



Model of wetland development of the Amapá coast during the late Holocene

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ABSTRACT

The modern vegetation types, sedimentary sequences, pollen records and radiocarbon dating obtained from three sediment cores from Calçoene Coastal Plain were used to provide a palaeoecological history during the late Holocene of Amapá coastal wetland according to flood regime, sea-level and climatic changes. Based on these records, four phases of vegetation development are presented and they probably reflect the interaction between the flow energy to the sediment accumulation and the brackish/freshwater influence in the vegetation. This work suggests interchanges among time periods characterized by marine and fluvial influence. The longitudinal profile did not reveal the occurrence of mangrove in the sediment deposited around 2100 yr B.P. During the second phase, the mud progressively filled the depressions and tidal channels. The mangrove probably started its development on the channel edge, and the herbaceous field on the elevated sectors. The third phase is characterized by the interruption of mangrove development and the increase of “várzea” vegetation that may be due to the decrease in porewater salinity related to a decrease in marine water influence. The last phase is represented by the mangrove and “várzea” increase. The correlation between current patterns of geobotanical unit distribution and palaeovegetation indicates that mangrove and “várzea” forests are migrating over the herbaceous field on the topographically highest part of the studied coast, which can be related to a relative sea-level rise.

Key words: Amazon river, climatic changes, mangrove, palynology, sea-level.

INTRODUCTION

Mangroves are the most favorable environment for palaeoclimatic studies during the Holocene because of their high sedimentation rates and susceptibility to climatic and sea-level changes (Gornitz 1991). Hence, the sediments deposited beneath mangrove vegetation provide useful indications of tidal regime (Scholl 1964, Woodroffe 1981, Van de Plassche 1986). Furthermore,

the relative proportion between mangrove and “várzea” vegetation contributes to the study of fresh and brackish-water influence, as mangroves are more tolerant to soil salinity (Lacerda et al. 1995, Youssef and Saenger 1999, Alongi et al. 2000) than “várzea” forest (Gonçalves-Alvim et al. 2001). Soil salinity is basically controlled by flooding frequency and position along the estuarine gradient (Lara and Cohen 2006).

Regarding the Amapá coastal plain, the mangrove community presents a zonation parallel to the shoreline (Boaventura and Narita 1974). These zones are gener-

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ally the response of individual mangrove species to the gradients of flooding frequency (Cohen and Lara 2003), waterlogging (Hutchings and Saenger 1987), nutrient availability (Junk 1997), soil salinity across the intertidal area (Wolanski et al. 1990) and volume of river water discharge, which depends of regional rainfall (Mörner 1999, Cohen et al. 2005b).

Palaeoecological and sedimentological studies in the Amazon basin during the Late Pleistocene and Holocene have suggested that dryer periods correspond to less precipitation and reduced river discharge (e.g. Colinvaux and De Oliveira 2000, Vital and Statterger 2000, Maslin et al. 2000). Thus, interchanges between dry and wet periods may have significant impacts on coastal wetland, as they modify the soil salinity gradients and the soil moisture (Cohen et al. 2005a).

In a previous work using remote sensing (Cohen and Lara 2003), pollen analysis, and radiocarbon dating, it was possible to identify the impact of climatic changes during the last thousand years on the eastern sector of the Amazonian mangroves (Behling et al. 2001, 2004, Cohen et al. 2005a, b, 2008, Lara and Cohen 2008). Using these same tools, this work presents a model of wetland development of the Amapá coast during the late Holocene.

STUDY AREA

The study site is located close to the city of Calçoene on the Amapá coast, in the eastern Amazon region (Fig. 1). Allison et al. (1990) identified coastal mudflat colonized by mangroves and marshes. According to Boaventura and Narita (1974), this region is characterized by Holocene deposits formed in a fluvio-marine coastal plain with tidal influence. The area with muddy deposits is mainly colonized by mangroves. The tidal range is about 5.2 m and the current velocities reach 2 m/s (Schaeffer-Novelli and Cintron-Molero 1988).

Modern vegetation of the Calçoene is represented by “terra firme” (Amazon coastal forest) vegetation (10.288 km²), savanna (1.236 km²), mangrove, “várzea” and flooded herbaceous plain (2.808 km²) (Morais and Morais 2000). The periodically inundated herbaceous field occurs on the limit of the tidal influence and it is represented mainly by Poaceae, Cyperaceae, Nymphaeaceae, Alismataceae, Araceae and Maranthaceae. Fol-

lowing the topographical gradient, there is a permanently inundated herbaceous field composed of “aguapé” (*Eichornia crassipes* (Mart.), “cabomba” (*Cabomba aquatica* DC.) and “mururé” (*Nynphaea* sp.) in some sectors with small depressions that have no significant inflows, outflows and peat accumulation (Costa Neto 2004). The “várzea” vegetation includes “tiriricão” (*Scleria* sp.), “aninga” (*Montrichardia arborescens* L. Schott), “buriti” (*Mauritia flexuosa* L.f.), “açai” (*Euterpe oleracea* Mart.), “mururés” (*Eichornia* sp.) and “piri” (*Cyperus giganteus* Vahl.). The mangroves present the *Avicennia nitida* Jacq., *Avicennia germinans* (L.) Stearn, *Rhizophora mangle* L., *Laguncularia* sp. and *Laguncularia racemosa* Gaertn. (Leite et al. 1974).

