Modern and fossil pollen record from the Middle Araguaia River Floodplain, Tocantins State, Brazil

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Abstract. The Araguaia River is one of the most important hydrographic basin in Brazil. Its drainage system reaches two dominant Brazilian biomes that are Amazon Rainforest and Brazilian Cerrado. This study was carried out in a zone of ecotone between rainforest and savanna formations (belonging to referred biomes respectively), situated in the Middle Araguaia River basin, specifically at the floodplain of Javaés River, its tributary by right margin, in the State of Tocantins. The goal of this present study was to provide information about the vegetational succession in this forest-savanna ecotone area, in order to contribute to the understanding of this landscape dynamics. For this reason, a sedimentary core collected from a lake (Lago da Mata Verde) was submitted to palynological and radiocarbon dating analyses. 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 modern pollen rain and local vegetation data supported in the interpretation of the fossil pollen results. Our findings are according to other studies carried out in the similar ecotone zones and floodplains in Amazonian regions during the Late Holocene.

Keywords. Lacustrine sediments, Late Holocene, pollen analysis.

Resumo. REGISTRO POLÍNICO FÓSSIL E ATUAL DE UMA PLANÍCIE DE INUNDAÇÃO DO MÉDIO RIO ARAGUAIA, ESTADO DE TOCANTINS (BRASIL). O rio Araguaia constitui uma das mais importantes bacias hidrográficas brasileiras. Seu sistema de drenagem atravessa dois dominantes biomas brasileiros a saber o bioma Amazônico e o Cerrado brasileiro. Este estudo foi realizado em uma zona de ecótono entre formações de floresta tropical e savana (pertencentes aos referidos biomas respectivamente), situada na bacia do Médio Rio Araguaia, especificamente na planície de inundação do rio Javaés, seu tributário pela margem direita, no estado do Tocantins. O objetivo deste estudo foi fornecer informações sobre a sucessão vegetal nesta área de ecótono floresta-savana, visando contribuir para o entendimento da dinâmica desta paisagem. Dessa forma, um testemunho sedimentar coletado no Lago da Mata Verde foi submetido às análises palinológicas e de datação radiocarbônica. Os resultados mostraram que durante os últimos 400 anos este ambiente foi cercado por floresta refletindo um clima úmido, com um ligeiro aumento de margens inundadas nos dias atuais. Os dados de chuva polínica atual e de vegetação local fundamentaram a interpretação dos resultados palinológicos fósseis. Os resultados obtidos são similares a outros estudos realizados em outras áreas de ecótonos e planícies de inundação em regiões da Amazônia durante o Holoceno Tardio.

Palavras-chave. Sedimentos lacustres, Holoceno Tardio, análises palinológicas

1 Introduction

Palynological data have been useful to reconstruction of past vegetation and their related paleoclimates during the Quaternary around the South American landscapes. One of the most studied is the Amazon region, where several studies allowed draw the different sceneries and their environmental changes throughout Pleistocene and Holocene. Therefore, studies carried out by Colinvaux *et al.* (1996), Colinvaux & De Oliveira (2000), Haberle & Maslin (1999) and Bush *et al.* (2004) evidenced an undisturbed forest cover occurrence with establishing of cold climate and mountain adapted species. On the contrary direction, Absy *et al.* (1991) and Van der Hammen & Absy (1994) identified periods of retreat and fragmentation of the rainforest vegetation due drier climate conditions in Serra dos Carajás, southern of Amazon region. In zone of ecotones between forest and savanna vegetation, several works recognized changes in the vegetation caused by climate fluctuations during the Pleistocene and Holocene (Gouveia *et al.*, 1997; Pessenda *et al.*, 1998; Freitas *et al.*, 2001; Meneses *et al.*, 2015).

The Brazilian Cerrado (including savannas type) also have been relatively well studied as about the Pleistocene and mainly Holocene periods (Ferraz-Vicentini & Salgado-Labouriau, 1996; Salgado-Labouriau *et al.*, 1997; Barberi *et al.*, 2000). All of these records revealed a trend in increased moisture during the Late Holocene with a climate comparable to the present day.

The Tocantins state is situated in southeastern Amazon region and hosts diverse vegetation types including both amazon rainforest and savanna formations. Despite the ecological and geographic importance, the studies about the past vegetation dynamics are scarce. There are only two record using pollen analysis: the first one was carried out by Behling (2002), who examined sediments collected from a small rounded lake named Lagoa da Confusão (10°38' S, 49°43' W), recognizing the changes in vegetation occurred during the Late Pleistocene and Holocene. The second pollen work was performed by Mendes *et al.* (2015) in the Bananal

Island located 145 km from far the Lagoa da Confusão that counted the last millennium history of the local vegetation. In this context, the objective of this work is supply information about the past vegetation, climate and environmental changes occurred in this region during the Late Holocene aiming to contribute with the knowledge about these zones of forest-savanna ecotone in Amazon region. In order to interpret the fossil pollen data, we also intend to determine the modern pollen rain signatures, examining the spatially variability of the pollen rain and source of pollen of different sites along the lake neighboring forest and then to compare the pollen rain data with floristic composition to discover the modern pollen-vegetation relationships.

