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Tropical forest and mangrove history from southeastern Mexico: a 5000 yr pollen record and implications for sea level rise

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Abstract A 250 cm long core from El Palmar, a swamp area located along the Rio Hondo river in the south of the Yucatan Peninsula, near the Belizean border, reveals the environmental history of the mangrove and tropical forest of the last 5000 years. The period between 5000 and 4600 B.P. shows sandy deposits, which form the early infill and development of the swamp. A medium-statured tropical forest covered the area and members of the Moraceae and Fabaceae dominated this early forest. The period between 4600 and 4000 B.P. presents a clear change to a mangrove system with *Conocarpus erecta* and *Rhizophora mangle* as dominant trees. This vegetational change is due to flooding of the Rio Hondo river, which deposits sediments of high salinity due to higher sea-level. The medium-statured forest became established at some distance from the swamp area. After 4400 B.P. *C. erecta* appears as the dominant mangrove species and the *R. mangle* stands are less predominant in the area. The tropical forest was close to the swamp area and was mainly composed of members of the Moraceae, Arecaceae and Fabaceae as dominant taxa of this vegetational mosaic.

Keywords Mid Holocene · Pollen analysis · Tropical forests · Mangroves · Yucatan Peninsula · Mexico

Introduction

The Holocene vegetation and climate history of the Yucatan Peninsula has long been of interest to palaeoecologists and archaeologists due to the impact of the Mayan culture on this tropical environment. However, until now, only few palaeoecological studies are available from this complex

biogeographical region. Most of the available records are of Late Holocene age and few extend back beyond the Mid Holocene. The Lake Coba sediment core is one of the very few cores from the central part of the Yucatan Peninsula covering from the Mid Holocene onwards (Leyden et al. 1998). During the Mid Holocene semi-deciduous forest dominated the Lake Coba area. Earlier, Leyden et al. (1996) provided data on the Late Holocene vegetation development and high climatic variability from the San José Chulchaca cenote, located in the western region of the Yucatan Peninsula. Curtis et al. (1996) presented results of climatic variability from Punta Laguna, indicating that the period between 3300 and 1800 B.P. was relatively wet, while the following periods were considerably drier. Whitmore et al. (1996) studied the palaeolimnology of three lakes in the Yucatan Peninsula which gave evidence of changing water level fluctuations during the late Holocene.

The high resolution analysis of sediments from Lake Chichancanab by Hodell et al. (1995, 2001) gave clues to the high climatic variability of the Yucatan Peninsula and the catastrophic impact of drought on the Mayan culture. Changing climatic conditions during the Terminal Classic Period (A.D. 250–900) have been recently reported from the Cariaco basin (Venezuela) by Haug et al. (2003). Regional dry periods were dated to approximately A.D. 810, 860 and 910 (Haug et al. 2003). From the coast of the northern part of the State of Quintana Roo, data from Islebe and Sánchez (2002) showed vegetational changes in a mangrove ecosystem and also abrupt environmental change during the Classic period of the Maya culture. From the northern department of El Peten (Guatemala) palynological records from Leyden (1984), Vaughan et al. (1985) and Islebe et al. (1996) indicate human impact on the late Holocene vegetation. Rejmankova et al. (1995) studied floristic composition and standing crop in relation to soil characteristics in order to analyse the present day distribution of marsh vegetation in northern Belize.

This study reconstructs a tropical forest area in southern Quintana Roo near the Belizean border since the Mid Holocene, as sedimentary records spanning most of the

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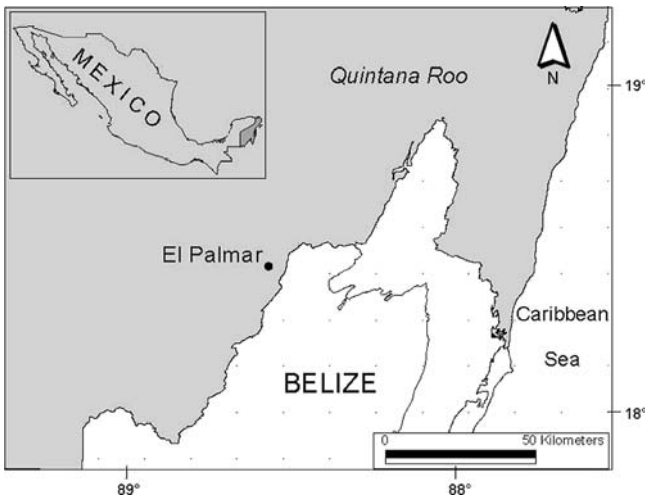


