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LATE HOLOCENE VEGETATION HISTORY AND ENVIRONMENTAL CHANGES FROM A SAVANNA – FOREST ECOTONE ZONE IN THE BANANAL ISLAND, BRAZIL

HISTÓRIA DA VEGETAÇÃO E MUDANÇAS AMBIENTAIS DURANTE O HOLOCENO TARDIO EM UMA ZONA DE ECÓTONO SAVANA-FLORESTA NA ILHA DO BANANAL, BRASIL

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Abstract

A sediment core taken from Quatro Veados lake located in a savanna-forest ecotone area in the Bananal Island (Brazil), allowed through palynological and AMS-radiocarbon analyses to reconstruct the local vegetation history and environmental changes during the last two thousands of years. From 2190 to 1470 years BP the forest types including *Bambusa*, *Cecropia*, Moraceae/Urticaceae, *Sebastiana*, Rubiaceae, *Sloanea* and Melastomataceae/Combretaceae settled the lake margins. Savanna vegetation dominated by Poaceae and marsh/lacustrine types dominated by Cyperaceae, *Eichhornia* and *Sagittaria* were less important. Between 1470 and 590 years BP the vegetation was marked by forest retreating events occurring simultaneously with peaks of marsh/lacustrine elements, indicating increase of the flooded area and/or upper lake water level. After 590 years BP until nowadays the forest maintained stable until reduces in the present day. On the other hand, the marsh/lacustrine types increased indicating higher lake water level. This palynological record revealed that climate conditions were wet similarly to present day and oscillation between periods of longer and shorter rainy seasons and duration of flooding events governed the vegetational dynamic due to increase or decrease of the lake water level or waterlogged soils.

Keywords: Bananal Island, Late Holocene, Pollen Analysis, Savanna – Forest Ecotone

Resumo

Um testemunho sedimentar coletado no lago Quatro Veados, localizado em uma área de ecótono savana-floresta, na Ilha do Bananal (Brasil), permitiu através de análises palinológicas e datação por radiocarbono, reconstruir a história da vegetação local e das mudanças ambientais durante os últimos dois mil anos. De 2190 a 1470 anos AP, os tipos florestais incluindo *Bambusa, Cecropia,* Moraceae/Urticaceae, *Sebastiana,* Rubiaceae, *Sloanea* e Melastomataceae/Combretaceae ocuparam as margens do lago. A vegetação de savana dominada por Poaceae e os tipos pantanosos/lacustres dominados por Cyperaceae, *Eichhornia* e *Sagittaria* foram menos importantes. Entre 1470 e 590 anos AP, eventos de retração da floresta ocorreram simultaneamente a picos de elementos pantanosos/lacustres, indicando aumento da área alagada e/ou subida do nível d'água lacustre. A partir de 590 anos AP a floresta se manteve estável, até retrair-se nos dias atuais. Por outro lado, os tipos pantanosos/lacustres aumentaram sugerindo um aumento do nível da lamina d'água. Esse registro palinológico revelou que as condições climáticas foram geralmente úmidas similarmente ao presente e as oscilações entre períodos chuvosos mais longos e mais curtos, e a duração dos eventos de inundação governaram a dinâmica da vegetação devido ao aumento ou diminuição do nível da água do lago ou dos solos alagados.

Palavras – chave: Ilha do Bananal, Holoceno Tardio, Análise Polínica, Ecótono Savana – Floresta

Introduction

The interest about the paleoclimates and palaeoenvironmental history of Quaternary landscapes has grown expressively in recent decades. In this context, a broad assortment of sedimentological, biological and chronological methods have been used for paleogeographical purposes. Among these tools it is noticeable the use of palynological data which have contributed plentifully to the reconstitution of the Quaternary landscapes, especially for Late Pleistocene and Holocene periods, since provide information about the paleovegetational succession and related paleoclimatic variability.

In this regard, several studies based on palynomorph data were carried out in the Cerrado biome, in central part of Brazil, and revealed the environmental changes in response to Pleistocene and mainly Holocene climate oscillations as for example, in Salitre (LEDRU, 1993), Lago do Pires (BEHLING, 1995), Cromínia (FERRAZ-VICENTINI and SALGADO-LABOURIAU, 1996), Lagoa Santa (PARIZZI ET AL. 1998), Águas Emendadas (BARBERI ET AL. 2000), Lagoa da Confusão (BEHLING, 2002), Lagoa Nova (BEHLING, 2003) and Lake Caçó (LEDRU ET AL. 2006). About the Holocene period, in all these places, wetter conditions prevailed during Late Holocene replacing the Middle Holocene drier conditions. Nevertheless, exceptional cases were verified for Laçador palm swamp (CASSINO and MEYER, 2013) and São José palm swamp (CASSINO ET AL. 2018), both located in north of Minas Gerais state that revealed a different tendency from the general pattern observed in other mentioned Cerrado sites. According to these researches, the climate was more humid in the Middle Holocene becoming drier in the Late Holocene especially during the last two millennia. These places are close to the southernmost occurrences of the Caatinga, a biome associated with the modern semiarid climate of the Northeast region of Brazil (CASSINO ET AL. 2018).

Considering the vast extent of Cerrado biome region and its high present floristic biodiversity, several areas have scarcely been studied, which prevents the improvement of a regional perspective about the vegetation dynamic, climate fluctuations and human activity as well as their interactions along the time.

The Tocantins state, for example, is the least studied, counting with only 3 pollen fossil records (BEHLING, 2002; MENDES ET AL. 2015; MENDES ET AL. 2021). The last two studies reaching only the last millennia interval, and then, little is known about its paleoenvironmental and paleoclimatical regional evolution.

The Tocantins state is characterized by presence of different ecosystems such as grasslands, savanna, palm swamps, dry forest (Cerrado biome), rainforest, Babaçu palm tree stands, besides the vast farming and pastures lands that currently are increasing progressively towards native vegetation formations. Various of these vegetation formations can be observed in the Bananal Island where configure a complex mosaic arrangement. The Bananal Island is located in the southwest of Tocantins state, in a ecotonal zone between the two dominant Brazilian biomes that are Amazon Rainforest and Cerrado.