The following units represent the vegetation of study site: Amazon coastal forest, “várzea”, herbaceous field and mangrove (Fig. 1). Calçoene mangroves present an area of about 311 km² and are densely covered of forests, mainly by *Avicennia*, *Rhizophora*, and *Laguncularia*, from the high spring tide to the mean tidal level. The hinterland mangrove makes contact with the herbaceous field (1.201 km²) mainly represented by Cyperaceae and Poaceae, conditioning the development of discontinuous fringes. The “várzea” forests are generally represented by *Mauritia flexuosa* L.f., *Eichornia* sp., and *Euterpe oleracea* Mart. They cover an area of about 684 km², which is influenced by periodic floods of sediment loaded, nutrient-rich fresh water rivers. Only a few sectors of topographically elevated areas are covered by the Amazon coastal forest (18 km²).

MATERIALS AND METHODS

REMOTE SENSING DATA AND IMAGE PROCESSING

Characterization and spatial distribution of the main geobotanical units were carried out by satellite image interpretation aided by field validation. The Landsat ETM+ (225/058, 225/059, 226/057, 226/058 and 226/059) images acquired on September 2000 were purchased from the National Institute of Space Researches – Brazil (INPE). The dataset, processed using the Spring 4.3 software, was geometrically corrected through another ETM+ image previously corrected, and later re-sampled with a nearest neighbor interpolation to 30 m pixels.

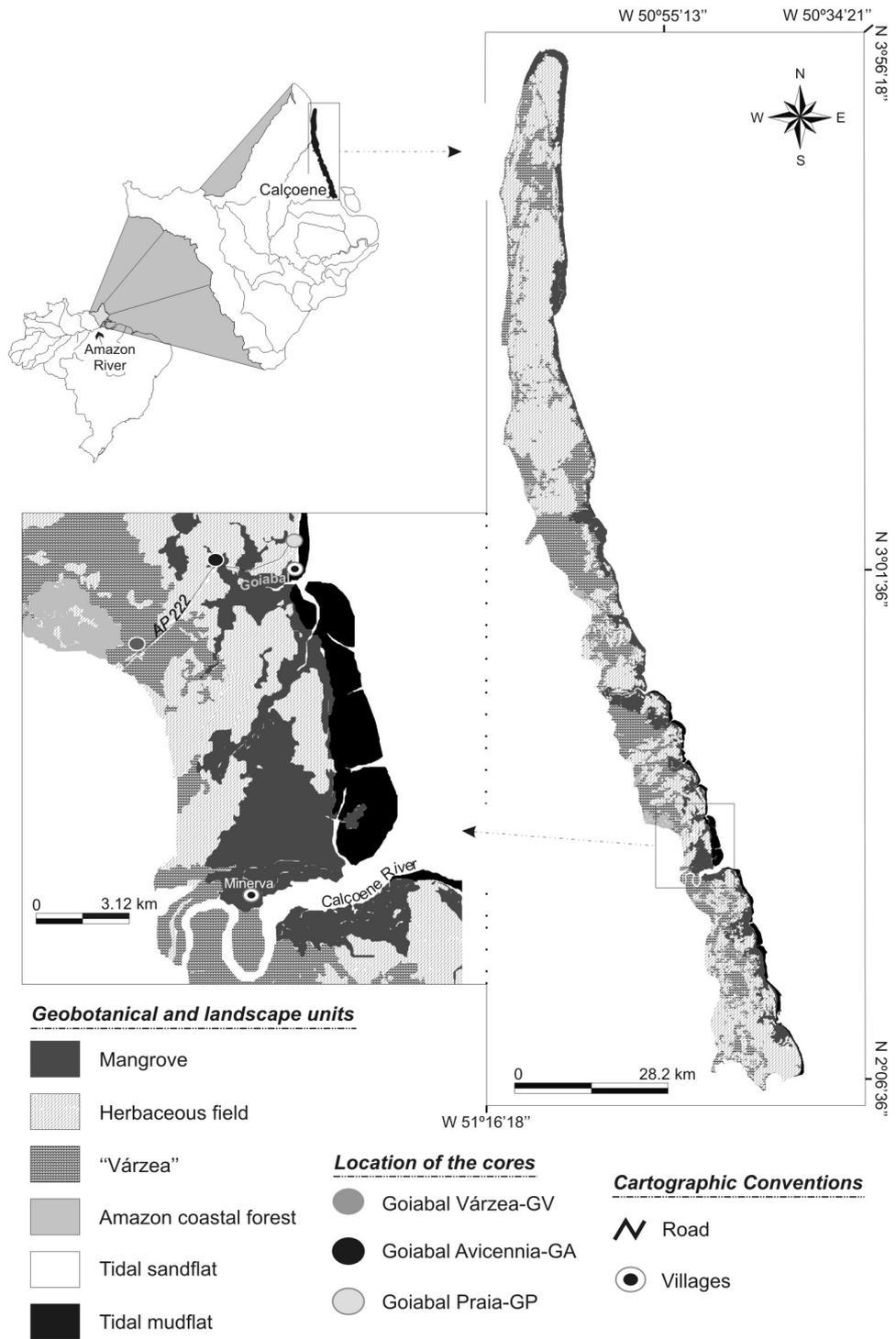


Fig. 1 – Study site.

The radiometric correction was related to the attenuation of atmospheric effects and was based on the minimum histogram pixel approach (Chavez 1988). Image

enhancements were applied based on linear and equalization stretches. The three bands for a red-green-blue (RGB) color composite (TM4, TM5 and TM3 bands)

were selected based on the optimum index factor scheme (Chavez et al. 1982), and chosen for visual interpretation. Validation was assisted by allocating ground control points for the classification of different physiognomies. The typical species of plants in each unit was documented by photographic documentation and GPS measurements. These sites were located in a Geographic Information System (GIS) by matching and distinguishing botanical formations.

SAMPLING AND SAMPLE PROCESSING

Three sediment cores were collected using a Russian Sampler. The geographical position of the cores was determined by GPS. Sediment color was classified according to the Rock-Color Chart (Goddard et al. 1984).

