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Origin and dynamics of the northern South American coastal savanna belt during the Holocene — the role of climate, sea-level, fire and humans

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A B S T R A C T

Presence of a coastal savanna belt expanding from British Guiana to northeastern Brazil cannot be explained by present-day climate. Using pollen and charcoal analyses on an 11.6 k old sediment core from a coastal depression in the savanna belt near the mouth of the Amazon River we investigated the paleoenvironmental history to shed light on this question. Results indicate that small areas of savanna accompanied by a forest type composed primarily by the genus *Micropholis* (Sapotaceae) that has no modern analog existed at the beginning of the Holocene. After 11,200 cal yr BP, savanna accompanied by few trees replaced the forest. In depressions swamp forest developed and by ca 10,000 cal yr BP replaced by *Mauritia* swamps. Between 8500 and 5600 cal yr BP gallery forest (composed mainly of Euphorbiaceae) and swamp forest succeeded the treeless savanna. The modern vegetation with alternating gallery forest and savanna developed after 5600 cal yr BP. We suggest that the early Holocene no-analog forest is a relict of previously more extensive forest under cooler and moister Lateglacial conditions. The early Holocene savanna expansion indicates a drier phase probably related to the shift of the Intertropical Convergence Zone (ITCZ) towards its northernmost position. The mid-Holocene forest expansion is probably a result of the combined influence of equatorwards shift of ITCZ joining the South Atlantic Convergence Zone (SACZ). The ecosystem variability during the last 5600 cal yr BP, formed perhaps under influence of intensified ENSO condition. High charcoal concentrations, especially during the early Holocene, indicate that natural and/or anthropogenic fires may have maintained the savanna. However, our results propose that climate change is the main driving factor for the formation of the coastal savanna in this region. Our results also show that the early Holocene sea level rise established mangroves near the study site until 7500 cal yr BP and promoted swamp formation in depressions, but did not influence the savanna vegetation.

1. Introduction

Present-day savannas occupy approximately 16.1 million km^2, or 11.5% of the global landmass. The proportion of trees and grasses in savannas is related to climate and land use practice. In addition, extensive biomass burning during the dry season plays an important role to inhibit tree growth (Scholes and Hall, 1996; Murphy and Bowman, 2012). Considering the large difference between above ground carbon storage capacity of treeless grasslands (2 tons C/ha) and woodland savannas (30 tons C/ha), besides the huge amount of CO_2 that may be emitted to atmosphere by biomass burning of savannas (estimated at 0.5–4.2 Gt C per year globally) (Grace et al., 2006), plans for CO_2 management need to consider climatic/anthropogenic influences which trigger change from savanna with arboreal taxa (cerradão) to treeless grasslands (campo limpo).

A narrow strip of savanna known as "coastal savanna belt" in northern South America is found along the coast of British Guiana, Surinam, French Guiana, and in State of Amapá, Marajo Island and in part in the state of Pará. This discontinuous belt about 2000 km long is disrupted locally by other types of coastal vegetation (Fig. 1a). Based on the meteorological data (NOAA), annual

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precipitation in the coastal savanna belt is in a range similar to most of Amazon regions (between 1750 and 3500 mm) (Snow, 1976; Nimer, 1989; Weischet, 1996). Therefore instead of savanna presence of Amazon rainforest would be expected. Because of its considerable area the savanna's existence and its dynamics should have a substantial effect on the regional carbon budget.

Several palaeo-environmental studies using pollen and charcoal analyses have previously been carried out to investigate the history of the coastal area in northern South America. Although these studies are mainly focused on mangrove development, useful clues can be obtained regarding savanna/forest/mangrove interaction. Records from Guyana (Van der Hammen, 1963), Suriname (Wijmstra, 1971) and French Guiana (Tissot and Marius, 1992) show expansion of savanna during the full glacial period (and shoreline regression) and mangrove development during the interglacial period (and sea level transgression). Swamp savanna with dominance of Poaceae and Cyperaceae was present during the last c 5700 cal yr BP in the coastal regions of Guyana, Suriname, and French Guiana (Behling and Hooghiemstra, 2001). In Amapá State lacustrine littoral records from lakes Tapera and Marcio (Toledo and Bush, 2007) also demonstrate changes in vegetation from closed forests with swamp taxa to open flooded savanna at c 4750 cal yr BP. In the pollen record of Lago Arari, on Marajó Island in the mouth of the Amazon River in northeastern Pará there is a marked change from the more or less closed to open swamp savanna and forest at ca 7400 cal yr BP (Absy, 1985). Another study from Lake Arari investigated four sediment cores, which reveal replacement of mangrove by herbaceous vegetation at 2300 cal yr BP and an expansion of herbs during the last 1000 years (Smith et al., 2012). In the Southern Hemispheric part of the coastal area, in Lago Crispim (Behling and Costa, 2001), Lagoa da Curuca (Behling, 2001) and Lagoa do Caco (Ledru et al., 2001; Pessenda et al., 2005) Holocene started with arboreal taxa dominating in the vegetation, which with different timing (due to different latitudinal position) gradually were accompanied by swamp trees and finally replaced by open vegetation.