The present work aims to study a sediment core from a lake so-called Quatro Veados lake (L4V), by palynological analyses in order to reconstruct vegetation, climate, anthropogenic action and other environmental changes in the northern region of Bananal Island during the Late Holocene. Therefore, we are supposed to response some questions as for example: 1) which drivers are responsible for savanna - forest boundary origin and maintenance? 2) What are the anthropogenic activities in the local and how they impact the landscape evolution?

Environmental Setting

The Bananal Island with an area of 20,000 km² is considered the largest fluvial island in the world (BORMA ET AL. 2009). This study was carried out in the northern part of the Bananal Island located in the Tocantins state (Fig. 1). This portion of the Bananal Island is a protected area by Araguaia National Park since 1959 which takes almost the whole island and comprising part of the Pium and Lagoa da Confusão municipalities (Fig. 1).

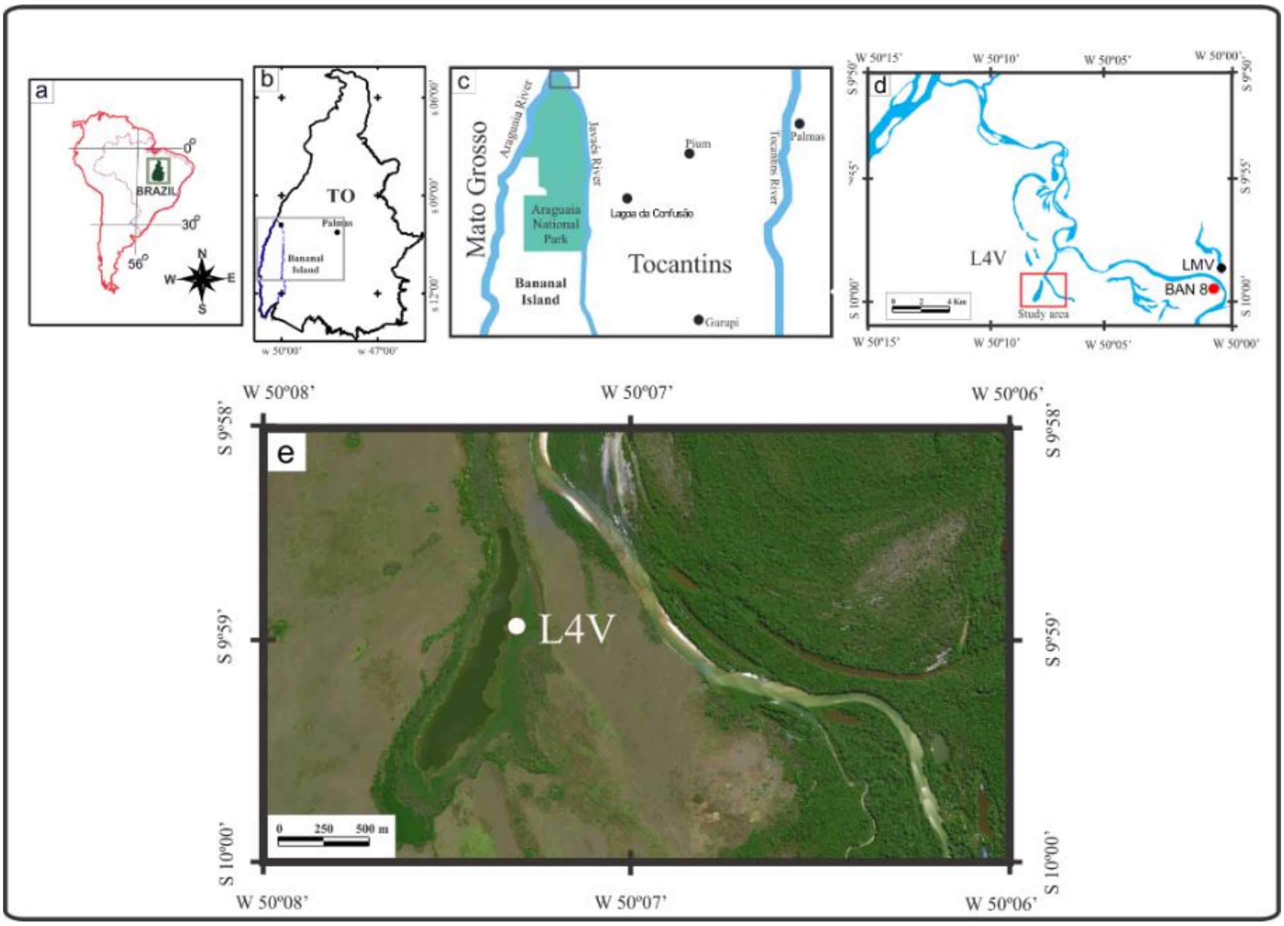
This portion of the island is a floodplain periodically flooded during the rainy season by precipitation of local waters, being classified as a seasonal wetland characterized by a fluvial-lacustrine plain, with numerous lakes, lagoons and intermittent channels (VALENTE ET AL. 2013).

The climate is tropical with two well defined seasons: a dry season and a wet season, which corresponds to the Aw in Köppen's Climatic Classification. The mean annual rainfall is about 1700 mm/year with more than 70% rainfall during the November and March interval. The annual mean temperature is around 24 °C.

The modern vegetation from this region is composed by a mosaic of forest and savanna vegetation describing an ecotone zone. In this context, grassland savanna, shrub savanna, wooded savanna and gallery forest physiognomies occur in the studied region. Grassland savanna presents a dominant herbaceous stratum with rare bushes and total absence of trees. This kind of vegetation is rich in species of the Poaceae family covering the plain and lowermost areas subjected to flooding with saturated water soils. The shrub savanna is a mixed herbaceous-shrub vegetation, with bushes scattering an extensive grassy covering. In the wooded savanna, *Byrsonima sp., Curatella americana* and *Tabebuia sp.* are the most important shrubs and trees types dispersed along the herbaceous stratum, occurring in a denser group occupying the relatively more elevated areas where the surface remains distant from the flooding or are affected by short flooding period only.

