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Source and distribution of pollen and spores in surface sediments of a plateau lake in southeastern Amazonia

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ABSTRACT

In the past two decades, several paleobotanical studies on lakes have indicated a drier climatic condition in Amazonia during the Last Glacial Maximum (LGM) and early-mid Holocene, which likely resulted in the contraction of the tropical forest and expansion of savanna. However, these investigations in the eastern Amazon are scarce, and the reliability and precision of the inference remains largely limited. In this study, palynological analyses were carried out in surficial sediments of Violão Lake, southeastern Amazonia, to assess the distribution and sources of pollen and spores from montane savanna and forest, based on surrounding vegetation types, catchment basin and wind patterns, and also to identify modern pollen rain characteristics of the ecosystems developed under edaphic conditions. Considering the spatial distribution of pollen and spores in the lake basin, the montane savanna pollen are predominant in the eastern and western borders and subordinate in the central portion of the lake, whereas those of forest formations are mainly present in its western margin. Pteridophytes and algae spores show a distinct surface distribution compared to montane savanna pollen, while the algae spores have a good correlation with forest formation pollen. The correlation of these data along with vegetation types of the catchment basin indicates that the absence of pollen grains from species, that present large occurrence along the catchment basin, may be partially related to phenological characteristics that avoided pollen losses. However, in general, montane savanna pollen in the bottom sediments tends to represent a signal of the regional vegetation developed over ferruginous duricrusts in the Serra do Carajás, while forest formation pollen may be used to identify changes in forest structure of the catchment basin of Violão Lake. As montane savanna is developed under edaphic conditions in hydric stress substrate, a systematic description of pollen grains clearly demonstrates that only changes in forest vegetation can be used as a reliable indicator of paleoclimate changes.

1. Introduction

In the past two decades, several paleoecological and paleobotanical studies on lake environments have indicated a drier climatic condition in Amazonia during the Last Glacial Maximum (LGM) and early-mid Holocene, which likely resulted in the contraction of the tropical forests and expansion of savanna (Absy et al., 1991; Hooghiemstra and Van Der Hammen, 1998; Mayle et al., 2000; Sifeddine et al., 2001; Cordeiro et al., 2008, 2011; Hermanowski et al., 2012), as well as influenced the speciation patterns of this biome (Haffer, 1969; Haffer and Prance, 2001; Cheng et al., 2013). However, some authors have argued about the continuous presence of forest under relatively stable climate conditions throughout the LGM (Colinvaux and De Oliveira, 2000, 2001; Colinvaux et al., 2000, 2001; Bush et al., 2004).

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The scientific impasse about such changes in community structure raised difficulties in the interpretation of fossil pollen from the tropics (e.g. Gosling et al., 2003, 2005; Burn et al., 2010; Jones et al., 2011) which might be solved by the study of the ways in which modern pollen grains are transported into lakes and by the understanding of the relationship between pollen and regional or local vegetation signals in order to precisely determine palaeoecological conditions. This depends much on local vegetation processes and the present biotic and abiotic factors where the region is exposed (Jantz, 2013). Analysis of the modern pollen rain on an elevation gradient from neotropical Amazon lowland and Andean forest, contributed considerably to refine the palaeoclimatic interpretations of temperature depressions in western South America (Weng et al., 2004; Jantz et al., 2013). However, similar investigations in the eastern Amazon are scarce, and the reliability and precision of the inference remains largely limited. The scarcity of data about modern pollen rain is mainly due to the size of the region from which modern calibration samples are drawn, to show a large turnover in species composition (Bush et al., 2001).

The plateau lakes of the Serra dos Carajás are one of the best examples of natural traps with surface samples that can provide an exact analogue of the depositional environment and match the ecosystem of the montane savanna are under study. Thus, this work aims to present an accurate analysis of the provenance and distribution of pollen and spores deposited in surface sediments of Violão Lake considering its drainage basin, vegetation types and wind patterns. This information will be helpful to calibrate the palaeoclimatic interpretations of the LGM and early-mid Holocene in the southeastern Amazonia.

2. Regional setting

Violão Lake lies in the Serra dos Carajás, southeastern Amazonia, at an altitude around 730 m above mean sea level (Fig. 1A). This lake is hydrologically restricted, formed by structural and dissolution process of an extensive lateritic crust (Golder, 2010). It has a catchment area of around 1.8 km^2, NE–SW elongated shape, 0.27 km^2 of surface area, steep-sided with a circumference of about 600 m, maximum water depth around 10 m, with a flat and muddy bottom (ITV, 2014).