The cores were sampled from an area colonized by “várzea” (N 02°34'38”, W 50°53'17”), mangrove vegetation (N 02°35'59”, W 50°52'08”) and on a tidal sand-flat (N 02°36'48”, W 50°50'41”), and they were called Goiabal Várzea – GV (1.45 meter depth), Goiabal *Avicennia* – GA (1.65 meter depth) and Goiabal Praia – GP (1.45 meter depth), respectively (Fig. 1).

For pollen analysis, 1 cm³ sediment samples were taken at 5 cm intervals along the cores. Prior to processing the sediment, one tablet of exotic *Lycopodium* spores was added to each sample for the calculation of pollen concentration (grains/cm³) and pollen accumulation rates (grains/cm²/yr). All samples were prepared using standard pollen analytical techniques including acetolysis (Faegri and Iversen 1989). Sample residues were mounted in a glycerin gelatin medium. Identification of pollen grains and spores were based on pollen morphological descriptions (Roubik and Moreno 1991, Herrera and Urrego 1996, Colinvaux et al. 1999). Samples were counted to a minimum of about 300 pollen grains or to 100–200 pollen grains in the case of samples with a low pollen concentration. The total pollen sum excludes fern spores, fungal spores, algae and microforaminifers. Pollen and spore data are presented in pollen diagrams as percentages of the total pollen sum. Taxa were grouped into mangrove, herbaceous field, “várzea” and Amazon coastal forest. The softwares Tilia and Tilia Graph were used to the calculation and plot of the pollen diagrams (Grimm 1987).

RADIOCARBON DATING

Three bulk samples of 2 cm³ each were used for radiocarbon dating. The sediment samples were checked and mechanically cleaned under the microscope. The residual material was then extracted with 1% HCl, 1% NaOH at 60°C, and again 1% HCl (alkali residue). The alkali extraction of the organic fractions (humic acids) was precipitated with HCl, washed and dried. The ¹⁴C concentration of the samples was measured by comparing the simultaneously collected ¹⁴C, ¹³C, and ¹²C beams of each sample with those of Oxalic Acid standard CO₂ and coal background material. The samples were analyzed by the Accelerator Mass Spectrometry (AMS) at the Leibniz Laboratory of Isotopic Research at the Christian-Albrechts University in Kiel (Germany). The calibration of the radiocarbon dates was carried out following Stuiver et al. (1998). The results are reported in calibrated years before 1950 AD. (cal yr B.P.) with precision of 2σ.

RESULTS

TEXTURAL DESCRIPTION OF SEDIMENT CORES

The sediment cores from the Amapá coast were zoned in sixteen segments based on color gradient and qualitative grain size descriptions (Table I). The 145 cm-long Goiabal Várzea – GV core is mainly composed of homogeneous pelitic sediments rich in organic matter at the top. The core base (145–90 cm) shows grayish orange silty clay with light gray spots that grade upward into light gray mud (90–70 cm) and dark gray organic clay compacted (70–40 cm) in the middle of the core. A brown organic mud bioturbated with abundant root and leaf remains dominates the last segment (40–0 cm). The 165 cm-long Goiabal *Avicennia* – GA core consists of five muddy units, including: a lower (165–125 cm) dark brown unit, with decomposed plants and millimetric root marks; three intermediate (125–105 cm; 105–90 cm; 90–40 cm) light and dark gray units; and an upper (40–0cm) dark yellow unit with interbeddings of fine-grained sands. The 145 cm-long Goiabal Praia – GP core presents massive sand and silty sand with colors ranging from brown, grayish brown to yellowish brown and plants with a variable degree of decomposition from base to top.

TABLE I
Textural description of the sediment cores.

Core	Depth (cm)	Textural description
Goiabal Várzea	0–40	Brown organic mud bioturbated
	40–70	Dark gray organic clay, compact
	70–90	Light gray mud with dark gray and grayish orange spots
	90–145	Grayish orange silty clay with dark grey spots, very compact
Goiabal Avicennia	0–40	Dark yellow oxidized mud, with light gray spots, somewhat fine sandy
	40–90	Light gray mud, compact
	90–105	Dark gray organic mud
	105–125	Light gray mud
	125–165	Dark brown organic mud bioturbated
Goiabal Praia	0–30	Moderate brown sand
	30–50	Pale yellowish brown silty sand with very few root fragments remains, compact
	50–70	Grayish brown sandy silt phytoturbated, compact
	70–85	Moderate yellowish brown sand
	85–95	Grayish brown sandy silt, compact
	95–115	Moderate brown sand with dark brown spots
	115–145	Moderate yellowish brown sand

RADIOCARBON DATES AND SEDIMENTATION RATES

Radiocarbon dating of the GV core at 70 cm (KIA-28169), GA core at 127 cm (KIA-28170) and GP core at 137 cm (KIA-28171) depths yielded ages of 2100 ± 60 , 970 ± 35 and 3490 ± 140 cal yr B.P, respectively. The calculated sedimentation rates, based on the calibrated radiocarbon dates (Table II), are about 0.33 mm/yr (GV), 1.3 mm/yr (GA) and 0.39 mm/yr (GP), which are similar to sedimentation rates from other areas of the Pará coast, for instance, 0.3–1 mm/yr in the Marajó Island (Behling et al. 2004, Cohen et al. 2008), and 0.3–1.3 mm/yr in Taperebal (western Bragança) and Bragança Peninsula (Cohen et al. 2005a, Vedel et al. 2006). Besides, the sedimentation rates estimated in the study site are within the vertical accretion range of 8 to 0.1 mm/yr recorded in other mangrove forest (e.g. Bird 1980, Spenceley 1982, Cahoon and Lynch 1997).