The gallery forest vegetation that consists of the perennial forest occurs alongside of Araguaia and Javaés rivers and their tributaries. Forest fragments are common along the abandoned channels and floodplains associated with shrubs or trees savanna species. The main representatives of gallery forest vegetation belong to Fabaceae, Myrtaceae, Euphorbiaceae and Rubiaceae families.

Figure 1. Localization map of the study area.



a) Geographic location of Tocantins State. b) Bananal Island location. c). Detail of Araguaia National Park localized in the north of Bananal Island. d) Study area: the red rectangle indicates the Quatro Veados lake detailed area; the red dot shows the previously studied Bananal 8 (BAN 8) site and the black dot illustrates the Lago da Mata Verde (LMV) location. e) Detailed Quatro Veados lake (L4V) coring site.

Material and Methods

The coring site is a lake about 3,613 m in circumference, located about 3.27 km from the right edge of Bananal Island (09°59'30.8" S and 50°07'45.1" W) (Fig. 1). A 50 cm long sediment core was recovered from Quatro Veados lake (L4V) using a Russian corer.

In total, two organic-rich bulk samples (1 cm thick) were taken for radiocarbon dating by accelerator mass spectrometry (AMS). Samples were dated at the Poznan Radiocarbon Laboratory in Poland. The derived age-depth model was used to guide intervals between subsamples taken for pollen analysis along the core. For pollen analysis, 26 subsamples (0.5 cm^3 each) were taken at 2 cm intervals along the core for pollen, spores, non-pollen palynomorphs, and micro-charcoal particles analyses. All samples were prepared using adopted methods including hydrofluoric acid treatment (FAEGRI and IVERSEN, 1989), as well as acetolysis method by Erdtman (1952). It was added one tablet of exotic *Lycopodium clavatum* (20,848 ± 1,546) spores to each sample to determine the pollen concentration (grains/cm^3) and pollen accumulation rate (grains/cm^2/yr).

A minimum of 300 pollen grains were counted for each sub-sample. The identified taxa were grouped by ecological affinities according to habitat, such as forest, floodplain forest, marsh/lacustrine, palm tree, savanna, algae, fern spores, and the sum of pollen groups. In addition, charcoal particles (5–150 µm) were counted on pollen slides and presented as charcoal concentration (particles/cm³)

The pollen sum includes trees, shrubs, and herbs and excludes aquatic taxa, fern and moss spores, and colonies of the algae *Botryococcus*. Pollen and spore data are presented in pollen diagrams as percentages of the pollen sum. The software TILIA, TILIAGRAPH, and CONISS were used for illustration of the pollen and spore data, calculations, and cluster analysis (GRIMM, 1987).

Results

Landscape, Core Stratigraphy and Radiocarbon dates

The Quatro Veados lake landscape is locally constituted by an extensively flat relief slightly depressed towards the inner portion of the Bananal Island. The vegetation spatial arrangement follows the relief patterns. Thus, in the border of the island on more elevated topography (e.g. marginal levee) occur wooded savanna with savanna trees and shrubs scattering the herbaceous stratum which is dominant around the lake at swampy area and along the neighboring low and flattened surfaces. An isolated forest block occurs close to the sampled lake left margin on higher well-drained terrains (Fig. 2).

Figure 2. Aspects of the Quatro Veados lake landscape, showing the flat topography and vegetation types around the lake.

The local soil is composed by a superficial gray clayey horizon with 40 cm of thickness on average covering sandy sediments layers possibly old bars that were overlapped by a recent settled floodplain, nowadays under poor drainage conditions during the rainy season. All these features were favorable to establishments of several stagnant water bodies similar to the Quatro Veados lake whose morphological features indicate to be abandoned fluvial channels during avulsions processes very common in this landscape according Latrubesse (2015).

The L4V core was 50 cm long and 5 cm thick. Its constitution from the base to 40 cm was represented by sediment characterized as black sandy clay loam. Between 40 cm and the top the sediment comprises a black silty clay, being enriched in leaves and roots fragments from 20 cm to the top.

Ages obtained by ^{14}C analysis indicated that the studied core deposition occurred entirely during the Late Holocene. The dating from the 40 cm revealed to be 1555 ± 30 years BP and the sample at 20 cm was dated in 365 ± 30 years BP. The obtained and calibrated ages from L4V core samples are shown in Table I.

Table I. Radiocarbon dating and calibrated ages.

Depth	Lab. cod.	Conventional Age 14C BP	Calibrated Age (cal yr BP)
20	Poz- 97377	365±30	429
40	Poz-97376	1555±30	1465

Description of the pollen and charcoal record

The record contains about 65 different pollen types dominated by Cyperaceae, Poaceae, *Bambusa*, *Mimosa*, *Sagittaria*, *Cecropia*, Moraceae/Urticaceae, *Byrsonima*, *Eichhornia* and *Sebastiana* (Fig. 3 and 4).

A total of 72 *taxa* of palynomorphs were identified along to the L4V core, including taxa of algae/fungi, pteridophytes and angiosperms. The concentration of carbonized particles was also analyzed. The pollen diagram (Figs. 3 and 4) shows the distribution of palynomorphs which were grouped according to their ecological affinities (habitat) The distribution was supported by Marchant et al. (2002) as well as based on local observations. The sum of environmental groups is shown in figure 5. The cluster analysis (CONISS) discriminate analyses the major paleofloristic changes occurring in pollen groups. It was possible to establish four distinct ecological phases, L4V I, L4V II, L4V III and L4V IV, which are described below in an ascending stratigraphic order. Charcoal particles were frequent throughout the record.