2 Area, material and methods

2.1 Area

The Lago da Mata Verde (9°58'41.80" S and 50°1'2.10" W) is located in the region of the Middle Araguaia River basin, specifically in the Javaés River floodplain that by its turn is one of the most important tributary of Araguaia River by right margin channel (Fig. 1A, B, C, and D). This lake has an elongated shape and is connected to other lake (Lago do Arrozal) during the rainy season throughout an intermittent inflowing channel (Fig. 1D and E; 2A and B).

The modern regional climate is hot and semi-humid. The average annual precipitation is between 1,400 and 2,200 mm. The rainy season occurs from November to April. The dry season is marked by very low or no precipitation, and the driest months ranges from June to September. The average annual temperature is 26°C, the maximum temperatures of 38°C occurring during the months of August and September.

The regional modern vegetation is composed by forest and savanna mosaic. However, locally the lake is surrounded by an extensive block of riparian forest that accompanies all the Javaés River course. The savannas formations vary from grassland where the Poaceae family is dominant to wooded savanna which presents bushes and

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 study area detail of the Lago da Mata Verde. E). Coring site in the Lago da Mata Verde.

Figura 1. Mapa de localização da área de estudo; A) Localização geográfica do Estado do Tocantins; B) Localização da Ilha do Bananal; C) Detalhe do Parque Nacional do Araguaia localizado ao norte da Ilha do Bananal; D) Área de estudo: o retângulo vermelho indica o detalhe da área de estudo do Lago da Mata Verde; E) Localização da sondagem no Lago da Mata Verde.

trees scattered along the herbaceous stratum or forming denser groups. *Byrsonima* sp. and *Curatella americana* are the shrubs or trees types dispersed along the herbaceous stratum.

The riparian forest vegetation occurs as an extensive patch that consists of the perennial forest alongside of Javaés River. According to Kurzątkowski (2017), who carried out a floristic inventory in this region, a number of 69 species of trees belonging to 30 families are found locally and the main representative are Fabaceae, Myrtaceae, Anacardiaceae, Rubiaceae and

Annonaceae families.

The study site is geologically placed in the Bananal Basin. It is a well-developed Quaternary sedimentary basin, located in the region of the Middle Araguaia River with approximately 106,000 km² in the Amazon forest-savanna ecotone region. The Bananal Basin, formed by quaternary alluvial deposits of the Araguaia Formation, is temporarily flooded during the rainy season by both local rainfall waters and a saturated water table (Valente, 2007).

2 Material and methods

A 63cm long sediment core was recovered from the lake so-called Lago da Mata Verde (LMV) using a Russian corer (Fig. 2 A). 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 modern pollen rain analysis 11 artificial aerial pollen traps were installed along the forest patch close to the studied lake (Fig. 3A, B and C) for a 12 months period (2016-2017). The preparation of the pollen traps was performed as described by Bush (1992).

For pollen record analysis, 32 subsamples were taken at 2 cm intervals along the core for analyzing pollen, spores and other palynomorphs, and charred particles. All samples were prepared using adopted methods including hydrofluoric acid treatment (Faegri & Iversen, 1989), as well as acetolysis method by Erdtman (1952). It was added one tablet of exotic *Lycopodium clavatum* ($20,848 \pm 1,546$) spores to each sample to determine the pollen concentration (grains/cm³) and pollen accumulation rate (grains/cm²/yr).

A minimum of 300 pollen grains were counted for each sub-sample. The pollen grains, spores, other palynomorphs were identified by optical microscopy (Axiostar plus, Carl Zeiss), using the objective of 40x, and with 100x when grains that could not be identified with a smaller magnification. The computer program Neotropical pollen (free to use) created by Bush & Weng (2007) was used, as well as the pollen keys of Roubik & Moreno (1991), Carreira & Barth (2003), Colinvaux *et al.* (1999), and a pollen reference collection at the Department of Palynology and Climate Dynamics (University of Göttingen, Germany) containing more than 3000 neotropical taxa were also used to identify pollen grains.

The identified taxa were grouped by ecological affinities according to habitat, such as forest, marsh/lacustrine, palm tree, savanna, algae, fern spores, and the sum of pollen groups.

In addition, charcoal particles (5-150µm) 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 algae. 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).

The pollen diagrams include individual records of the most abundant pollen and spore taxa (Fig. 4 and 5) and records of the following groups: Forest, Marsh/Lacustrine, Palm Trees, Savanna, Spores, Algae/Fungi as well as concentration and accumulation rate of pollen and a cluster analysis dendrogram (Fig. 7). The zonation of the pollen record is based on changes in the pollen assemblages and CONISS analysis.

The chemical treatment of the samples followed the same standard method used for sediment core samples (Faegri & Iversen, 1989). Pollen and spores were calculated as percentages of the pollen sum and concentration (grains/cm³). The pollen rain results were compared with regional floristic inventory carried out in this region.