Palaeoenvironmental studies on the Pará coast indicate a decrease in the sedimentation rate from the low to the topographically higher limit of the mangrove areas (Cohen et al. 2005a, Behling et al. 2001), which al-

lowed to propose a model of Holocene mangrove development to Bragança Peninsula-northern Brazil (Cohen et al. 2005b). Thus, the similar sedimentation rates between the Pará coast and the study site suggest that these sediments accumulated in a continuous way.

POLLEN DATA

Based on the pollen analyses of the GV, GA and GP cores (Fig. 1), three pollen profiles were developed, which show the different paleovegetation zones (Figs. 2, 3 and 4).

GOIABAL VÁRZEA RECORD

The GV core base, in Zone GV-1 (145–65 cm, 16 samples for pollen analysis), does not present pollen concentration suitable for statistical analysis. However, in Zone GV-2 (65–60 cm, 2 samples) a sedimentary unit occurs mainly with herbaceous pollen, constituted by Poaceae (40–45%) and Cyperaceae (5–20%). “Várzea” pollen is frequent and consists of Euphorbiaceae (18%) and *Mauritia* (2–11%). After this herbaceous field zone, the pollen becomes progressively less frequent,

TABLE II
Radiocarbon dates (AMS) of the samples.

Sample	Lab. number	Depth (cm)	Conventional C-14 age (yr B.P.)	Calibrated ¹⁴ C age (yr B.P.)
Goiabal Várzea	KIA-28169	70	2140 ± 25	2100 ± 60
Goiabal Avicennia	KIA-28170	127	1070 ± 25	970 ± 35
Goiabal Praia	KIA-28171	137	3260 ± 70	3490 ± 140

which characterizes again a barren interval with coal fragments restricted to Zone GV-3 (60–40 cm, 3 samples). The next zone, GV-4 (40–30 cm, 3 samples), is represented by Poaceae (16–95%), Cyperaceae (2–16%), Asteraceae (0–25%), Arecaceae (0–20%) and *Mimosa* (0–5%) pollen, which represent an herbaceous vegetation assembly. The top of GV core (Zone GV-5, 30–0 cm, 6 samples) is dominated by Euphorbiaceae (2–70%), Rubiaceae (2–60%), Fabaceae (2–25%), *Byrsonima* (0–47%) and *Mauritia* (0–14%) pollen, which characterizes the current “várzea” vegetation (Fig. 2).

GOIABAL AVICENNIA RECORD

The GA core bottom, in Zone GA-1 (165–100 cm, 14 samples), is marked by the dominance of herbaceous field pollen, mainly constituted by Poaceae (25–97%) and Cyperaceae (5–36%). The mangrove pollen percentage, represented by *Avicennia* (0–53%) and *Rhizophora* (0–25%), increases to the top of this zone. However, the samples in the Zone GA-2 (100–70 cm, 5 samples) did not present pollen (barren interval).

The next zone, GA-3 (70–40 cm, 6 samples), reveals a heterogeneous vegetation assembly. This zone is characterized by the herbaceous, Amazon coastal forest and mangrove pollen grains, mainly represented by Cyperaceae (6–40%) Poaceae (5–30%), Asteraceae (2–5%), Rubiaceae (5–20%), Fabaceae (0–30%), Euphorbiaceae (0–10%), Anacardiaceae (0–10%), *Rhizophora* (0–33%) and *Avicennia* (0–15%).

In the Zone GA-4 (40–10 cm, 7 samples), the herbaceous field (48–70%) and the Amazon coastal forest pollen (15–35%) are well represented, while the mangrove pollen decreases significantly (2–15%). However, the Amazon coastal forest and herbaceous pollens decrease progressively until Zone GA-5 (10–0 cm, 2 samples), which is marked by the mangrove pollen, mainly represented by *Avicennia* (35–40%) and *Rhizophora*

(5–10%). Nowadays, the study site is mainly colonized by *Avicennia* trees.

GOIABAL PRAIA RECORD

The Goiabal praia-GP core presents, for each sample, a mean pollen amount of one hundred (Fig. 4). The Zone GP-1 (145–80 cm, 13 samples) reveals a sector that was either unproductive or that contains only a few pollen grains. The next zone, GP-2 (80–30 cm, 11 samples), is characterized by the herbaceous, Amazon coastal forest and mangrove pollens, mainly represented by Poaceae (2–65%), Cyperaceae (1–5%) and *Avicennia* (2–10%). This vegetation assembly probably indicates a sediment deposition in a transition environment between herbaceous field and mangrove. In Zone GP-3 (30–0 cm, 6 samples) the pollen becomes less frequent, which characterizes again a barren interval.

In the case of the GP core, the low pollen quantity is probably due to the sediment grain size, because this core is constituted basically of sand. Grain size is the main factor determining the pollen preservation (Collinvaux et al. 1999). The pollen fixed in muddy sediments generally presents better preservation (Cohen 2003) ahead of the effects of biochemical action on pollen and spore structure (Sangster and Dale 1961, 1964).

DISCUSSION

THE POLLEN SIGNAL IN THE SEDIMENT

From the viewpoint of the palynology, there often exists two pollen components in sediment-pollen from “local” vegetation (the crown of the hat), and background pollen from “regional” vegetation (the brim of the hat) (Andersen 1970, Janssen 1973, Sugita 1994). The terms are useful, even though the distinction cannot be drawn sharply: the transition between the crown and brim is gradual, and the sizes of the crown and brim will differ for each pollen taxon (Davis 2000).