Phase L4V I (50 to 40 cm: 2190 to 1470 cal yr BP). This phase was characterized by the abundance of forest components (31-53%), which are dominated by pollen of *Bambusa* (3-20%), *Cecropia* (2-8%), Moraceae/Urticaceae (2-8%), *Sebastiana* (3-8%), Rubiaceae (0-4%), *Sloanea* (0-4%), *Mimosa* (0-3%), Melastomataceae/Combretaceae (0-3%), Fabaceae Cesalpinoideae and Fabaceae Mimosoideae (0-3%), Myrtaceae (0-2%), Anacardiaceae, Euphorbiaceae and *Mabea* (0-2%), *Piper* and other *taxa* are less than 2%. The savanna ecological group consists mainly of Poaceae (15-24%), *Byrsonima* (2-7%), Curcubitaceae (0-2%), *Roupala* (0-2%), *Anadenanthera*, *Borreria*, *Curatella* and *Solanum* pollen (0-1%), that presented pollen sum between 22 and 35%. The ecological group marsh/lacustrine showed percentages between 12 and 27%, dominated by Cyperaceae type 1 (6-22%), *Eichhornia* (1-7%) and *Sagittaria* (2-5%), Lentibulariaceae, *Ludwigia* and Polygalaceae (0-1%). The group of palm trees pollen computed 0-2% and floodplain forest computed percentage of 0-1%. Algae amounted 23 to 28% almost composed by *Botryoccocus*, and a fungi identified as a type of *Bryophytomyces sp.* (5-10%), pteridophytes spores only 0,1%.

Phase L4V II (40 to 24 cm: 1470 to 590 years cal BP). This phase was characterized by the abundance of forest components (34-63%), which are dominated by pollen of *Cecropia* (0-28%), *Bambusa* (8-19%), Moraceae/Urticaceae (2-7%), *Sebastiana* (1-5%), *Alchornea* (0-5%), Fabaceae Papilonoideae (0-4%), Melastomataceae/Combretaceae and Rubiaceae (0-4%), *Mimosa* (0-4%), Anacardiaceae and Myrtaceae (0-3 %), *Celtis* (0-3%) and other taxa are less than 2%. The savanna ecological group consists mainly of Poaceae, *Byrsonima*, *Roupala*, *Alibertia*, *Borreria*, Dilleniaceae and *Spermacoce*, presented pollen sum between 14 and 35%. The ecological group marsh/lacustrine showed percentages between 13 and 34%, dominated by Cyperaceae type 1 (6-15%), *Sagittaria* (3-15%) and *Eichhornia* (1-7%). The group of palm trees computed 0-1% and floodplain forest does not appear. Algae amounted 23 to 38% almost composed by *Botryoccocus*, and a Fungi *Bryophytomyces sp.* (6-14%), pteridophytes spores only 0,2%.

Phase L4V III (24 to 8 cm: 590 years cal BP to the present). This phase was characterized by the rise of marsh/lacustrine vegetation (30-48%), which are dominated by *Sagittaria* (10-25%), Cyperaceae type 1 (11-24%), *Eichhornia* (1-6%), Lentibulariaceae (0-4%) and *Cuphea* pollen (0-2%). Forest continues being abundant (27-44%) and dominated by *Bambusa* (7-15%), *Mimosa* (1-13%), *Cecropia* (2-11%), Moraceae/Urticaceae (1-8%), *Sebastiana* (0-6%), Euphorbiaceae (0-4%), Flacoutiaceae, *Psicotrya* and Rubiaceae (0-3%), Myrtaceae (0-2%), *Alchornea* and Melastomataceae/Combretaceae (0-2%), Anacardiaceae, Annonaceae, *Celtis* and Fabaceae Papilonoideae (0-2%), and other taxa are less than 2%. The savanna ecological group consists mainly of Poaceae (7-22%), *Byrsonima* (1-9%), *Borreria* (0-2%), and other less than 2% presented pollen sum between 15 and 30%. The group of palm trees and floodplain forest computed percentage of 0-1% each one. Algae amounted 26 to 32% almost composed by *Botryoccocus*, and fungi *Bryophytomyces sp.* (0-9%) and pteridophytes spores only 0,6%.

Phase L4V IV (8 to 0 cm: present day). In this phase the marsh/lacustrine vegetation continues to be dominant (38-54%) showing a peak at the top of the core, but now it is dominated by Cyperaceae type 1 (31-38%), Cyperaceae type 2 (0-19%), *Sagittaria* (0-5%), *Eichhornia* (0-3%) and *Cuphea* pollen (0-1%). Forest taxa are abundant (31-45%) and dominated by *Mimosa* (9-29%), *Bambusa* (2-6%), *Cecropia* (3-5%), Rubiaceae (1-4%), Moraceae/Urticaceae (0-4%), Asteraceae (0-3%), Myrtaceae (0-3%), Melastomataceae/Combretaceae (0-3%), and other taxa are less than 2%. The savanna ecological group decreased, being Poaceae (7-22%), *Byrsonima* (1-9%), *Borreria* (0-2%), *Roupala* (0-2%), *Acalypha* (0-1%) and the presented pollen sum is between 15, and 30%. The group of palm trees and floodplain forest computed percentage of 0-1% each one. Algae amounted 26 to 32% almost composed by *Botryoccocus*, and a fungi *Bryophytomyces sp.* (0-1%), pteridophytes spores only 0,6%.

Figure 3**.** Pollen diagram percentages of L4V core with *taxa* included in ecological groups such as Forest. It features a 7x exaggeration to better visualization of pollen types with low percentages.