3 Results

3.1 Lithology and chronology

The Lago da Mata Verde sedimentary core from the base 63 cm to 58 cm is composed by black sand. From 58 cm to 37 cm the material is black silt loam being substituted by black loamy sand between 37 and 35 cm. From 35 to 33 cm an interval of silt loam is found. Between 33 and 31 cm a fine layer of black sand is found. From 31 cm to the top of the core, the material is composed by very dark brown loam.

Ages obtained by ¹⁴C analysis indicated that the studied core fine sediments deposition occurred recently. The dating from the 55 cm revealed to be 320 ± 30 years BP and the sample at 30 cm was dated in 114.35 ± 0.38 pMC representing modern age. Samples obtained and calibrated ages from LMV core are shown in table 1.

Figure 2. Aspects of the Lago da Mata Verde landscape. A) Drilling activities; B) Detail of the pioneer vegetation on the lake shore.

Figura 2. Aspectos da paisagem do Lago da Mata Verde. A) Atividades de sondagem; B) Detalhe da vegetação pioneira na margem do lago.

Table 1. Radiocarbon dating and calibrated (cal) ages. AD: Anno Domini; BP: Before Present. Lab. Cod: Laboratory code. Tabela 1. Datação por radiocarbono e idades calibradas (cal). AD: Anno Domini; BP: Antes do presente, Lab Cod: Código de laboratório.

Depth (cm)	Lab. cod.	Conventional Age ^{14}C	Calibrated Age
30	Poz-93934	114.35 ± 0.38 Modern	1846* yr cal AD
55	Poz-93775	320 ± 30	382 yr cal BP

Figure 3. Localization map of artificial pollen traps; A) Study area: the red rectangles indicate the study area details of the artificial pollen traps; B) Location of artificial pollen traps in the margin of Javaés River; C) Location of artificial pollen traps in the margin of the intermittent channel near the Lago da Mata Verde (LMV).

Figura 3. Mapa de localização de armadilhas artificiais para a coleta polínica; A) Área de estudo: os retângulos vermelhos indicam os detalhes da área de estudo das armadilhas artificiais de pólen; B) Localização das armadilhas artificiais de pólen na margem do Rio Javaés; C) Localização das armadilhas artificiais de pólen na margem do canal intermitente próximo ao Lago da Mata Verde (LMV).

3.2 Description of the pollen and charcoal record

The pollen record contains about 83 different pollen types dominated by *Cecropia*, Cyperaceae, Melastomataceae/Combretaceae, Poaceae, Moraceae/Urticaceae, *Alchornea*, *Byrsonima*, *Sebastiania*, *Sagittaria*, *Celtis*, Fabaceae, *Mabea*, *Psychotria*, *Roupala* (Fig. 4 and 5). The main palynomorphs types are displayed in the figure 6.

A total of 93 taxa of palynomorphs were identified along to the LMV core, including taxa of algae/fungi, pteridophytes and angiosperms. The concentration of carbonized particles was also analyzed. The pollen diagram (Fig. 4 and 5) shows the distribution of palynomorphs which were grouped according to their ecological affinities (habitat). The distribution was supported by Marchant *et al.* (2002) and Kurzątkowski (2017), as well as based on local observations. The sum of environmental groups is shown in figure 7. The cluster analysis (CONISS) discriminate analyses the major paleofloristic changes occurring in pollen groups. It was possible to establish four distinct ecological phases, LMV I, LMV II, LMV

III and LMV IV, which are described below in an ascending stratigraphic order. Charcoal particles were frequent throughout the record showing concentration between 11,000 and 390,000 particles/cm³ presenting the lowest values towards to the top of the core, in LMV III and LMV IV phases. The pollen concentration values were very low in the phase LMV I and become higher in the last phases LMV III and LMV IV (Fig. 7).

The basal core samples (63 to 59 cm: 500 to 415 cal yr BP, 2 subsamples), did not present fine and organic material and then this interval is characterized by the non-preservation of pollen grains, ferns spores, as well as algae taxa.

Phase LMV I (59 to 33 cm: 415 to 148 cal yr BP, 13 subsamples). This phase is characterized by the abundance of forest components (59-76%), which are dominated by pollen of *Cecropia* (4-27%), Melastomataceae/Combretaceae (6-19%), Moraceae/Urticaceae (3-15%), *Alchornea* (2-15%), *Sebastiania* (0-10%), *Celtis* (0-8%), Fabaceae (1-8%), *Mabea* (0-8%), *Psychotria* (0-8%), Flacourtiaceae (0-6%), Myrtaceae (0-5%), *Mimosa* (0-5%), Rubiaceae type 1 (0-4%), Anacardiaceae,

Figure 4. Pollen diagram percentages of LMV core with taxa included in ecological groups. It features a 7x exaggeration to better visualization of pollen types with low percentages.
Figura 4. Diagrama de porcentagens polínicas do perfil de LMV com táxons incluídos em grupos ecológicos. O diagrama apresenta exagero de 7x para melhor visualização dos tipos de pólen com baixos percentuais.