Fig. 1 Study area and location of the core taken in El Palmar

Holocene are still rare (Islebe and Sánchez 2001). Because of its short distance from the Caribbean Sea, the record could present new evidence on changing sea levels for the area. Toscano and Macintyre (2003) constructed a corrected western Atlantic sea-level curve, and we were able to compare our calibrated ¹⁴C dates with those data published.

Study area

The study area is located near the small village of El Palmar (18°26'48"N, 88°31'47"W, 10 m elevation) about 50 km southeast of Chetumal, the capital of the state of Quintana Roo (Fig. 1). The coring site is a swampy area along the Rio Hondo, which forms the border between Mexico and Belize. The distance from the Caribbean Sea is

about 23 km. The following climate data from Subteniente López are considered to be representative: the mean annual temperature is about 26°C, with a mean annual precipitation of 1300 mm (CETENAL 1975). Most of the precipitation falls between May and November and the area is under considerable threat of hurricane impact during those months (Sánchez and Islebe 1999). Vegetation types in the area include mangroves with stands of *Rhizophora mangle*, *Avicennia germinans*, *Conocarpus erecta* and *Laguncularia racemosa*. *R. mangle* forms the coastline and *A. germinans*, *C. erecta* and *L. racemosa* are found behind the *R. mangle* fringe. Canopy heights of the mangroves reach 15 m and generally mangrove forests contain few species of plants compared to the surrounding tropical forests or savanna types (Miranda 1958; Islebe 1998). The dominant vegetation type in the area is the medium-statured semi-evergreen tropical forest, which is also the dominant vegetation of the Yucatan Peninsula (Rzedowski 1978; Sánchez and Islebe 2002). This forest type has canopy heights up to 30 m with well defined strata (Sánchez 2000). Characteristic families of those forests are Moraceae, Sapotaceae, Meliaceae, Fabaceae, Burseraceae, Anacardiaceae, and Bignoniaceae among others. Dominant species of trees of these vegetation types are *Manilkara zapota*, *Bursera simaruba*, *Brosimum alicastrum*, *Piscida piscipula*, *Metopium brownei* and *Sideroxylon* spp.

Materials and methods

A 250 cm long core was collected in May 2000; extracted in 20 cm lengths using a Dachnovsky corer. The sampling interval of the El Palmar record was 10 cm. We used standard acetolysis techniques and heavy liquid separation with bromoform to extract the fossil pollen