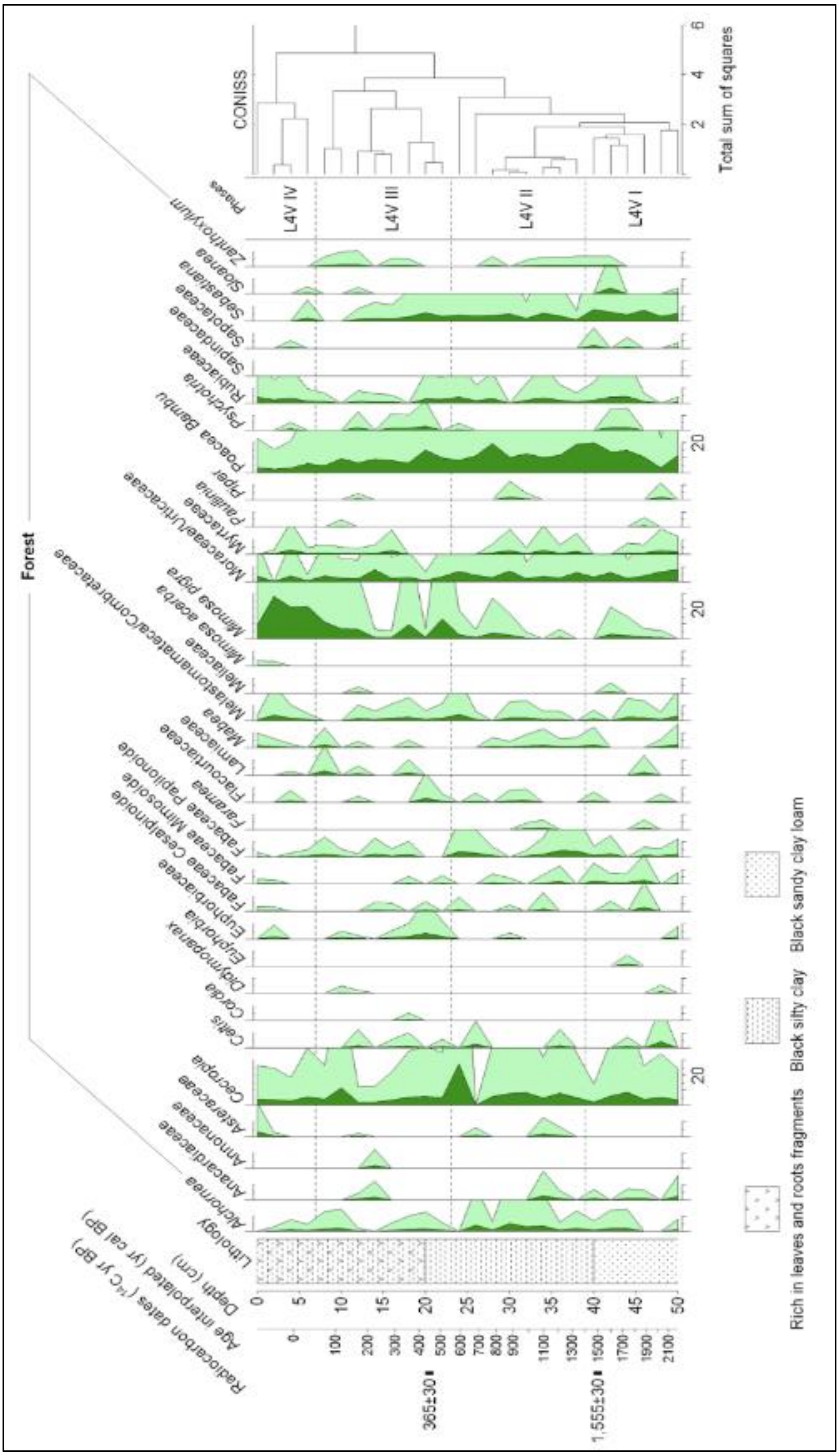


Figure 4. Pollen diagram percentages of L4V core with *taxa* included in ecological groups such as Forest, Floodplain Forest, Marsh, Palm Trees, Savanna, Algae/Fungi, Spores (Pteridophytes). It features a 7x exaggeration to better visualization of pollen types with low percentages.