Figure 5. Pollen diagram percentages of LMV core with taxa included in ecological groups such as Marsh/Lacustrine, Palm Trees, Savanna, Algae/Fungi, Spores (Pteridophytes). It features a 7x exaggeration to better visualization of pollen types with low percentages.

Figura 5. Diagrama de porcentagens polínicas do perfil de LMV com táxons incluídos em grupos ecológicos como pântano/lacustre, palmeiras, savana, algas/fungos, esporos (Pteridófitas). Exagero de 7x para melhor visualização dos tipos de pólen com baixos percentuais.

Figure 6. Photomicrographs of main palynomorphs found in the sediments of LMV core. 1. *Alchornea*, 2. *Byrsonima*, 3. *Cecropia*, 4-5. Cyperaceae, 6. *Eicchornia*, 7-8. Fabaceae, 9. Flacourtiaceae, 10. *Mabea*, 11. Melastomataceae/ Combretaceae, 12. *Mimosa* 13. Moraceae/Urticaceae, 14. Myrtaceae, 15-16. Poaceae. 17. *Roupala*, 18. *Sagittaria*, 19. *Sebastiania*, 20-24. Tipos polínicos não identificados. 25. Algae *Botryococcus*. Scale bar 10 μ m

Figura 6. Fotomicrografias dos principais palinórmofos encontrados nos sedimentos do testemunho LMV. 1. *Alchornea*, 2. *Byrsonima*, 3. *Cecropia*, 4-5. Cyperaceae, 6. *Eicchornia*, 7-8. Fabaceae, 9. Flacourtiaceae, 10. *Mabea*, 11. Melastomataceae/ Combretaceae, 12. *Mimosa* 13. Moraceae/Urticaceae, 14. Myrtaceae, 15-16. Poaceae. 17. *Roupala*, 18. *Sagittaria*, 19. *Sebastiania*, 20-24. Tipos polínicos não identificados. 25. Alga *Botryococcus*. Escala 10 μ m.

Euphorbia, Sapotaceae and Euphorbiaceae (0-3%), *Clusia*, Asteraceae, *Chamaesyce*, *Guettarda*, Rubiaceae type 2 (0-2%) and other taxa are less than 2%. The savanna ecological group consists mainly of *Byrsonima* (0-12%), Poaceae (0-11%), *Roupala* (0-8%), *Curatella* and *Trema* (0-3%), Malpighiaceae, *Caryocar* and *Styrax* (0-2%), Apocynaceae, *Borreria*, Curcubitaceae and Dilleniaceae less than 2%, that presented pollen sum between 6 and 26%. The ecological group marsh/lacustrine showed percentages between 10 and 22%, dominated by Cyperaceae type 1 (8-22%), Cyperaceae type 2 (0-5%), *Eichhornia* (0-3%) and *Sagittaria* (0-2%), *Cuphea*, Polygalaceae, *Cabomba*, Lentibulariaceae presented less than 1%. The group of Palm trees pollen computed 0-1%. Algae amounted 1 to 5% almost composed by *Botryococcus* (1-5%), pteridophytes spores only 1%.

Phase LMV II (33 to 31 cm: 148 to 104 cal yr BP, 1 subsample). This phase is characterized by the non-preservation of pollen grains due sandy sediments layer. Few ferns spores, as well as algae taxa, were poorly preserved and presented some charcoal.

Phase LMV III (31 to 15 cm: 104 cal yr BP to the present, 8 subsamples). This phase is characterized by the abundance of forest components (66-70%), which are dominated by pollen of *Cecropia* (16-30%), *Alchornea* (3-10%), *Sebastiania* (1-9%), Melastomataceae/Combretaceae (3-8%), Moraceae/Urticaceae (3-7%), Flacourtiaceae (0-6%), Myrtaceae (1-5%), *Euphorbia* (0-5%), *Celtis* (0-4%), Asteraceae (0-4%), Fabaceae (1-3%), Euphorbiaceae (1-2%), Anacardiaceae, Rubiaceae type 1 and 2, *Bambusa*, and *Mimosa* (0-3%), other taxa are less than 2%. The savanna ecological group consists mainly of Poaceae (6-12%), *Byrsonima* (0-3%), *Trema* (1-3%), *Roupala* (1-2%), Apocynaceae, *Sapium* (0-2%), *Styrax*, Rutaceae, Convolvulaceae, Dilleniaceae, *Alibertia*, *Curatella*, *Caryocar* and others presented less than 1%, that presented pollen sum between 14 and 24%. The ecological group marsh/lacustrine showed percentages between 8 and 19%, dominated by Cyperaceae type 1 (4-13%), *Sagittaria* (1-4%), *Cuphea* (0-3%), Cyperaceae type 2, *Eichhornia* (0-2%) and *Ludwigia*, *Cabomba*, Lentibulariaceae and Araceae presented less than 1%. The

group of palm trees pollen computed 0-2%. Algae amounted 5 to 6% almost composed by *Botryococcus* (4-6%), pteridophytes spores only 1%.