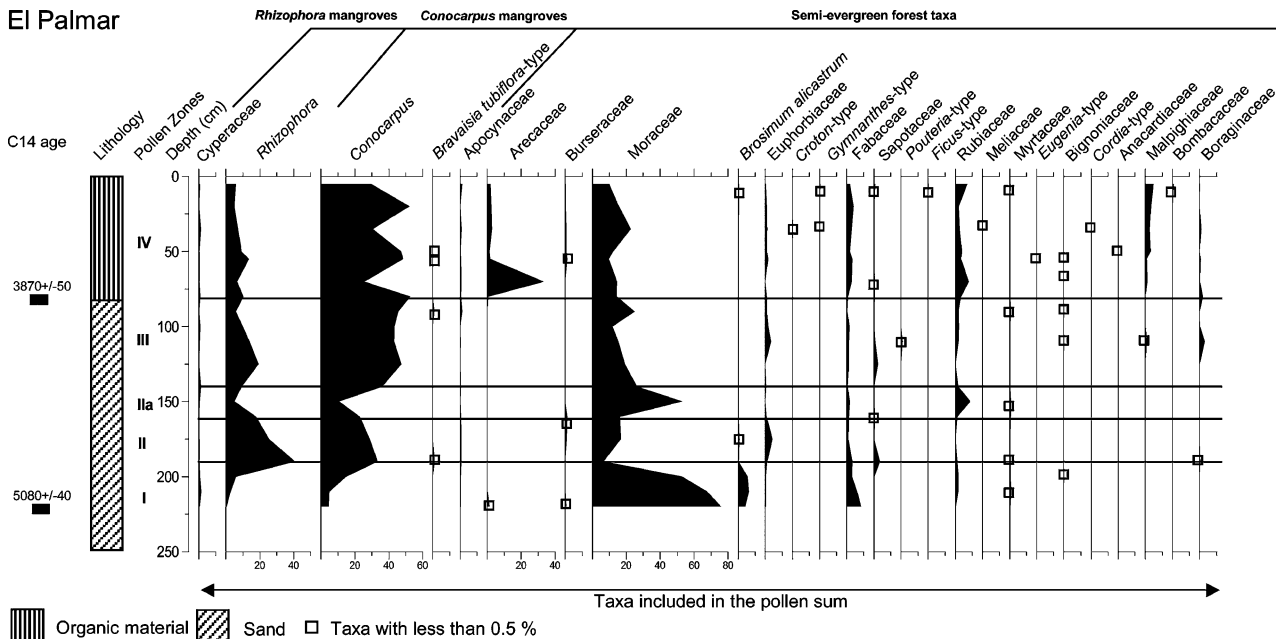


Fig. 2 Pollen percentage diagram of core El Palmar

Table 1 List of radiocarbon samples and calibrated ages

Depth (cm)	Lab. No	¹⁴ C yr B.P.	Cal B.P.
80	NSRL 11098	3870±50	4149–4417
220	NSRL 11099	5080±40	5736–5912

grains (Faegri and Iversen 1975) from subsamples of 1–2 cm³ of sediment. The residue was mounted in a glycerine gelatine medium. We aimed at a minimum pollen sum of 200 grains, but this was not achieved in all samples. Fern and fungal spores were not included in the pollen sum, because they are local elements. The pollen zones were established using TWINSPAN (Hill 1979), a divisive classification technique, which has proved to be very useful in defining indicator species and groups in paleoecology (Van't Veer et al. 1995). The order of the taxa in the pollen diagram was arranged according to ecological groups which form the present day vegetation (Sánchez and Islebe 2002). Those ecological groups include mangroves, medium-statured tropical forest and herb taxa of the medium-statured forest type. The pollen diagram was plotted with Palaeo Data Plotter (Juggins 2002).

The identification of the fossil pollen was made with help of the recent pollen collection of the ECOSUR Chetumal Herbarium, which hosts some 400 taxa from the Yucatan Peninsula. Published pollen atlases of Palacios et al. (1991), Hooghiemstra (1984) and Roubik and Moreno (1991) were used. AMS radiocarbon dating of unidentified organic material and fossil wood (Table 1) was done at INSTAAR, University of Colorado. The radiocarbon dates were calibrated with the CALIB 4.4.2 program (Stuiver and Reimer 1993; Stuiver and Braziunas 1993; Stuiver et al. 1998a, b) to compare them with data presented by Toscano and Macintyre (2003).

Results

Stratigraphy of core El Palmar

Sandy material was found at the bottom of the record between 220–80 cm. Organic rich material was found between 80 cm and the upper part of the core.

Description of the pollen diagram

Four pollen zones were identified (Fig. 2).

Pollen zone I (220–190 cm, about 5080–4800 B.P.) is characterised by high percentages of Moraceae (>50%), and lower percentages of taxa of the medium-statured forest, with taxa like Rubiaceae, Fabaceae types, Boraginaceae and Euphorbiaceae. *Brosimum alicastrum* is well represented in this zone. The mangrove vegetation is represented by increasing values of *Conocarpus* and *Rhizophora* (up to 30%). At the transition to pollen zone II Sapotaceae are present, indicating a well-developed forest (Islebe et al. 2001).

Pollen zone II (190–165 cm, about 4800–4600 B.P.) is dominated by high percentages of *Conocarpus* and *Rhizophora* (40%). Moraceae pollen decrease considerably compared to the previous zone. Percentages of *Acacia* (to 15%), Euphorbiaceae and Solanaceae increase.

Pollen zone IIa (165–140 cm, about 4600–4400 B.P.) is characterised by a steady decrease of *Rhizophora* and *Conocarpus*, increase of Moraceae, and higher percentages of the tropical forest families like Rubiaceae and Leguminosae-*Acacia*, Solanaceae is conspicuous.