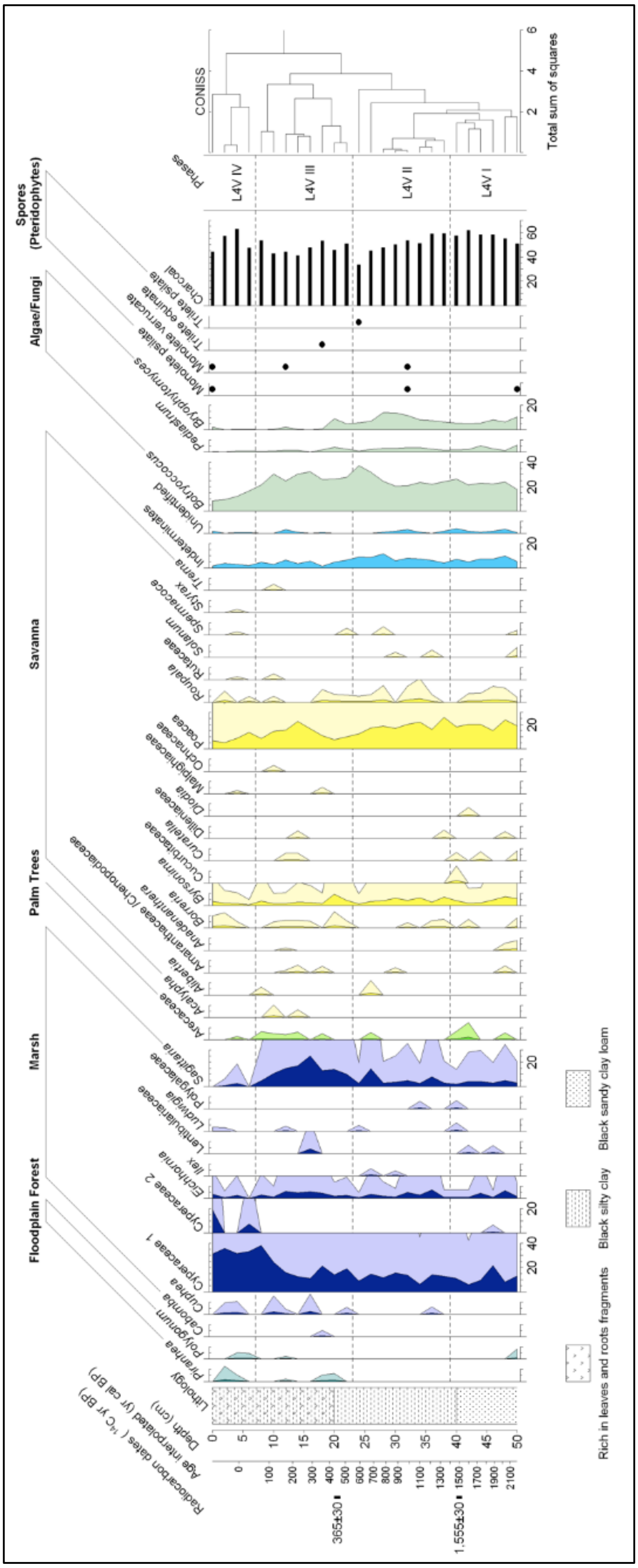
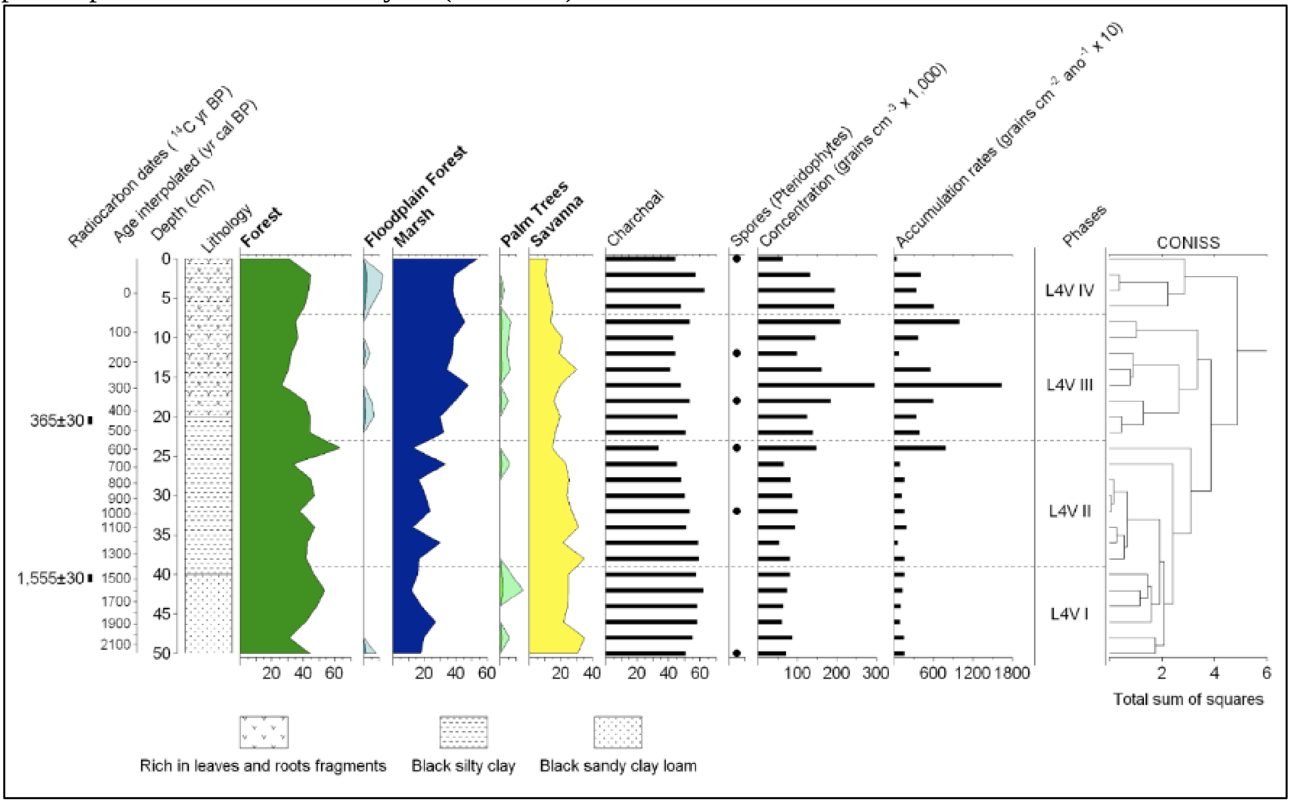


Figure 5. Summary pollen diagram showing radiocarbon ages, interpolated and extrapolated ages, lithology, ecological groups, pollen concentration and accumulation rate, charcoal concentration, pollen phases and cluster analysis (CONISS).



Discussion

Vegetational history and environmental changes in the Bananal Island during the last 2000 years BP

The pollen record retrieved from Quatro Veados lake situated in a savanna-forest ecotone inside the Bananal Island provided information about the climate conditions and vegetational dynamic as well as the fire history and revealed few environmental changes occurred during the last two thousands of years. In a general way, the climate conditions were wet similarly to situations verified in the most of the studied places in the Cerrado region for the Late Holocene period (LEDRU, 1993; BEHLING, 1995; FERRAZ-VICENTINI and SALGADO-LABOURIAU, 1996; PARIZZI ET AL. 1998; BARBERI ET AL. 2000; BEHLING, 2002; BEHLING, 2003; LEDRU ET AL. 2006).

The lowermost radiocarbon date shows which the depositional process indicative of establishment of the lake began at around 2190 cal yr BP. From this period until 1470 cal yr BP, a forest enriched in *Bambusa*, *Cecropia*, Moraceae/Urticaceae, Melastomataceae/Combretaceae and *Sebastiana* occurred close to this lake. In this period, the savanna vegetation also was present in the lake adjacencies. The proportion of savanna decreased from middle to end of this period. The pollen grains typical for marsh/lacustrine environments like Cyperaceae and *Sagittaria* also decreased suggesting a size reduction of the surroundings flooded areas. At the end of the period, the forest vegetation, by other hand, expanded as result of the lowered water table and reduced soil saturation caused by lower rainfall rates (if compared to present day) or more probably to a short rainy seasons with shorter duration of the flooding. This interpretation is based on the fact that waterlogged soils inhibit the growth of the Cerrado arboreal formations being a controlling factor of vegetation distribution pattern in this biome (GIBBS ET AL. 1983). Thus, the duration of flooding events controls the vegetation dynamics, for example, periodic flooding that persists for a long time avoid the forest expansion.

