the accurate use of fossil pollen data for late Quaternary sea level and environmental reconstructions. Here, we investigate whether the analysis of pollen rain data corroborates existing floristic and structural characterisation of different mangrove types at the Caribbean island of San Andrés, Colombia. At 82 plots along 20 transects of four distinct mangrove types, samples were obtained of (i) surface sediments for pollen analysis, and (ii) a range of environmental parameters (including inundation levels, salinity and pH). This information was compared to previously sampled mangrove composition and tree basal area. In surface sediment samples 82 pollen taxa were found, from which 19 were present in the vegetation plots. However, because pollen may be transported by wind and/or watercourses, the overall floristic composition of the different forest types may not necessarily be reflected by the pollen spectra. Local vegetation (i.e. mangroves and beach) represented >90% of the pollen spectra, while the regional one (i.e. hinterland forests) represented <5% of it. Unlike the four mangrove types that were previously described in the vegetation, the analysis of pollen samples suggested only three distinct types of forest.

The groups were characterised based on (i) the dominance of at least one of the true mangrove species from pollen data ordination and the presence of associated species, and (ii) their relationship with environmental parameters. *Rhizophora* was present in all plot samples, but did not contribute to forest type separation. In fact, just three true mangrove species proved reliable indicators of (i) high salinity and fringe mangroves (i.e. *Avicennia*), (ii) high pH levels and landward mangroves (i.e. *Conocarpus*), and (iii) natural or anthropogenic caused disturbance of forest stands (*Laguncularia* and associated *Acrostichum* fern). Hence our study confirms that mangrove pollen spectra can be accurately used to describe different mangrove environments for fossil based palaeoecological reconstructions.

1. Introduction

Fossil pollen records of mangrove forests have been widely used to reconstruct past environmental changes of tropical and subtropical coastal zones at different time scales. For example, mangrove expansion during the marine transgression following the Last Glacial Maximum (Scourse et al., 2005; González et al., 2006; Hooghiemstra et al., 2006; Tossou et al., 2008) and during the late Holocene (Behling et al., 2001; Cohen et al., 2005; Ellison, 2005, 2008). Research indicates that the dieback of mangroves in the late Holocene period arose as a consequence of sea level rise, coastal erosion and submersion of coast of islands (Ellison, 1993). The combined effect of increased fluvial sedimentation and coastal dynamics (Parkinson et al., 1994; Grindrod et al., 1999) has facilitated the adaptation of mangroves to changing sea levels and consequently, expand or contract along coastal plains. Natural catastrophic events such as hurricanes and tsunamis or human activities such as mangrove replacement by coconut plantations (Donders et al., 2008; González et al., 2010) have also affected mangroves. Nevertheless, a more precise characterisation of present-day mangrove ecosystems based on pollen rain is required to accurately interpret fossil pollen data.

A number of studies have explored the relationship between vegetation composition and pollen occurring in the surface sediments of mangroves. Prime examples include the western Pacific and the Malayan region (Ellison, 1989; Kamaludin, 1993), tropical Africa (Elenga et al., 2000; Van Campo and Bengo, 2004), and China (Sun et al., 1999; Mao et al., 2006; Li et al., 2008). However, there is a paucity of information for South America, limited to studies at the Orinoco Delta in Venezuela (Muller, 1959; Hofmann, 2002), north-east Pará, Brazil (Behling et al., 2001) and Cispatá Bay in the Caribbean region of Colombia (Urrego et al., 2009a).