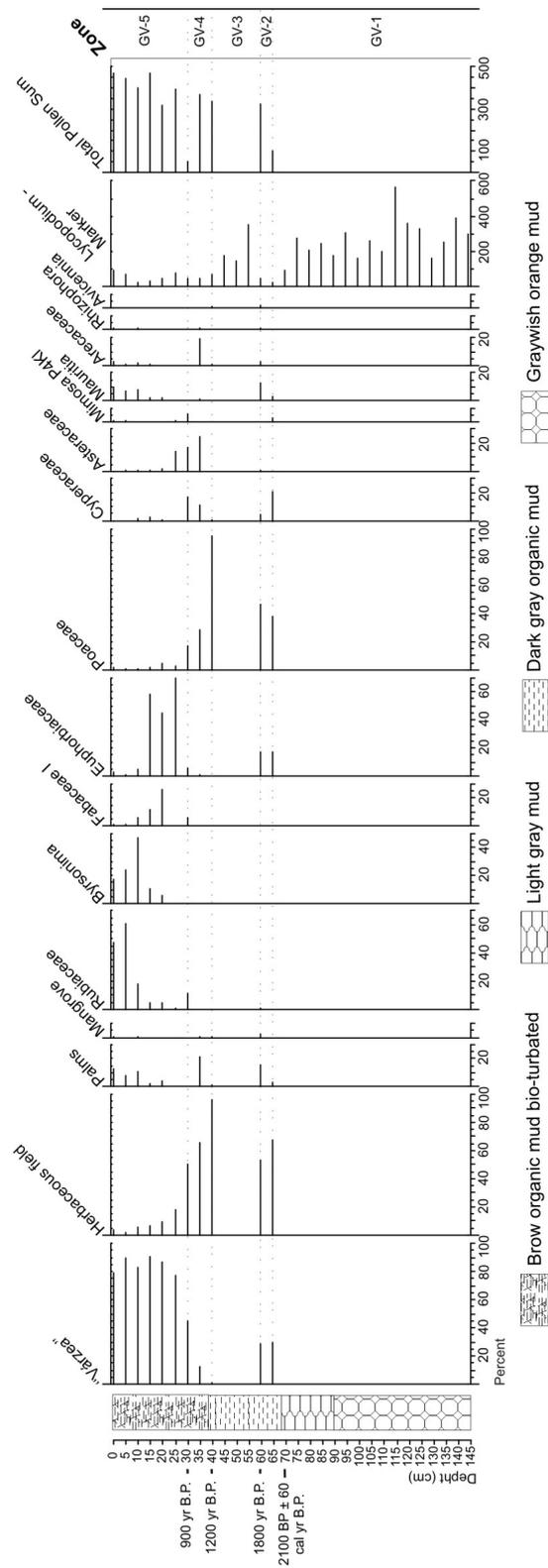


Fig. 2 – Textural description integrated to the pollen profile along the Goiabal Várzea core.

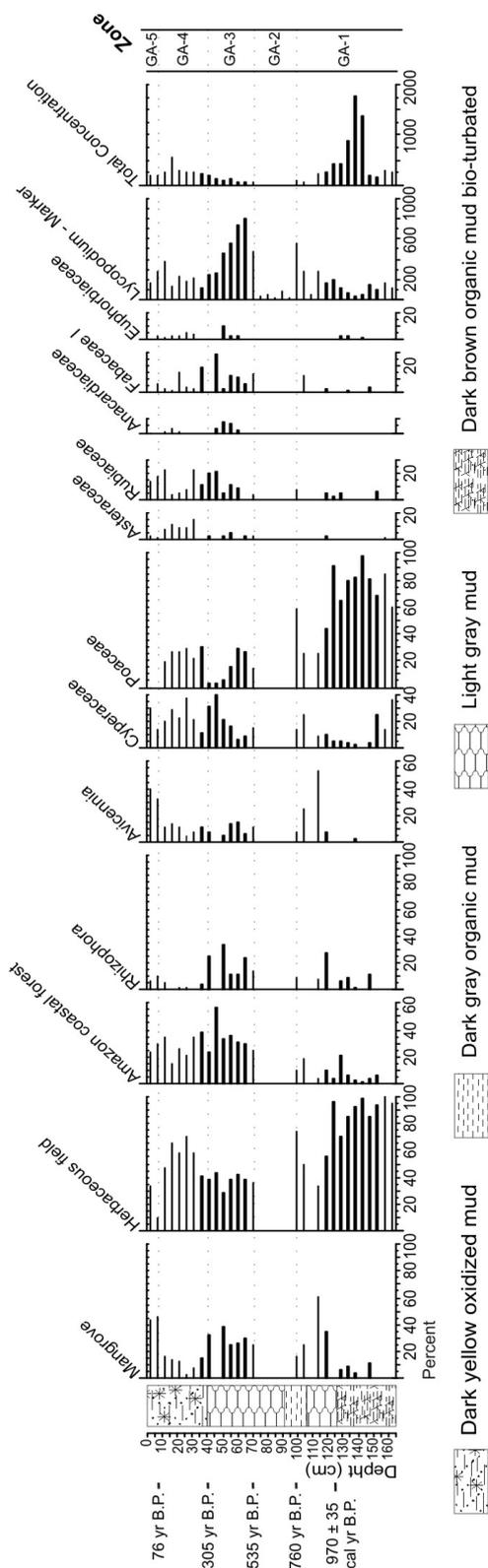


Fig. 3 – Textural description integrated to the pollen profile along the Goiabal Avicennia core.

