Journal of South American Earth Sciences 62 (2015) 186–194

Contents lists available at ScienceDirect

Journal of South American Earth Sciences

journal homepage: www.elsevier.com/locate/jsames

Vegetation changes and human impact inferred from an oxbow lake in southwestern Amazonia, Brazil since the 19th century

Paula A. Rodríguez-Zorro [a], [*], Dirk Enters [b], Barbara Hermanowski [a], Marcondes Lima da Costa [c], Hermann Behling [a]

[a] University of Göttingen, Albrecht-von-Haller Institute for Plant Sciences, Department of Palynology and Climate Dynamics, Untere Karspüle 2, 37073 Göttingen, Germany
[b] GEOPOLAR, Institute of Geography, University of Bremen, 28359 Bremen, Germany
[c] Universidade Federal do Pará, Centro de Geociências, Departamento de Geoquímica e Petrologia, Av. Augusto Correa 1, Guamá, 66075-900 Belém, Brazil

ARTICLE INFO

Article history:
Received 2 May 2015
Accepted 1 June 2015
Available online 4 June 2015

Keywords:
Brazil
Acre river
Floodplain
Oxbow lake
Pollen analysis
XRF analysis
Amazon rainforest
Human impact
Late Holocene

ABSTRACT

Pollen and X-ray fluorescence spectrometry (XRF) analyses from a 272 cm-long sediment core of Lago Amapá, an oxbow lake in western Amazonia, reveal the first palaeoecological investigation of late Holocene sediments in Acre state, Brazil. Radiocarbon dating of older sediments failed due to re-deposition of organic material but a historical map suggests that lacustrine deposition started at 1900 AD. We detected two periods of changes in sediment and vegetation, dominated by pioneer taxa especially *Cecropia*. The first period around 1900 AD is documenting an initial oxbow lake, with regular fluvial input (high Ti) and low accumulation of organic matter (low inc/coh ratio). During that period Andean pollen taxa originating from Peruvian Andean headwaters were deposited. A fully lacustrine phase started about 1950 AD and is characterized by prolonged periods of stagnant water (low Fe/Mn ratio). The increase of pioneer taxa, sedimentation rates and a reduction of most of the XRF element counts point to a period during which Lago Amapá was a more isolated lake which was flooded only during exceptional severe flood events and is catching mainly anthropogenic disturbances. The extensive human influence during this period was assumed by 1) the high occurrence of pioneer taxa and the absence of charcoal which could indicate changes in vegetation possibly as a result of logging, 2) the Ca and Ti/K ratio which reflect changes to a local sediment source, and 3) comparison of Landsat images from the last 30 years which shows broad changes in vegetation cover and land transformation in the peripheral areas of the oxbow lake.

1. Introduction

Alluvial plains and associated features such as oxbow lakes can be interpreted as a succession of different palaeohydrological events (Morais et al., 2008). In the Brazilian Amazon floodplains, especially in the southwestern part, strong fluvial dynamics control the vegetation succession along the floodplain (Salo et al., 1986; Kalliola et al., 1991; Morais et al., 2008). Water and transported sediments are the main factors for river ecology in recycling nutrients to the biota. During floods erosive and depositional sites develop on the floodplain and form complex habitats. This dynamic affects the distribution, diversity and functioning of riparian vegetation (Kalliola et al., 1991; Latrubesse and Kalicki, 2002; Morais et al., 2008; Stevaux et al., 2013). The vegetation succession is initiated on depositional bars which are exposed during the annual low water season. Although colonized immediately after their exposure, these sites and their vegetation are continuously changing with the river processes (Puhakka et al., 1992). On well-drained floodplain sites, the most important colonist species are trees and shrubs which occupy newly exposed sites. These species resist severe flood damage and can tolerate considerable coverage by sediments (Kalliola et al., 1991).