In pollen zone III (140–80 cm, about 4400–3900 B.P.) *Conocarpus* dominates, while *Rhizophora* is less abundant

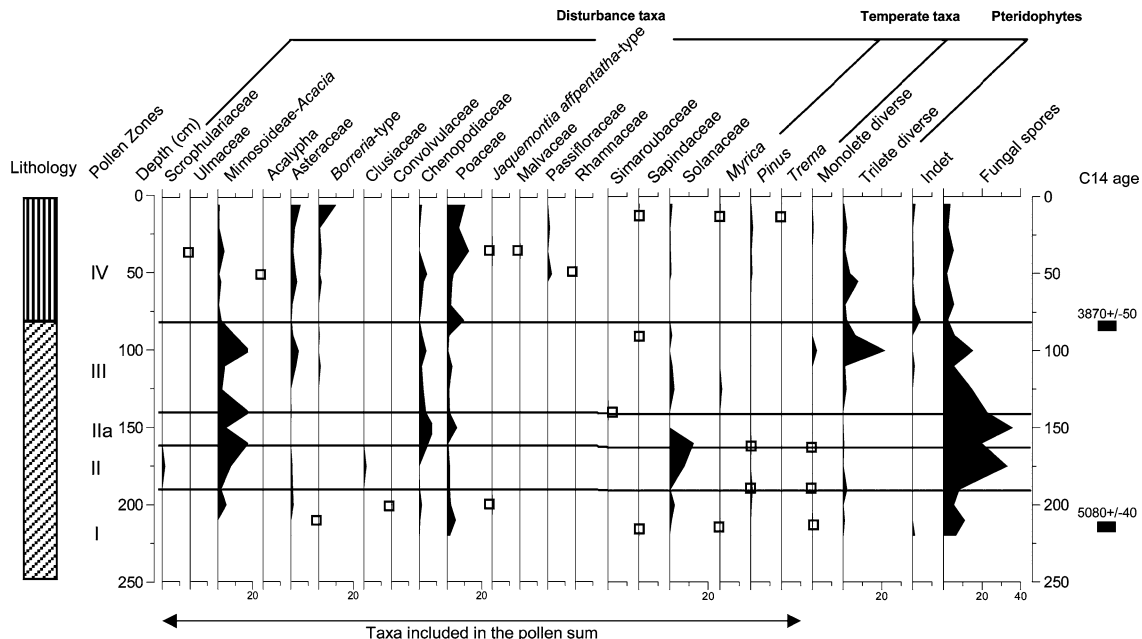


Fig. 2 Continued

(20%). Moraceae percentages decrease compared to zone IIa. A typical member of *Conocarpus* mangroves is *Bravaisia tubiflora*, which appears in low percentages at the top.

Pollen zone IV (80–0 cm, about 3800–3200 B.P.) is characterised by Moraceae around 20%, high percentages of *Conocarpus* (20–40%) and relatively low presence of *Rhizophora*. A peak in Arecaceae pollen is conspicuous, probably belonging to the species *Acoelorrhaphe wrightii*, characteristic of *tasistal* vegetation, a vegetation type present between mangroves and medium-statured forest. *Borreria* and Malphiaceae are relatively well represented.

Discussion

The core shows the last 5000 years of vegetation change from a tropical forest type to a mangrove dominated forest and later a transition to a mixture of tropical forest and mangroves due to sea-level changes. During the Mid Holocene, taxa of the high and medium-statured forest dominated in the area until approximately 4800 B.P. Trees of the Moraceae, Rubiaceae and Leguminosae dominated during that period. However, only a few pollen grains of the Sapotaceae or Bignoniaceae were recorded, indicating more primary forest conditions as corroborated by modern pollen rain studies in the area (Islebe et al. 2001). In pollen zone I, a first peak of Moraceae appears with higher percentages of *Brosimum alicastrum* and Fabaceae types. This indicates moister conditions than at present. After 4800 B.P., environmental conditions changed drastically and the vegetation became a mangrove ecosystem, dominated by *Rhizophora* and *Conocarpus*.