During the period between 1470 and 590 cal yr BP, the nearby forest continues being abundant, however, retreating events are observed. At the end of this period a peak of forest is noticed due increase of the pioneer *Cecropia* indicating forest regeneration. Simultaneously to forest retreat occasions, peaks of marsh/lacustrine elements, mainly Cyperaceae and *Sagittaria* appear indicating increase of the flooded area and/or upper lake water level. This scenery suggests that occurred fluctuation between drier and wetter periods with shorter and longer rainy seasons respectively. Therefore, longer rainy seasons produced increase of the flooded areas catchment which diminished the forested areas being restricted to more elevated terrains like for instance the adjacent well-drained fluvial belt. On the other hand, shortened rainy seasons caused reduction of the flooded areas and lower lake water level which permitted expansion of the forested areas towards the lake margins. However, a long duration of drought season would be not favorable to forest expansion and possibly arboreal savanna would settle in this area.

Since 590 cal yr BP until the present day the vegetational changes were marked by decrease in the forested area occurred in the middle of this period while the marsh/lacustrine components increased with presence of Cyperaceae and *Sagittaria.* The proliferation of the *Botryococcus* algae reinforces the presence of an extensive lake and expansion of the flooded areas with stagnant water body added. These indicators support the occurrence of wetter climate conditions with rainy seasons similarly to nowadays.

For the last recorded phase that corresponds to the present day, the pollen spectrum reflects a scenery marked by increased forested areas being in this turn *Mimosa pigra* the main taxa. *Mimosa pigra* is well-known invasive species in tropical wetlands that is reduced when the lake water level abruptly increases at the final of the phase. Savanna vegetation maintain lower representation occurring around the lake as observed now in the local.

The low occurrence of pteridophytes and bryophytes spores meaning that ferns were absent as result of lack of shadow in the environment, indicating that forest vegetation did not occur locally and the pollen types came from the adjacent forest. This pollen record shows vegetational stability along the recorded period with few environmental changes due to humidity fluctuations with longer and shorter flooding duration under a wet climate. In spite of the modern moister climate predominance, the forest formations did not expand over the savanna area as it was expected and also probably did not establish around the lake. Besides the climate, several other environmental variables may influence the floristic components variation, including topography, substrate mineralogical and chemical composition, water table fluctuations, fire events and edaphic factors. According to Gibbs et al. (1983), the variations in soil water table, fires, herbivory and human disturbances are considered important factors in the determination of the floristic composition and heterogeneity of the South American savannas. In case of the Bananal Island we understanding that a team of factors are responsible by the vegetation control especially the flooding caused by rainy seasons and rising of water table which causing hydromorphic situations inhibits the forest installation. Thus, the existence of a wetter climatic conditions is not favorable for forest growth once the presence of wetlands that can becomes longer and reaches bigger areas and then favoring the kept or expansion of savanna instead rainforest.

Similar situation was noticed in an Amazonian savanna-forest ecotone area situated in the north portion of Roraima State, Brazil by Meneses et al. (2013) and Meneses et al. (2015). The authors studied the vegetational dynamic during the Late Holocene and their findings revealed that hydromorphic conditions are one of the factors that block the expansion of the forest formations even under modern wet climate. Additionally, the fire frequency has been another of the key drivers of open vegetation maintenance in that savanna-forest ecotone region as pointed by the mentioned authors.

About the fire activity we consider which charred particles counted at the sedimentary sequence as suggestive for natural origin once no other anthropogenic indicators (e.g presence of palms) were recorded in the studied area during this recorded period. In fact, the flooded areas conditions become this region non attractive for people establishments. Because of this, the vegetation in the northern Bananal Island is one of the few remaining large and intact areas in Central Brazil with no important anthropic interference. On the other hand, in the non-floodable areas placed in the southern portion of the Bananal Island that is inhabited by indigenous and non-indigenous people, several anthropic activities, especially cattle raising and man-made fires have been occurring along the last decades and even in the present day.

Comparison with previous studies in the Bananal Island and adjacent region

The results presented in this work are partially comparable to the previously pollen record (Bananal 8 site) studied by Mendes et al. (2015). The Bananal 8 site is a small lake placed approximately about 13 km far from the Quatro Veados lake, also in the north portion of Bananal Island. Nevertheless, it is currently surrounded by forest instead savanna as occur in Quatro Veados lake and its pollen record presented the vegetational and climate history for the last millennium.

The Mendes et al. (2015) findings exposed that the last millennium was dominated by forest reflecting a wet climate and three different phases were recognized. Thus, at the beginning of the record between 920 and 770 cal yr BP the wet climate and high rainfall produced flooding during long rainy seasons that maintained the Javaés River connected to the studied lake, and hence, this environment was marked by the presence of a homogenous forest rich in Moraceae/Urticaceae. In Quatro Veados lake this time interval (zone L4V II) was marked by lower lake water level and dominance of forest too. Supposedly the lake was in its initial phase indicating increase of humidity and the forest was closer than the following phases. Comparing both sites, it is possible to infer that climate was wet.

During the following period (770-300 cal yr BP) the reduced rainfall and shortening of the rainy seasons isolated the lake Bananal 8 from the Javaés River for long period which caused a diversification of the forest and gave rise to the appearance of the components of floodplain forest and marsh vegetation adapted to waterlogged soils. During this period Poaceae and Cyperaceae settled the lake margins, while the *Pediastrum*, a genus of Algae colonized the water surface evidencing the lacustrine trait of this environment. Thus, drier conditions were observed that shortened rainy seasons and diminished the flooded areas allowing the expansion of forested areas and higher diversity in its floristic composition as seen in the pollen diagram. In Quatro Veados lake area, for this period that is corresponding to L4V II and entire L4V III phases we observed fluctuation between dry and moist periods responsible by growth and decrease of forest plants. However, these types were especially the short-lived *Cecropia* and *Bambusa* that are well-known pioneers in forest regeneration. No clear evidence was found for supporting drier climatic conditions at the Quatro Veados lake. On the contrary, especially from the 590 years an increasing moisture trend is noticed due growth of aquatic plants suggesting enlargement of the wetland area.