The catchment lithologies are mainly composed of Fe-mineralized laterites (ferruginous duricrusts), and locally, banded iron formations (BIFs) and mafic rocks. Slopes with open forest and small patches of high-and-low forest occur over detritic crust and mafic sills, respectively, surrounding part of the southern border of Violão Lake (Fig. 1A). Slopes with montane savanna occupy the largest areas over iron-ore duricrust and detritic crust. Considering the drainage basin of Violão Lake, the most important input of water into the lake occurs in its southern portion (Fig. 1A).

The climate is tropical humid, with mean temperature of around 30 °C in the wet season (December–February), while in the dry season (June–August) it is 34 °C. The total annual precipitation is ~1600 mm. During the peak of the wet season, the total precipitation is ~1300 mm, decreasing to 320 mm during the dry season (Moraes et al., 2005).

3. Material and methods

3.1. Sampling site and procedures

A total of 23 surface sediment samples were collected in September 2012 from Violão Lake using a Van Veen Grab sampler (Fig. 1B), with geographical coordinates obtained by a TRIMBLE DGPS model AG-132 with differential correction from OmniSTAR satellite ASAT L1 band, with sub-meter accuracy (Table S1). The sampling points were chosen based on the bathymetric map of the lake to ensure spatial representativeness. Soil samples have also been used in the tropics because of the ease of sampling and their ubiquitous occurrence, but in the study area, all soil types, when exposed, are oxidized, which resulted in very poor pollen preservation.

3.2. Pollen and spore preparation and identification

Pollen and spore extractions from ~10 g of bulk samples were performed using standard techniques of pollen analysis including acetolysis (Faegri and Iversen, 1989). A tablet of Lycopodium spores containing 20,848 ± 3457 grains/tablet was added to each sample prior to chemical treatments in order to calculate pollen concentration (grains/g). Pollen and spore counts were made at ×400 and ×1000 magnification under a transmitted light optical microscope (Zeiss). Pollen and spore identification were achieved by comparing their morphological traits with specialized Handbooks (Roubik and Moreno, 1991; Carreira et al., 1996; Colinvaux et al., 1999) and the pollen database from the Serra dos Carajás describing several taxa occurring in the study area (Carreira and Barth, 2003). Almost all samples were counted to a minimum of 300 terrestrial pollen grains. The software Tilia and Tilia Graph were used to the calculation and plotting of pollen diagrams as percentages of the total pollen and spores counts and concentration of pollen and spores per gram of sediment. Pollen taxa were grouped into montane savanna and forest formation according to floristic surveys in the study area (Nunes, 2009; Golder, 2010), while spore taxa were grouped into pterydophyte, algae, and fungi. Using ArcGIS 10, these data were also spatially plotted for surface modeling considering the vegetation cover of the catchment basin.

3.3. Statistical analysis of pollen and spores distribution patterns

Multivariate ordination analyses of pollen and spores data were evaluated by Detrended Component Analysis (DCA) and Principal Component Analysis (PCA) using the free statistical software R. Pollen concentration and absolute density data (number of species per hectare) from Nunes (2009) were evaluated using Wilcoxon signed rank test and Pearson's product–moment correlation to test the calibration between modern pollen rain and vegetation patterns. Vegetation and drainage data were used together with regional and local historical data of wind velocity and direction to analyze the main driving forces acting on pollen distribution into the lake.

4. Results

4.1. Composition of vegetation cover

The vegetation types of the drainage basin of Violão Lake are predominantly characterized by the dominance of open-shrub montane savanna in detriment of high-low forest formation that are restricted around the border of the lake (Fig. 2) (Nunes, 2009; Golder, 2010). These typologies are mainly presented in absolute density (number of species per hectare), as described below (Table S2):

(1) Open montane savanna: *Axonopus cf. leptostachyus* (Poaceae), *Vellozia glochidea* (Velloziaceae), *Sobralia liliastrum* (Orchidaceae), *Cuphea tenella* (Lythraceae), *Periandra mediterranea* (Fabaceae), *Byrsonima coriacea* (Malpighiaceae), *Cuphea annulata* (Lythraceae), *Ananas ananassoides* (Bromeliaceae), *Andropogon bicornis* (Poaceae), *Ipomoea marabaensis* (Convolvulaceae), *Lippia grandis* (Verbenaceae), *Ichthyothere*