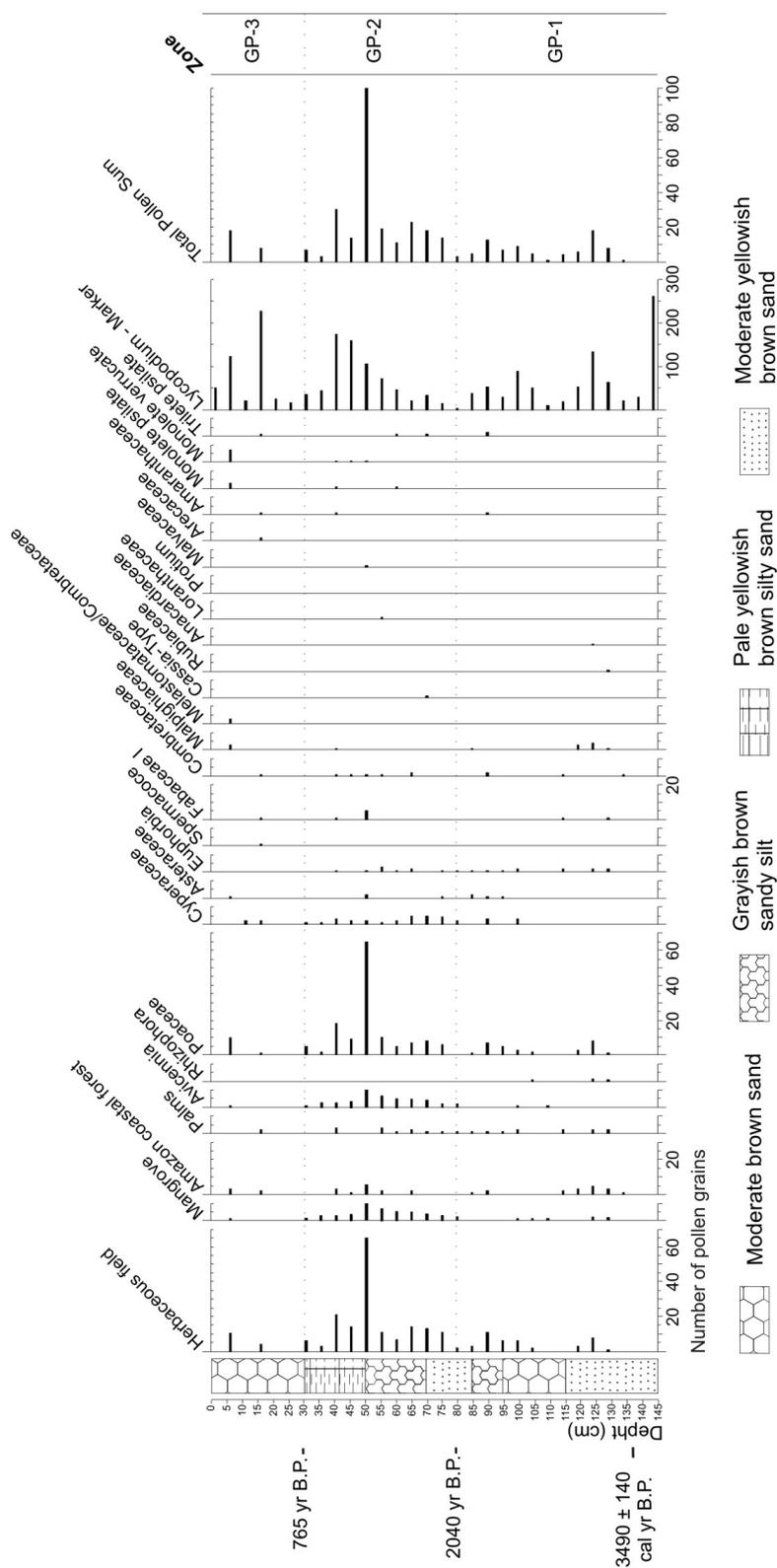


Fig. 4 – Textural description integrated to the pollen profile of Goiabal Praia core.

The pollen records of sediment cores assume that pollen accumulating in the sediment represents the vegetation above (local vegetation). Thus, the strength of the pollen signal from each kind of vegetation is distance-weighted (e.g. Davis 2000). The dates on the modern pollen accumulation rate from Bragança Peninsula-northeastern Pará coast indicate that, in the mangroves, *Rhizophora* is a very high pollen producer, while *Avicennia* and *Laguncularia* are very low ones. The pollen accumulation rates of *Rhizophora* and *Avicennia* on the *Rhizophora/Avicennia* dominated forest area are about 14,500 and 450 grains/cm²/yr, respectively. The pollen traps from the herbaceous plain site, which are located at least 1–2 km away from the next *Rhizophora* trees and 100 m away from the next *Avicennia*, document an average of 410 *Rhizophora* grains/cm²/yr and an average of 8 *Avicennia* grains/cm²/yr. This indicates that a certain amount of *Rhizophora* pollen grains can be transported by wind, while wind transportation of *Avicennia* pollen is very low (Behling et al. 2001). Therefore, regarding the Goiabal sediments, it would be reasonable to propose that the vegetation patterns, which probably extended about 1 km, will be reflected in pollen records of the sediment cores. Those contributions to pollen loading at the sampling site from each vegetation pattern on the landscape will decrease with the increasing distance from the sampling site.

THE WETLAND DYNAMICS

Krauss et al. (2008) described the effects that multiple ecological factors may have on mangrove development, such as salinity, light, nutrients, and flooding impact. In addition, they identified the importance of non-traditional factors – temperature, CO₂, and sea-level rise – as important drivers not only to mangrove establishment on a global scale, but also to seedling growth and persistence on a local scale.