Sea level changes

Changes in sea level changed the environment into a saline one. The changing sea-level coincides with corrected data presented by Toscano and Macintyre (2003). Comparing our calibrated data with mangrove peat data from Florida, Belize and Jamaica, the sea-level rose ca. 2–3 m between 6000 and 4000 cal B.P. Rise in water levels was earlier interpreted as rise in sea level by High (1975).

Between ca. 4600 and 3800 B.P. the soils had higher saline concentrations than most medium-statured forest trees can tolerate. The change from the closed forest to a more open mangrove system is related to changes of the Rio Hondo river, which inundated the area with saline sediments continuously from 4600 B.P. onwards. After 4300 B.P. the mangrove *Rhizophora mangle* increased up to 20%, however it only covers one sample from our core. Percentages of *Rhizophora* between 10 and 20% indicate an increase of this mangrove type close to the coring site near the coastline. *Rhizophora* and *Conocarpus* also form the present coastline vegetation, and the dominance of both mangrove species around 3800 B.P. could indicate the definite establishment

of the present coastline in this area. Siemens (1978) found that present day hydrology is mainly controlled by intra-annual changes in the water table of ca. 1 m.

Vegetation change

About 4800 B.P., the nearby forest had a more secondary character as indicated by the presence of taxa like Burseraceae, *Acacia* and the appearance of Malvaceae. This first important development of mangrove vegetation lasted until ca. 4600 B.P., when for a brief period the tropical forest dominated in the area, as shown by the increase in Moraceae and Rubiaceae. The local swamp vegetation was characterised by Poaceae and Chenopodiaceae, nowadays typical of transition zones between mangrove areas and tropical forest. Species of Poaceae and Chenopodiaceae in the region can resist a wide range of ecological conditions, from occasional flooding to dry conditions. These conditions of altered *Conocarpus* mangrove are very common along the coasts of Quintana Roo, as these taxa tolerate changing hydrological conditions very well (Islebe and Sánchez 2002).

After ca. 4400 B.P. (pollen zone III) a strong increase in *Conocarpus* is observed and all relevant tropical forest taxa decrease considerably with exception of Euphorbiaceae. The remaining tropical forest was relatively distant from the coring site. The peak in trilete spores is probably from *Acrostichum* (Tryon and Tryon 1982), which is common in the area in brackish or salt water, and is also characteristic of mangrove communities. This is related to another slight increase in sea-level. However, we know from recent modern pollen rain studies in the area that the forest is not necessarily far away, the distance possibly being from 1 to 5 km (Islebe et al. 2001; Torrescano and Islebe unpubl.). The type of mangrove forest which dominated during this period is very similar in composition to present day mangrove stands distributed along the coast of Quintana Roo and has low species diversity (Islebe and Sánchez 2002). Such a species-poor environment suggests seasonal flooding, but *Conocarpus erecta* can also tolerate longer periods of drier conditions than *R. mangle* stands.

In the upper part of our sedimentary record there is a hiatus and the last 2500 years B.P. are not represented. At the transition from pollen zone III to IV, there is a noteworthy increase in percentages of pollen grains from Arecaceae. The most likely palm species based on the fossil pollen identifications are *Acoelorrhaphe wrightii* and *Thrinax radiata*, as both species are characteristic of transition zones between low-statured forests and mangroves, and are abundant at mangrove borders (Quero 1982; Sánchez and Islebe 2002). In addition, both palm species are relatively good pollen producers. The increase in Poaceae pollen supports the evidence of a development of a local palm swamp called *tasistal*. The recovery of the nearby forest is conspicuous with an increased representation of Moraceae, Malpighiaceae and Fabaceae.

Conclusions

Vegetation change from the Mexican-Belizean border area is inferred from the pollen record of El Palmar swamp area. The Mid Holocene climate in the region was humid, probably more humid than today. The change to a mangrove dominated vegetation cover is due to sea-level rise. The vegetation changed into a *Conocarpus* dominated mangrove forest and this vegetation type covered the swamp area until the top of the profile. The record shows that *C. erecta* replaced *R. mangle* as the dominant mangrove tree in the area. The present study elucidates the highly dynamic character of the vegetation types distributed within the southern part of the Yucatan Peninsula. However, more fossil pollen data and radiocarbon dates are needed to understand the palaeoecology of the region in detail.

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