In addition to being interesting for palaeoenvironmental research, lands on the eastern Amazonia on the Amazon River bank or near the river mouth host many archeological surveys. Late Pleistocene Paleo-Indian camp side at Monte Alegre in the eastern Brazilian Amazon documents presence of ecologically adapted foragers with presumably limited big-game hunting habit (Roosevelt et al., 1996). In another study on Marajo Island, Roosevelt and her colleagues (1991) found that mound builders have occupied the alluvial floodplains of the Lower Amazon from A.D. 400–1300.

This work presents the analysis of a 750 cm-long sediment core taken from a key area of the coastal savanna belt near the mouth of the Amazon River, which forms an ecotone between Amazon rainforest and coastal vegetation. In order to test different hypotheses concerning probable driving forces for the development of a savanna belt, such as sea level change, climate, fire, human and edaphic factors, this continuous pollen and charcoal record was analyzed and compared with other results from northern South America.

2. Study area

The core named Curiau (CUR), was collected from a small *Mauritia* swamp 15 m in diameter (00°12′30.3″ N, 51°01′12.1″ W, 5 m a.s.l) located 16 km north of Macapá City in the south of Amapá State near the mouth of Amazon river (Fig. 1b). The studied swamp is surrounded by small hills which have an elevation up to 22 m a.s.l.

2.1. Regional geomorphology

During the late Pleistocene and Holocene, sea-level changes besides tectonic movements resulted in alternation of erosional and depositional processes, which shaped a hilly terrain (relief) along the coast of Amapá (Lima et al., 1991). These reliefs are broad low elevation hills (mean height is 20 m a.s.l.), formed by water erosion of old colluvial clayey terraces which constitutes Pleistocene plain. On the eastern side of this plain, the sediments deposited during the Holocene cover the Amazon River coastal plain and on its western border, Amapá Hills cover crystalline basement rocks. The Mesoarchean-Devonian Crystalline rocks continue to constitute basement rocks beneath the Pleistocene terraces as well (Souza, 2010).

2.2. Hydrology

Depressions between reliefs on Pleistocene terraceae form a network of meandering inundated palaeo-channels and shallow lakes. The largest water body of this kind is an isolated lake called Lago do Curiau that covers area of 150 km^2 including some small lakes such as Tapera and Marcio which may dry out almost completely in the dry season (Toledo and Bush, 2007). Meandering ramified branches of these lakes expand in the area and at the end produce low-order drainage channels on the Pleistocene plains (Guimarães et al., 2013). The studied swamp lies at the end of one of these channels connected to a lake, which is located 3 km distant from the site. This lake has accumulated fluvial-lacustrine sediments during the Holocene, and is only 3–4 m above the sea level.

2.3. Geobotany

Four different plant communities cover today the study area, which from margin of the swamp up to the top of the hills are composed of (1) *Mauritia flexuosa* and some stands of *Euterpe* that colonizes the highest central part of the gallery forest, (2) secondary forest taxa that constitute the outer zone of the gallery forest, (3) savanna with a sparse *Byrsonima* shrubs that is positioned between gallery forest and the outer most zone which is (4) grass savanna on top of the hills dominated by Poaceae. The mentioned secondary forest is mainly represented by Euphorbiaceae and few members in the families of Melastomataceae, Combretaceae, Anacardiaceae and the genus *Sloanea*.

About 30 km distance from the study site, *terra firme* rainforest grows on the Amapá hills. Therefore the site is located in a key area of savanna-forest boundary. Also a complex of wetlands and denser secondary forest with patches of grasslands covers the 5 km wide area on the river bank. This vegetation is established on extensive north-south trending Holocene terraces of sand and clay representing fluvial-marine deposits along the bank of Amazon River (Guimarães et al., 2013). More information on the vegetation of Amapá is available from Carvalho et al. (2006), Costa Neto (2004), Costa Neto et al. (2007), Costa Neto and Silva (2004) and Thomaz et al. (2004).

2.4. Climate

The climate of the study area is tropical humid with 2500–3000 mm annual rainfall with the wet season between December and August and three dry months (September, October, November) (IBGE – UNIT OF STATE AMAPÁ, 2002). Based on updated Köppen-Geiger climate classification (Peel et al., 2007), the area is located in the tropical monsoon region. The temperature fluctuates between 23 and 32 °C with a mean annual of 27 °C (IBGE, 2002).