At a landscape scale, existing literature indicates that high proportions of pollen (≥60%), of the wind-pollinated species of *Rhizophora*, typically indicate the presence of mangrove forests in the vicinity of adjacent coastal zones (Muller, 1959; Grindrod and Rhodes, 1984; Chappell and Grindrod, 1985; Woodroffe et al., 1985;

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Hooghiemstra and Agwu, 1986; Grindrod, 1985, 1988; Elenga et al., 2000; Behling et al., 2001). On the other hand, low proportions of this taxon's pollen (<25%) may indicate the downstream transport of pollen grains, comprising either landward or disturbed mangrove stands (Hooghiemstra and Agwu, 1986; Lézine and Hooghiemstra, 1990; Van Campo and Bengo, 2004; Engelhart et al., 2007; Urrego et al., 2009a). Changes in the relative abundance of this taxon have been used to interpret sea level reconstructions at a range of tropical and subtropical coastal zones across the globe (e.g. north-west Africa, Hooghiemstra et al., 2006; Indonesia, Engelhart et al., 2007; and other locations, Ellison, 2008). Along the continental shelves, historical sea level rise and pro-gradation have been indicated by increased proportions of *Rhizophora*. In comparison, the diminution of pollen proportions of this taxon on carbonate mudflats of oceanic islands has been associated with coastal erosion and/or the submersion of mangroves as a result of sea level rise (Ellison 2008). The fact that mangroves are set in a heterogeneous environment, with a broad spectrum of associated vegetation between and within forest stands, has been given limited consideration. For example, the pollen rain signature of an individual species may not necessarily be representative of all mangrove forest types. Furthermore, the strong relationship between mangrove forest structure and composition with environmental parameters has been overlooked in palaeoclimatic studies. Such parameters include regional climate, geomorphology, hydrology (Thom, 1967; Woodroffe, 1992), local slope, drainage, tidal amplitude and sediment type (Méndez-Linares et al., 2007). A close relationship between vegetation type and pollen signature has been established for several coastal systems (e.g. Willard et al., 2001). However, aside from *Rhizophora*, the indicative potential of important mangrove taxa such as *Avicennia*, *Conocarpus* and *Laguncularia*, has received limited consideration due to their relatively low pollen rain contribution in comparison to that of *Rhizophora* (Behling et al., 2001; Hofmann, 2002; Li et al., 2008). Modern mangrove ecology indicates that the occurrence of these species is linked to clear ecological and environmental preferences (Hogarth, 2007; Tomlinson, 1986). For example, the high relative abundances of *Avicennia* are indicative of high salinity conditions, while *Conocarpus* indicates the proximity of mangroves to the hinterland and a reduced tidal influence. On the other hand, the dominance of *Laguncularia* indicates an open forest canopy as a result of natural or anthropogenic disturbance (Tomlinson, 1986; Benfield et al., 2005; Hogarth, 2007).

The accurate characterisation of the relationship between pollen rain, vegetation and environmental parameters may provide the ability to determine whether fluctuations in the relative abundance of mangrove pollen species have the potential to indicate climate change, sea level, the flooding of soils and geomorphology, as well as endogenous forest dynamics and/or anthropogenic disturbance. Small islands have been shown to provide ideal environments in which to evaluate such parameters in mangrove systems, due to their isolation from other landmasses and usually complete floristic descriptions (Lowy, 2000). Previous research at the Caribbean island of San Andrés, Colombia has indicated the differentiation of four types of mangrove forest (two riverine and two fringe) based on floristic and structural vegetation characteristics (for details see Urrego et al., 2009b). However, there are distinct differences in edaphic and hydrological characteristics of these forests, which may additionally influence their structure and composition.

Hence, in this study we set out to corroborate the findings of Urrego et al. (2009b) through the analysis of pollen rain spectra in surface sediments at the San Andrés mangroves. Our primary objective was to evaluate whether the pollen rain signature of surface samples for each forest stand serves as a reliable indicator for (i) the composition of the vegetation growing at the sampled sites, and (ii) the degree of environmental variability between coastal sites on the island. The identification of this relationship would provide a basis from which mangrove palynological records could be used to infer past climatic and environmental changes on the island and the wider Caribbean region.