Oxbow lakes are typical features of the southwestern Amazonian meandering rivers (Räsänen et al., 1991; Kalliola et al., 1992; Toivonen et al., 2007; Latrubesse, 2012). They are formed by active river channel dynamics, together with an intensive lateral and vertical floodplain aggradation plus the high annual seasonal discharge variability (Räsänen et al., 1991; Latrubesse and Kalicki, 2002; Wójcicki, 2006; Junk and Piedade, 2010). The sediments of

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[*] Corresponding author.
E-mail address: paula.rodriguez@biologie.uni-goettingen.de (P.A. Rodríguez-Zorro).

http://dx.doi.org/10.1016/j.jsames.2015.06.003
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these lakes are mainly composed of fine grained mineral particles which are deposited during annual inundations (Räsänen et al., 1991).

Several studies were performed on the western Amazon floodplain trying to understand palaeohydrological and vegetation changes mainly on the Peruvian and Bolivian Amazon (Salo et al., 1986; Räsänen et al., 1991; Burbridge et al., 2004; Bush et al., 2007a, b; Mayle et al., 2007) as well as in the Brazilian Amazon (e.g. Behling and Costa, 2000; Behling et al., 2001). They report high sedimentation rates and different phases of vegetation succession during the late Quaternary, with a tendency to wetter conditions towards the late Holocene. Wetter climatic conditions during the late Holocene are also indicated by the expansion of the Amazon rainforest into the savanna in the Llanos Orientales of northwestern Amazonia (e.g. Behling and Hooghiemstra, 1997, 1999) and into the savanna of southwestern Amazonia (Mayle et al., 2004, 2007).

In addition, some of these studies showed a strong transformation of the landscape by pre-Columbian civilizations. In the case of llanos de Moxos in the Bolivian Amazon, complex drainage systems were developed (Mayle et al., 2007; Erickson, 2008, 2010; Lombardo, 2011). Ditches and causeways were created to get better drainage by cutting through the palaeo-levees or by taking water from the flat savannas to the rivers (Lombardo, 2013). Different proxies were used to detect the signal of human influence along these areas like charcoal, pollen of pioneer species and cultivated plants (*Zea mays, Manihot esculenta, Cucurbita* sp., *Gossypium* sp.) (Dickau, 2012). These proxies show that landscape transformation on llanos de Moxos already took place around 400BC by pre-Hispanic people (Saunaluoma and Schaan, 2012).

It is also known that the landscape has been transformed in Acre State (western Brazil) before Hispanic and Portuguese settlement. The main alterations in this region are geometric earthworks (geoglyphs) that were made by natives (Schaan et al., 2007; Erickson, 2008; Pärssinen et al., 2009). According to Saunaluoma and Schaan (2012) the most intensive period of geometric enclosure use occurred between 200 BC and AD 900.

After the Portuguese conquest (16th century) landscape alterations in Acre State resulted from logging industry, livestock farming and urban expansion. The capital city of the state, Rio Branco, is one of the most affected with 28 percent of deforested territory between 1994 and 2007 (Lani et al., 2008; Silva et al., 2008; Figueiredo, 2010). Changes in land cover are linked to the development of the city which started when the rubber industry boom began in the 19th century due to the huge amount of *Hevea brasiliensis* tree plantations in the area (Leite, 2007). Until now no palaeoecological studies confirm the anthropogenic influence on vegetation establishment in this area.

As a first palaeoecological approach on late Holocene vegetation changes on the Acre River floodplain, our study focuses on the different changes in vegetation inferred from the sediment deposits in the oxbow lake Lago Amapá, including the expansion of Rio Branco City and the influence of the Acre River on the lake. Radiocarbon dating, pollen and X-ray fluorescence spectrometry (XRF) data were used for this pilot study to investigate the potential of oxbow lakes in western Amazonia for palaeoecological research.