Regarding the formation of the sedimentary deposits from mangroves, this can be described by a combination of models that include both lateral accretion and aggradation (e.g. Woodroffe et al. 1989), following the topographic zone of mangrove development (Cohen et al. 2005a). The analysis of sub-environments set within a depositional system by facies variation can indicate lateral sediment accretion. The lateral migration

of sub-environments coexisting within a depositional system produces deposits with different characteristics that are superposed upon each other in the stratigraphic column. This mechanism can be driven by changes in the flow energy through, for example, wave action or tidal currents in mangrove forest (e.g. Furukawa and Wolanski 1996, Cohen and Lara 2003, Cohen et al. 2005b). This process can produce displacement of wetland zonation due to modification of topography and flood frequency, imposing gradients in soil salinity. The wetland boundaries are displaced when the soil is inundated by brackish or saline tidal water. Therefore, there is no need to invoke only changes in seawater salinity to explain such vegetation migrations. This can also justify changes in a mangrove dominated by *Rhizophora* to one predominantly colonized by *Avicennia* according to changes in the topography, as the first mangrove genus has lower salinity tolerance than the second one.

Physical processes may be used to explain also the transition of terra firme to “várzea” vegetation. However, these mechanisms explain certain wetland migration, such as the “várzea”/mangrove one. Salinity is an essential physicochemical component for the survival of mangrove (e.g. Snedaker 1982, Clark et al. 1998, Alongi et al. 2000), while the “várzea” vegetation has low salinity tolerance (e.g. Wittmann et al. 2004, Junk 2005). Thus, it is probably necessary to invoke changes in tidal water salinity in this case.

GEOBOTANICAL UNITS FROM CALÇOENE: DEVELOPMENT AND DYNAMICS

Pollen records from coastal zones may be useful to identify paleo salinities of estuarine waters, since the plant assemblages, for example on Pará coast (e.g. Behling et al. 2001, Cohen et al. 2005a), follow well-known patterns. Salinity excludes competing and intolerant species (Snedaker 1978), leading to a characteristic species zonation (Baltzer 1970) and predictable types of community structure (Menezes et al. 2003), where the mangroves are more tolerant to soil salinity than the “várzea” forest (Gonçalves-Alvim et al. 2001). Soil salinity is basically controlled by flooding frequency (Cohen and Lara 2003), position along the estuarine gradient (Lara and Cohen 2006) and volume of river water discharge that depend of regional rainfall (Mörner

1999, Cohen et al. 2005b). The specific properties of propagules, namely their dispersal characteristics (Rabinowitz 1978), their mass arrival linked to individual storms (Eagler 1952, Pernetta 1993) and their resistance to consumption by predators (Smith et al. 1989), help to explain many features of the mangrove zonation. Flood tolerance (Naidoo 1985, McKee 1993) and the height of ground surface (Baltzer 1969, Chapman 1976) also indirectly control the zonation.

The term 'Mangrove' was used to denote the morpho-dynamic units within which mangrove forests are inserted. It includes the geophysical, geomorphic and biogeochemical components of the area (Thom 1984).

The sedimentary sequences, pollen records and distribution of modern vegetation types obtained from the study site, added to previously published models on mangrove development proposed to the Bragança Peninsula, northern Brazil (Cohen et al. 2005a), allowed to propose a model of wetland development to the Amapá coast according to its flood regime, sea-level and climatic changes during the Late Holocene. Based on these records, four development phases are proposed (Fig. 5):

Phase 1

The longitudinal profile did not reveal the occurrence of mangrove in the sediment deposited around 2100 yr B.P. (Zone GV-1). Sandy sediments covered topographically high areas and tidal flats, while the muddy sediments occupied coastal valleys.

Phase 2

The limited radiocarbon dates hinder a precise synchronization of the events. However, assuming a regular sedimentation rate within the sediment accumulation rates obtained to the Pará coast (Behling et al. 2001, 2004, Cohen et al. 2005a, b, 2008, Vedel et al. 2006, Lara and Cohen 2008), from 1900 until 1200 yr B.P., the mud progressively filled the depressions and tidal channels. The mangrove probably started its development on the channel edge, and the herbaceous field on the high sectors. At the end of this time period, a brown organic mud was accumulated simultaneously to the herbaceous field at GA and GV sites. Mangrove and the "várzea" forest are still incipient.

At the GP site, between 1100 and 800 yr B.P., an increase in grain-size occurred (silty sand to sand), probably originated from the increase in the water flow energy, which buried the mangrove area, while the GA and GV sectors present transitional environments with herbaceous field/mangrove and herbaceous field/"várzea", respectively (Zone GA-1 and GV-4).

Phase 3

The interruption of mangrove development in the zones GA-2 and GP-3, between ~760 and 530 yr B.P., indicates unfavorable conditions to mangrove development in these sectors, which may be due to the decrease in porewater salinity.

During this time interval, the "várzea" vegetation, adapted to fresh water flooding, expanded in GV area. This situation suggests that the study area may have been affected by a decrease in marine water influence.

Phase 4

Around 500 yr B.P., the environmental conditions favored the mangrove development in GA site, as well as the "várzea" increase in GV site. The distance of the sampling sites to the coastline, which determines the soil salinity with the topography (Lara and Cohen 2006), may explain the simultaneous mangrove occurrence on the GA and the "várzea" colonization on the GV site.

Between 300-80 yr B.P., a retraction of the mangrove area occurred in the GA, while the herbaceous vegetation increased or was kept constant. During this interval, a decrease in the porewater salinity may have occurred again.

The correlation between current patterns of geobotanical unit distribution and palaeovegetation indicates that mangroves and "várzea" forests are migrating over the herbaceous field on the topographically highest part of the studied coast.

CONCLUSIONS

The integration of pollen data, sediment descriptions and radiocarbon dating (AMS) allowed the assumption of a model of vegetation changes during the last 2100 years in Calçoene coast, Amapá. This study suggests interchanges between marine and freshwater influence.