1.1. Study area

The Colombian island of San Andrés (Fig. 1, 25 km^2, 12º 29′–12°36′ N and 81° 41′–81° 43′ W) is located in the south-west Caribbean, 800 km north-west off mainland Colombia and 150 km east off Nicaragua (Díaz et al., 1995; Baine et al., 2007). It is the largest island of the San Andrés, Old Providence and Santa Catalina Archipelago that comprise the Seaflower Biosphere Reserve (Baine et al., 2007).

The mean annual precipitation of 1800 mm is determined by the north-east trade winds, with 80% of rain falling between October and December (IGAC, 1986). The average annual temperature is 27 °C. There are no permanent surface freshwater sources on the island, however small watercourses form during the wet season. There is one semi-permanent gully which primarily flows westward to the Cove Inlet (Fig. 1), while other gullies flow eastward to the mangrove forests (IGAC, 1986). There are also underground water deposits which are supplied by percolation of 21% of the island's rainfall through the calcareous rocks (Díaz et al., 1995).

The San Andres landscape is composed of (i) a hills system of up to 100 m elevation above sea level in the central part of the island, and (ii) a coastal plain composed of emerged coralline terraces located a few meters above sea level (Fig. 1; Cortés, 1982). The original vegetation type of the hills was described as a combination of dry and moist forest (Lowy, 2000). However, today the island lacks primary vegetation, and is dominated by secondary forests formations (Bolívar and Vélez, 2004). On the landward sandy substrates neighbouring the mangrove forests, important species include: *Cocos nucifera* L., *Terminalia catappa* L, *Guazuma ulmifolia* Lam., *Casearia aculeata* Jacq., *Annona glabra* L., *Spondias mombin* L., *Psidium guajava* L., *Dalbergia brownei* (Jacq.) Schinz., *Artocarpus altilis* (Parkinson) Fosberg, *Morinda citrifolia* L. and *Leucaena leucocephala* (Lam.) de Wit (Bolívar and Vélez, 2004). Beach vegetation and mangrove forests dominate the coastal plains (Díaz et al., 1995; Lowy, 2000). On sandy beaches herbaceous vegetation predominates, including *Sesuvium portulacastrum* (L.) L., *Hymenocallis littoralis* (Jacq.) Salisb., *Ruellia tuberosa* L., *Batis maritima* L., *Tournefortia gnaphalodes* R. Br. ex Roem. & Schult., *Ipomoea pes-caprae* (L.) R. Br., and tree species include *Hippomane mancinella* L., *Chrysobalanus icaco* L., *Hibiscus tiliaceus* L., and *C. nucifera* (Díaz et al., 1995; Lowy, 2000). In this landscape besides coconut plantations (*C. nucifera*) other crops, such as *Morinda citrifolia* (L), *Manihot esculenta* Cranz and *Musa* spp., are commonly found (Bolívar and Vélez, 2004).

Most of the 96 ha of mangrove forests are located along the eastern coast of the island, but a small patch can be found on the western coast (Fig. 1). According to Urrego et al. (2009b), four mangrove types can be found in the island. Two of the forests on the east coast are classified as riverine mangroves (see Lugo and Snedaker, 1974) due to their isolation from direct tidal influence with only sporadic flooding from freshwater streams. The other two are classified as fringe mangroves, due to their being directly influenced by tides. The two types of mangrove forest differ in their edaphic and hydrological characteristics, forest structure and composition. The forests were primarily dominated by true mangrove species, including *Avicennia germinans* (L.) L., *Rhizophora mangle* L., *Laguncularia racemosa* (L.) C.F. Gaertn. and *Conocarpus erectus* L. and some non-mangrove species.

1.2. Riverine mangroves

There are two groups of riverine mangroves on the island. The first group is located along the lower half of the south-east facing part of the island. These mangroves are characterised by high mean fresh water inundation levels (57.4 ± 16.9 cm), low sediment salinity levels (1.4 ± 1.6‰). The dominant species are *Laguncularia racemosa* and