Phase LMV IV (15 to 0 cm: present day, 8 subsamples). This phase is characterized by the abundance of forest components (54-62%), which are dominated by pollen of *Cecropia* (9-23%), *Alchornea* (2-11%), *Sebastiania* (3-10%), Melastomataceae/Combretaceae (5-9%), Moraceae/Urticaceae (2-9%), *Bambusa* (0-6%), *Zanthoxylum* (0-5%), Flacourtiaceae, *Celtis* and Fabaceae (0-4%), *Euphorbia* (0-4%), *Mimosa* (1-3%), *Sloanea*, *Psychotria*, (0-3%), Sapotaceae, *Chamaesyce*, Meliaceae Myrtaceae (0-2%), Asteraceae and other taxa are less than 2%. The savanna ecological group consists mainly of Poaceae (8-16%), *Trema* (0-4%), *Byrsonima* (0-2%), *Roupala* and Amaranthaceae/Chenopodiaceae (0-2%), *Solanum* and Ochnaceae (0-1%), Apocynaceae, *Sapium*, Rutaceae, *Caryocar*, *Spermacoce*, *Cassia*, Acanthaceae, *Diodia* and others presented less than 1%, that presented pollen sum between 13 and 19%. The ecological group marsh/lacustrine showed percentages between 21 and 31%, dominated by Cyperaceae type 1 (9-22%), *Sagittaria* (3-8%), Cyperaceae type 2, *Eichhornia* (0-4%), Araceae (0-2%), *Cabomba*, *Cuphea* and Polygalaceae presented 1%. The group of palm trees pollen computed 0-1%. Algae amounted 4 to 12% almost composed by *Botryococcus* (4-12%), pteridophytes spores only 1%.

3.3 Description of modern pollen rain diagram

The modern pollen assemblages from the 11 artificial pollen trap samples across the studied forest patch vegetation are presented in figures 8 and 9. The modern pollen rain diagram shows the most frequent and important 65 taxa including 10 unidentified pollen types which are arranged according to the preferential ecological groups.

Forest taxa vary between from 76 to 90%, primarily due to higher pollen frequencies of Moraceae/Urticaceae (5-50%), *Tetrapterys* (0-35%), *Alibertia* (0-39%), *Chamaesyce* (0-23%), Malpighiaceae and *Euphorbia* (0-20%), Meliaceae (0-15%), Anacardiaceae (0-14%),

Figure 7. Pollen diagram showing radiocarbon ages, interpolated and extrapolated ages, lithology, ecological groups percentages, pollen grains concentration and accumulation rate, charcoal concentration, pollen phases and cluster analysis (CONISS).

Figura 7. Diagrama polínico mostrando as idades de radiocarbônicas, idades interpoladas e extrapoladas, litologia, porcentagens dos grupos ecológicos, concentração de grãos de pólen e taxa de acumulação, concentração de carvão, fases polínicas e análise de agrupamento (CONISS).

Celtis (0-13%), Melastomataceae/Combretaceae (2-11%), Fabaceae, *Cecropia* and *Alchornea* (0-9%), *Bertiera* and *Piranhea* (0-7%), *Protium* and Sapindaceae (0-6%), *Mimosa* and Flacourtiaceae (0-5%), Sapotaceae (0-4%), *Mabea* (0-3%) and other taxa less than 3%. This forest group was absolutely dominant in all sampled sites, being more abundant near to the Lago da Mata Verde margin (around 90%), with the *Tetrapteryx* (35%), Meliaceae (15%) and Moraceae/Urticaceae (14%) as the most representative taxa. At the margin of the Javaés River, in samples 3 and 9, the forest group was less abundant (76%), with Moraceae/Urticaceae (13%), *Celtis* (13%), Melastomataceae/Combretaceae (11%), *Cecropia* (9%) and Anarcadiaceae (7%), as well as in the margin of the intermittent channel (77%), with Moraceae/Urticaceae (24%), *Tetrapteryx* (10%), *Bertiera* (7%), *Celtis* and Melastomataceae/Combretaceae (6%) each one. Anomalous peaks were observed for some samples that occurred in high amounts in a unique sample, for instance *Alibertia* in sample of number 6 that reached 39%, *Chamaesyce* (23%) in sample number 7 and *Euphorbia* (20%) in sample number 2.

The Marsh/Lacustrine group is represented just by Cyperaceae, that appears in all pollen traps (1-4%), and by *Sagittaria* (0-1%), that appears only in two samples near Canguçu Research Center.

The group of Savanna vary between 5 to 17%, with the most common taxa: *Roupala* (0-10%), *Byrsonima* (1-16%), *Solanum*, *Styrax* and *Sapium* (0-4%), *Trema* and Poaceae (0-3%), Amaranthaceae/Chenopodiaceae and Dilleniaceae (0-2%), and others present less than 2%. The Savanna types are more abundant in the pollen trap 9 (in the margin of the intermittent channel), where *Roupala* (10%), *Trema* (3%) and Dilleniaceae (2%) are the most abundant types. And it is less represented in the in the margin of the intermittent channel near Lago da Mata Verde margin (pollen trap 8), which *Byrsonima* (2%), *Trema* and Apocynaceae (1%) are the most abundant types.