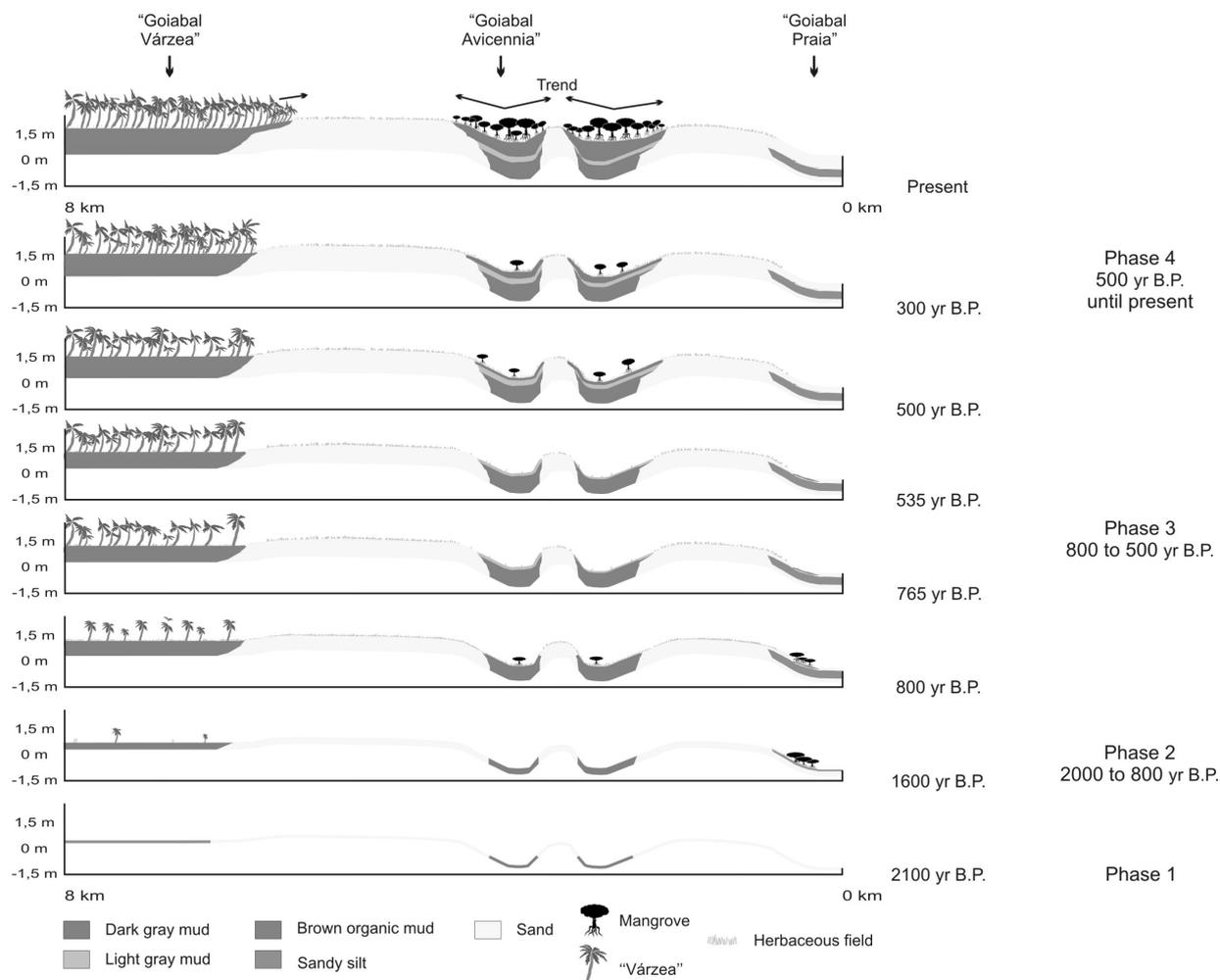


Fig. 5 – Model of wetland development in the Calçoene coastal plain.

The correlation between current patterns of geobotanical unit distribution and palaeovegetation indicates that mangroves and "várzea" forests are migrating over the herbaceous field on the topographically highest part of the study site, which can be related to a relative sea-level rise.

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RESUMO

Os tipos de vegetação atual, seqüências sedimentares, dados de pólen e datações por radiocarbono obtidas em três testemunhos de sedimento da planície costeira de Calçoene foram utilizados para estabelecer uma história paleoecológica durante o Holoceno superior das zonas úmidas costeiras do Amapá conforme as mudanças no regime de inundação, nível do mar e clima. Baseado nestes três registros, quatro fases de desenvolvimento da vegetação são apresentadas e provavelmente refletem a interação entre o fluxo de energia na acumulação do sedimento e a influência das águas salobras e doces na vegetação. Este trabalho sugere alternâncias entre períodos caracterizados por influências marinha e fluvial. O perfil longitudinal não revelou a ocorrência de manguezais nos sedimentos depositados por volta de 2100 anos A.P. Durante a

segunda fase, a lama preencheu progressivamente as depressões e canais de maré. Provavelmente, os manguezais iniciaram seu desenvolvimento nas margens dos canais, e os campos herbáceos nos setores elevados. A terceira fase é caracterizada por uma interrupção no desenvolvimento dos manguezais e a expansão da vegetação de várzea devido a uma diminuição na influência das águas marinhas. A última fase é representada pela expansão de manguezais e várzeas. A correlação entre os padrões atuais de distribuição das unidades geobotânicas e a paleovegetação indica que os manguezais e as florestas de várzea estão migrando sobre os campos herbáceos nos setores topograficamente mais elevados do litoral em estudo, o que pode estar relacionado a um aumento do nível relativo do mar.

Palavras-chave: rio Amazonas, mudanças climáticas, manguezal, palinologia, nível do mar.

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