2. Study area

Lago Amapá is located southwest of Rio Branco City in Acre State, Brazil (10°02′43.5″S 67°51′18.2″W, 153 m elevation) (Fig. 1). It is a 3 km-long, U-shaped oxbow lake of the Acre River. This river has a single-sinuous channel and asymmetric, complex meanders alternating with straight segments (Stevaux et al., 2010). Its basin is located on Tertiary claystones, siltstones and fine sandstones of the Solimões Formation. Acre River originates from Peruvian headwaters and carries a significant sediment load from the Andes. The climate in Rio Branco City is tropical humid (Am, Köppen classification) with an annual mean temperature of 25 °C and 1900 mm annual precipitation. It has a seasonal variability with two main seasons: a dry season from May to October and a wet season from November to April (Duarte, 2006; INMET, 2014).

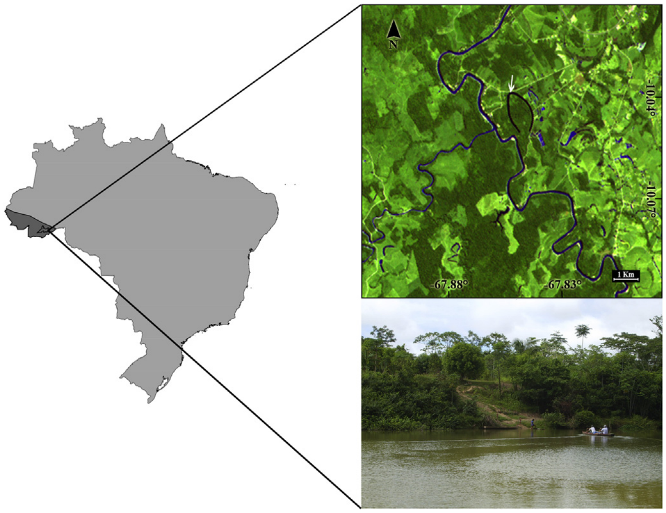

Fig. 1. Location, Landsat 5 image and picture from Lago Amapá oxbow lake. On the right side is shown a semi natural color map from the study area done by Landsat 5 shortwave infrared band 7, near infrared band 5 and green band 3. The white arrow is showing the coring site. The picture is showing the surrounding vegetation in the lake (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The current vegetation in the area is strongly altered and consists of large areas of pastures, crops and urban settlement. The natural vegetation is semi-evergreen tropical rainforest with a mixture of palm trees and bamboo. The lake is surrounded by small patches of tropical rain forest (Lani et al., 2008), crops and fishery ponds. The main tree families are Moraceae, Fabaceae, Bignoniaceae, Caesalpinaceae, Meliaceae, Apocynaceae, Euphorbiaceae, Bombacaceae and Lecythidaceae besides several palm species (Lani et al., 2008).

3. Materials and methods

A 272 cm-long core was taken with a Livingstone piston corer in 2009, in the convex part of the lake (Fig. 1). For palynological analysis 35 subsamples (0.5 cm^3) were taken in 8 cm intervals along the core. Pollen samples were prepared using standard pollen preparation techniques (Faegri and Iversen, 1989). One tablet of exotic marker (*Lycopodium clavatum*) was added per sample for the calculation of pollen concentration (Stockmarr, 1971). Almost all pollen samples were counted to a sum of 300 pollen grains, except for a few samples with low pollen content which were counted to a sum of 100 or 200 pollen grains. Two samples (104 and 264 cm) had a very low pollen content (<100 pollen grains) and were excluded from the pollen diagram. Pollen and spore identification was based on reference literature (Roubik and Moreno, 1991; Carreira et al., 1996) and a pollen reference collection at the Department of Palynology and Climate Dynamics (University of Göttingen, Germany). The grouping of the pollen taxa into the ecological groups has been done according to Salo et al. (1986), Kalliola et al. (1991) and modern vegetation studies done by Lani et al. (2008).

The zonation of the pollen diagram was created in base of important changes in the pollen assemblages and in cluster analysis of pollen data performed with CONISS (Grimm, 1987). Spores were excluded from the pollen sum. The Shannon index was calculated