Palm taxa represent just 1% of all of the recorded pollen in the traps. Arecaceae appearing in the sample 7 (in the margin of Javaés River) and in the sample 8, collected near Lago da Mata Verde.

Figure 8. Pollen percentages diagram of the pollen traps with taxa included in ecological groups such as Forest, Marsh/Lacustrine, Savanna, Palm Trees.
Figura 8. Diagrama de porcentagens polínicas das armadilhas de pólen com táxons incluídos em grupos ecológicos como floresta, pântano/lacustre, savana, palmeiras.

Figure 9. Pollen percentage diagram of the ecological groups and pollen grains concentration.

Figura 9. Diagrama de porcentagem polínica dos grupos ecológicos e a concentração de grãos de pólen.

4 Discussion

4.1 Environmental changes in the Lago da Mata Verde

The results obtained from the pollen analysis of Lago da Mata Verde core shown few changes in the vegetational composition during the last 400 years on the forest-savanna ecotone in Tocantins state and revealed unchanged wet climate conditions. Bellow 59 cm depth the sandy material and absence of preserved palynomorphs indicates a high dynamic at the water body probably lotic conditions when the lake probably kept permanent link with Javaés River before to become isolated from this. The elongated morphology of the Lago da Mata Verde and its position among vegetation covered bars indicates that this lake is an abandoned channel formed due lateral accretion of bars.

The lacustrine environment of Lago da Mata Verde was performed since 415 cal yr BP and since then until 148 cal yr BP (LMV I), the environment

was rounded by heterogeneous forest cover dominated by *Cecropia*, *Melastomataceae*/ *Combretaceae*, *Moraceae*/ *Urticaceae*, *Alchornea* and others. Some savanna vegetation rich in shrubs and trees like *Byrsonima* sp and *Curatella americana* did not occur so close, probably was surrounding this forest patch. The savanna pollen grains were probably transported by wind over some distance into the lake and also perhaps brought by the inflowing channel. The inflowing channel came from a lake called Lago do Arrozal that is located in a savanna area. Marsh/lacustrine plants like *Cyperaceae* and *Sagittaria* settled the lake margins while *Eichornia* occupied the shallow portions. The concentration of the charred particles was high indicating regional fires coming from neighboring savanna burning.

In the following identified phase (LMV II) from 148 to 104 cal yr BP the sediments core was marked by a thin layer of sandy sediments, and preserved pollen grains were not found. It was probably due entrance of terrigenous material carried by runoff waters during frequent flooding episodes, or it was brought by the inflowing small channel discharge. It also possible that the lotic conditions returned, because this hiatus lasted almost 50 years. In a general way, the sedimentation process was not continuous or regular, because the sediments texture changed several times along the core, reflecting variations in the hydrological dynamics.

From 104 cal yr BP to the present-day (LMV III) the dominance of forest over savanna cover was maintained. However, the savanna became poorly scattered by trees and shrubs as shown by decrease of *Byrsonima* in relation to previous phase. The human occupation likely is responsible for remove these trees replacing for grasses for cattle raising and installation of agriculture farms. Charred particles concentration was lower if compared to previous phases. Probably because the human occupation, once the agriculture farms and cattle usually does not make use of fires controlling (Meneses *et al.*, 2013).

The last phase that corresponds to modern time, forest and savanna slightly reduces while the marsh/lacustrine vegetation increases relation to other vegetation formations. This fact suggests that the lake area was enlarged

as confirmed by increase of algae/fungi group especially *Botryococcus* suggesting shallow water conditions due expansion of flooded areas.

4.2 Modern pollen-vegetation linkage

In order to establish modern pollen-vegetation relationships, the data of pollen rain were compared to floristic data from the present vegetation along the riparian forest in Javaés River floodplain (Fig. 8). Pollen analyses from 11 artificial pollen traps samples revealed good relationship between modern pollen assemblages and this forest formation.

The found pollen assemblage reflects mostly the local forest elements such as Moraceae/Urticaceae that is absolutely dominant, followed by Melastomataceae/Combretaceae, Malpighiaceae, *Tetrapteryx*, Anacardiaceae, Fabaceae, Euphorbiaceae, *Alchornea*, *Piranhea*, *Protium*, *Cecropia*, and *Celtis* which were the most frequent types. Comparing the pollen data with local forest vegetation, it is possible to observe that the most important families are represented in the pollen spectra. However, Fabaceae and Myrtaceae that are the richest families in number of species in this forest area presenting 15 and 5 species respectively are not so abundant in the pollen rain spectra as expected. The pronounced richness of Fabaceae species matches the floristic composition of many tropical moist forests of Central Amazonia (Wittmann *et al.*, 2013). According them, in inundated forests of Central Amazonia, Fabaceae and Euphorbiaceae normally have been recorded to be dominant. In the Araguaia forest, following Felfili (1995), besides Fabaceae, additional species-rich families are Myrtaceae and Rubiaceae. Locally Kurzątkowski (2017), highlighted the dominance of Moraceae, Rubiaceae, Annonaceae, Picrodendraceae and also Myrtaceae as the most representative families in richness of species.