During the last 300 years cal yr BP the Bananal 8 environment remained dominated by this diverse forest and the lacustrine conditions with a slight increase of moisture at the end of this phase that caused the increase of *Piranhea* a genus typical of Amazonian floodplain forests. In the Quatro Veados lake we observed an increase of humidity at the uppermost core corresponding to present day situation. In a general way our results are coincident with the study carried out previously in Bananal Island. As about the occurrence of the fires, Mendes et al. (2015) did not register particles of charcoal along the sedimentary sequence, possibly due the local forest was buffering the input of particles into the lake. Our results, by other hand, shown a constant occurrence of charred particles along the core, however, it is attributed to natural origin, probably resulting of the dry seasons savanna burning and apparently did not have a clear importance in the vegetational dynamic, because it was produced by lake water level oscillation.

In this context, a recent work published by Mendes et al. (2021) exposed through modern and pollen fossil data the last 400 years of the vegetational history from the Lago da Mata Verde. This lake is placed outside the Bananal Island domains, however is geographically nearby (13 km eastern, see figure 1 for location information) and belongs to Javaés river floodplain. The results showed that during the last 400 years this site was bordered by forest reflecting a wet climate with some increase of the flooded margins in the present day.

The pioneer palynological study for Tocantins state was carried out by Behling (2002) from lacustrine sediments core sampled of the Lagoa da Confusão situated about 157 km from the Quatro Veados lake. The recorded time interval extended since Late Pleistocene until Holocene times. Regarding the just Holocene period, the author assumed wetter climate conditions trend along the entire early and middle Holocene period if compared to Late Pleistocene. Furthermore, after 5460 cal yr BP forest cover increased markedly by the expansion Amazon forest populations and palm trees, reflecting the wettest climate period recorded.

Overall the results from Quatro Veados lake are accordingly to the general trend of wet climate conditions, as reported from other studies carried out in the region (BEHLING, 2002, MENDES ET AL. 2015, MENDES ET AL. 2021).

The Late Holocene in South American wetlands and savanna-forest ecotones

The Late Holocene history has been reconstructed in several environments along the South America places. To correlate the data from Bananal Island history we are considering the similar places conditions such as wetlands and savanna-forest ecotone regions. The Bananal Island is placed in one of the biggest wetlands in the South America that is the Araguaia river basin. In regions like that, according to Junk et al. (1989), the flooding is the main force in wetlands systems, because it controls the production patterns, influences decomposition and nutrient cycles in water and soil. Thus, the effects depend on the duration and hydrologic energy of the flood events. According them, the highest rates of production occur within periodic floods of short duration (oxidant conditions) due to the subsiding of nutrients and water, whereas stagnant flooding of long duration (anoxic conditions) causes physiological stress and results in lower production.

In order to understand the climate changes along the geological time and their effects in every landscape is necessary to comprehend the vegetation composition and its ecological behavior face to environmental changes as the nature and duration of floods, presence of humans, fire events, among others. According to Urrego et al. (2006), the vegetational composition is severally influenced by river water levels and drainage conditions. In Colombia, for instance, the studied floodplain forests show increase of *Mauritiella* and *Campnosperma* populations during the Late Holocene as result of flooding with better drainage. The increasing abundance of palms verified around 3500 cal yr BP in Laguna Piusbi (BEHLING ET AL. 1998), and around 3000 cal yr BP in Pantano de Monica area (BEHLING ET AL. 1999), located in Colombian Amazon lowlands region, were response to markedly wetter climatic conditions and also human disturbance. In the region of Bolivian lowlands, also a probable increase in precipitation facilitated an expansion of the Amazon rainforest, especially during the last 3000 years (MAYLE ET AL. 2000; BURBRIDGE ET AL. 2004).

In the Central Amazon forested areas during the Holocene period a moister climate was documented in Lake Tapajós, in the eastern Amazon, due presence of unchanged forest around the lake (IRION ET AL. 2006), since the last 4300 years BP. However, the abundance of Poaceae and *Cecropia* suggested an increase in human activity in the region according them.

Studies carried out in a region of ecotone savanna/forest located in north portion of the Roraima State (MENESES ET AL. 2013; MENESES ET AL. 2015) showed expansion of forest over the savannas cover during the Late Holocene in response to wetter climate dominance. According the authors, despite wetter climate situation, cycles of the forest contraction occurred related to fire events and from the last 300 years BP the forest expanded due to reduction of fire events. Besides, increase of forest over savanna, the spread of *Mauritia* palms swamps authors is another indicative of humidity increase in the region during the Late Holocene. In Bananal Island the seasonal flooding and water levels hamper the *Mauritia* palm swamps establishments, because this type of vegetation does not tolerate long duration of flooding conditions as occur in this region during long periods. About the fires, we consider the found charred particles as result of natural fires since grasses are burnt during the seasonal drought and its occurrence is not the reason for forest expansion hampering.

In summary, all these studies carried out in different regions of savanna-forest ecotones and wetlands indicated the dominance of a wetter climate during the Late Holocene comparable to the present, as shown in this study for the Bananal Island.

Conclusions

The pollen and charcoal record show that during the last 2190 cal yr BP the climate conditions were wet in the north region of the Bananal Island, similarly to present day. Alternations between periods of longer and shorter rainy seasons and duration of flooding events caused shrinkage and advance cycles of the forest along the studied period with few changes in vegetation composition due to increase or decrease of the lake water level or waterlogged soils. Even though of moist climate being favorable to forest expansion, environmental characteristics such as low waterproof terrains due superficial clayey soils, flattened and low surface added to long rainy seasons and high rainfall rates cause water table elevation and inhibits the establishment of forest formations, because of persistent hydromorphic conditions. So, the maintenance of savanna vegetation can be explained by a long duration of the flooding with a longer soil saturation situation.

In spite of the data provided by this project and other previous studies carried out in this region, the diversity of environments and features found across that wetland savanna-forest areas requires more investigations, in order to identify accurately the mechanisms that built this regional land and the environmental changes which probably occurred. It is extremely necessary to accomplish multi-proxy studies in other localities of this region in Bananal Island and surroundings which will allow distinctions between local effects and regional trends related to climatic changes.

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