Considering the mentioned forest floristic composition and its representation in the pollen rain assemblage, Euphorbiaceae are represented especially by *Alchornea*, *Chamaesyce* and *Sebastiania*; Rubiaceae types were *Alibertia* and *Bertiera* only. Picrodendraceae appears like *Piranhea* which was very frequent in the samples.

According to Kurzątkowski (2017), the most frequently occurring species in this forest patch are *Alibertia edulis*, *Inga marginata*, *Mouriri guainensis*, *Protium heptaphyllum*, *Protium paniculatum* and *Brosimum rubescens*. Among these species, only *Inga marginata* was not recorded in the modern pollen rain. *Mouriri guainensis* might have been counted as Melastomataceae/Combretaceae and *Brosimum rubescens* as Moraceae/Urticaceae that were the families with the most abundant pollen grains.

In case of Annonaceae described as one the most important family in the local forest, its pollen grains were not recorded in the modern pollen rain spectra, probably because it has very fragile pollen grains (Salgado-Labouriau, 1973). According to Behling & Negrelle (2006), several families with abundant occurrence in forests such as Annonaceae, Lauraceae and Chrysobalanaceae, are missing in the pollen assemblages and specific particularities in the pollen production, dispersal power and preservation conditions could be responsible for such anomalies. The same reasons could be pointed for explaining the registered low representation of Fabaceae and Myrtaceae families in the pollen trap samples.

Then, except for Annonaceae, the main families recorded in the forest around the lake Lago da Mata Verde are represented in the modern pollen rain spectra, indicating good relationship between them. However, the modern pollen signal has local representativeness. Poaceae and other savanna types appear in very low percentages because riparian forests are dense, and then, pollen dispersed from regional grasslands cannot easily enter into these forests. Moreover, the pollen signal of entomophilous plants may record only the community that actually grows locally (Colinvaux *et al.*, 1999). Consequently, grasslands pollen signal, of wide regional occurrence is under-represented in the pollen spectra from samples taken inside the studied riparian forest, although they consist mostly of trees and shrubs with zoophilous pollination. Exceptions may be observed for frequent *Alchornea*, and *Cecropia* that have anemophilous pollination and might have been brought from out the studied locals. Nevertheless, both genus in fact occur in the local forest patch.

Sagittaria and Cyperaceae (marshes/lacustrine group) appeared in low quantity, only as single grains. Cyperaceae pollen is accepted as one of the most representative elements found in marshes and lake margins, being generally associated to freshwater areas and humid environments, locally developed during the Holocene. However, some species occur in well drained grasslands and it difficult the interpretation (Absy *et al.*, 2014). So, it is necessary take into account the pollen associations to infer the occurrence or increase of humid terrains based in the presence of Cyperaceae pollen grains. At the present study is assumed that this family settle the lakes margins and swamps, based on local observations. Accordingly, the forest from the Javaés River floodplain matches the modern pollen signal except for some anomalies, as for instance, the over representation of *Alibertia*, (39%), *Chamaesyce* (23%) and *Euphorbia* (20%) which appeared restricted to unique trap sample location each one. This fact, however, is probably due to entrance of flowers or pollinator insect into the trap or due to the proximity of the installed trap with the individual plant source.

When compared the modern pollen rain assemblages with the lacustrine fossil pollen from Lago da Mata Verde, it is possible to observe that the families and pollen types are shared in both results and its frequency are almost similar, however, with some differences. Moraceae/Urticaceae pollen grains are the most abundant in the modern pollen rain from the traps than in the lacustrine sediments, reflecting in this context the forest vegetation where is widely occurring. On the other hand, *Cecropia* pollen is more frequent in the recorded sediments into the lake than in the pollen trap. Probably, because this genus occurs locally settled in borders of forest and due anemophilous pollination, it is coming from beyond of growth local.

In a general way, by these results we conclude that the lake since all the recorded time was surrounded by forest and the savanna vegetation was at the neighboring similarly to nowadays. In this context, the lacustrine sediments recorded the local and regional pollen signal and, therefore, the savanna pollen grains found in the lacustrine sediments were

carried into the lake by wind and also by the small inflowing channel during the rainy season. Because this mentioned channel cross savanna vegetated areas.

4.3 The Late Holocene in Amazonian forest-savanna ecotones areas and floodplains

Our findings about this site show that the climate was wet and did not change along the small reached time. They are accordingly similar to results obtained by the previous studies in this region. For instance, in a lake called Lagoa da Confusão, during the Late Holocene the climate was wetter than in the Early Holocene as observed by Behling (2002). This author found an increase of aquatic plants which he attributed to the expansion of the lake due to a probable increase in rainfall. In the record achieved by Mendes *et al.* (2015), in Bananal Island, the last millennium was marked by wet climate as indicated by unchanged forest vegetation. However, periods with minor flooding events was noticed. However, since 304 cal yr BP until the present day that environment continued dominated by this diverse forest, and the lacustrine conditions with a slight increase of moisture in the last 84 years as indicated by increase of *Piranhea*.

Studies carried out in Amazon forest-savanna ecotone areas similarly shown the occurrence of wetter climate during the Late Holocene. In Humaitá (Amazonas state) Freitas *et al.* (2001) and Pessenda *et al.* (2001) observed an expansion of the forest over the savanna for the last millennium. In Roraima state, situated in northern of Amazon region Meneses *et al.* (2013) and (2015), identified periods of expansion and contraction of forest related to fire events and the last cycle 300 years BP was marked by the expansion of the forest due to a wetter climate and reduction of fire events.

In the *Llanos Orientales* zone in Colombia (northwestern Amazon rainforest/savanna ecotone), in the Laguna Loma Linda, the rainforest expansion is documented since 6,850 cal BP and was more intensified after 3,200 cal BP (Behling & Hooghiemstra, 2000). In southwestern Amazonia, (Laguna Bella Vista and Chaplin, Bolivia) there is evidence for Amazon rain forest expansion

during the late Holocene at least since 3,200 cal BP (Mayle *et al.*, 2000).

In zones of wetlands and floodplains the pollen studies allowed to recognize periods of higher moisture during the Late Holocene times. According to Behling *et al.* (2001), in the Lago Calado (Central Amazonia) after 4,610 cal BP the area of *várzea/igapó* forests increased because the Amazonian water levels must have been higher than before and the period of the annual high-water stands was probably longer. Especially since 2,060 cal BP, the largest proportion of *várzea/igapó* forests is recorded, reflecting the highest Amazonian water level or also indicate that the cyclic annual period of the Amazonian high-water level was the longest since then. Pollen studies carried out in Curuá River located in eastern Amazonian region, shown that at 3,340 cal BP, occurred an expansion of inundated *várzea* and *igapó* forest area, as indicated by increase of *Virola*, *Euterpe/Geonoma* and *Macrobium*, trees which are common in flooded forests. Since about 2,560 cal BP, the pollen data reflect the largest extension of seasonally inundated forests and Curuá River reached a water level similar to that of present.

Behling (2011) compared several studies carried out by himself and co-workers in the Amazon lowlands and concluded that the marked increase of flooded areas of *várzea* (seasonally flooded) and *igapó* (permanently flooded) forests is apparently related to the late Holocene sea-level rise and practically the whole Amazon Basin lowland seem to have experienced this change. Then, huge areas of non-flooded Amazon rainforest were replaced by *várzea* and *igapó* during the Late Holocene. This fact was interpreted as indicators of climate change to wetter late Holocene periods if compared to early and Middle Holocene times.

Differently, from other mentioned Amazonian sites, in the Lake Cabaliana situated in the Solimões River basin, palynological and sedimentological data revealed two dry periods in the Late Holocene (2,800-2,550 cal yr BP and 1,450-550 cal yr BP) separated by a wetter phase (2,550-1,450 cal yr BP) (Sá *et al.*, 2016). According to the authors the successional dynamics that occurred in Lake Cabaliana indicate that the

present *várzea* forest was established recently (last 550 cal yr BP), and is composed of a mosaic of different successional stages that are controlled by the intensity of the flood pulse in response to variations in local and regional precipitation.

So, the increasing humidity verified in Amazon region during the Late Holocene especially the last two millennia also is confirmed in its southeastern portion. In fact, the studies compilation organized by Flantua *et al.* (2016) shows that fossil pollen records from the lowland Amazon basin indicate continuously wet climate throughout the last two millennia, however, centennial-scale shifts are observed in terms of forest composition attributed to hydrological changes.

5 Conclusions

The Lago da Mata Verde is a lake situated in the floodplain of Javaés River and it was formed due isolating from a channel (*paraná*), caused by intense process of deposition of sandbars posteriorly vegetated. The lacustrine conditions started around 400 cal yr BP. No significant vegetational changes were noticed during the recorded period and the scenery was almost similar to present day. Thus, a dense forest vegetation is found bordering the lake, whilst savanna formation occurs eastwards surrounding the forest. Few changes in the savanna floristic composition occurred during the last 100 years possibly due human impact like planting of grasses for cattle ranches. The lake experienced increasing of flooded areas as pointed increase of marsh and lacustrine plants as well as algae *Botryococcus*. The modern pollen rain presented good relationship with local forest vegetation, and reflects the local riparian forest. Thus, the savanna pollen grains found into the lake is coming from regional savanna covered areas brought by channel waters during the rainy season or by wind transport. Despite of no historical climate data is published yet, in order to confirm the regional increase of humidity, this assumed wet climate recorded in this area is local and regionally similar to the other Amazonian sites that also showed trend to increasing humidity.

Acknowledgments. The authors are grateful to the CNPQ, that conceded scholarships to LASM and MLC (Grant Nr. 305015/16-8 and Project Nr 442871/2018-0). We thank DAAD for financial support during first author's stage work in Germany for palynological analysis; We also thank the Canguçu Research Centre employees for supporting during the fieldworks.

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