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Altered nature of terrestrial organic matter transferred to aquatic systems following deforestation in the Amazon

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ABSTRACT

Slash-and-burn agriculture practiced by several thousand small-scale farmers in the Tapajós region of the Brazilian Amazon has contributed to accelerated deforestation over the past decades. The present study aims to quantify and qualify changes in the transfer of terrestrial organic matter (TOM) to aquatic environments following deforestation. Lignin biomarkers have been analyzed from sediment cores collected in three floodplain lakes and in suspended particulate matter sampled during both wet and dry seasons. These analyses are interpreted with regard to lignin biomarker signatures of surface and deeper horizons of common soils, and of dominant plant species from forested and deforested environments. Dating the sediment cores with ^{210}Pb allows reconstructing the successive deforestation cycles since the onset of European colonization two centuries ago. Further, satellite images coupled to a GIS approach is used to correlate the evolution of sedimentary TOM and anthropogenic land-use from 1986 to 2009. Over this period, sedimentation rates have sharply increased, and the nature of the sedimentary TOM has been shifted from being linked to primeval forest soils to degraded soils following deforestation for subsistence cropping and/or pasture lands. The intensity of changes in the nature of sedimentary TOM appears inversely related to the connectivity of flood lakes to the river. In the least connected flood lake, weathering of pasture soils in the watershed dominates TOM inputs particularly during the dry season. Massive deforestation in the Amazon thus triggers major changes in the nature of TOM transferred and sedimented in aquatic systems.

1. Introduction

The Tapajós River region (State of Pará, Brazil) is a major settlement area where subsistence agriculture is one of the principal causes of deforestation (Le Tourneau and Bursztyn, 2010). Several studies conducted in the region have examined the impacts of this perturbation on local population health (Lebel et al., 1997; Passos and Mergler, 2008), ecosystem dynamics (Philipps, 1997; Roulet et al., 1999), and soil functions (Béliveau et al., 2009). Besides, intense soil podzolization and arenization on slopes, aggravated by deforestation and subsequent land uses leave the uppermost soil horizons vulnerable to erosion (Farella et al., 2001; Roulet et al., 1998). This triggers major changes in the transfer of terrestrial organic matter (TOM) to aquatic environments, and as such profoundly modifies the nature of the sediments (Farella et al., 2001, 2006; Roulet et al., 2000). In that sense, several studies conducted in the boreal environment have advocated the need of relating TOM weathering to watershed characteristics (Moingt et al., 2014; Ouellet et al., 2009; Teisserenc et al., 2010).

The landscape of the Tapajós region has been profoundly modified by slash-and-burn agricultural practices over the last fifty years (Béliveau et al., 2009; Metzger, 2003). The ashes of the burnt vegetation are used as natural fertilizer allowing crops to grow in the nutrient poor and acidic soil of the region (Fearnside, 1991). However, these practices only enhance soil fertility for one or two years, forcing the farmers to return their land to fallow for several years or to use it as pasture (Béliveau et al., 2009; Farella, 2005; Fearnside, 1991), and to repeat the slash-and-burn process on another piece of land (Metzger, 2003).

The present study was conducted as part of the Poor Land Use, Poor Health interdisciplinary research project, which studied the health risks of vulnerable communities of the Amazon deriving from environmental degradation. This study aims at qualifying and quantifying the changes in TOM transfers after deforestation from terrestrial to aquatic environments in three watersheds of the Tapajós region. As such, we relate the characteristics of a watershed (physical geography, vegetation cover and soil nature) to TOM found in the aquatic environment

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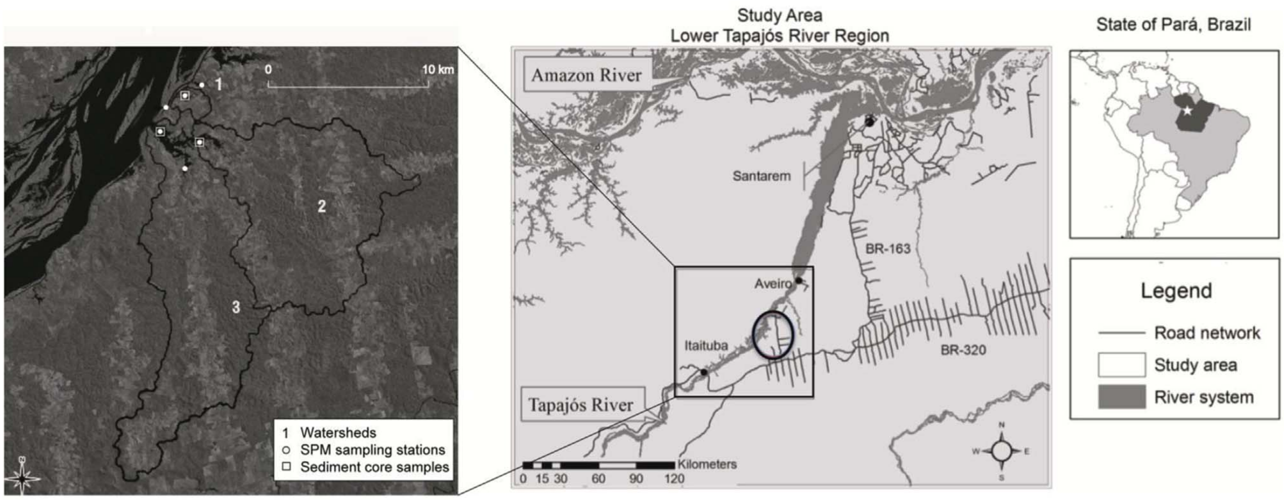

Fig. 1. Tapajos River region, watersheds delimitation (1 = Bom Intento, 2 = Demanda and 3 = Araipa), SPM and sediment core sampling sites selected for this study (modified from Oestreicher et al. (2016)).

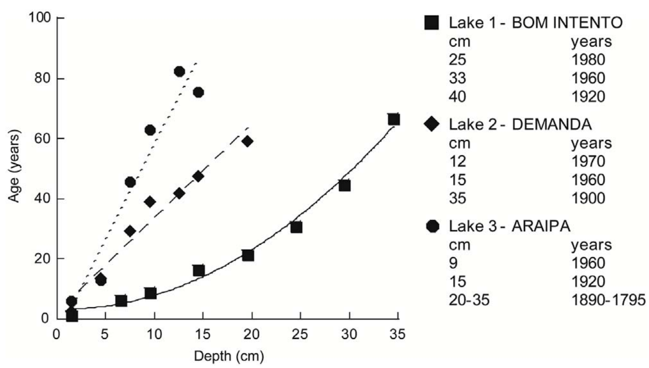

Fig. 2. ^{210}Pb sediment age prediction based on constant rates of supply model in the three lakes of the study.

(suspended particulate matter (SPM) and recent sediment). We use an approach combining Geographic Information Systems (GIS), ^{210}Pb core dating and lignin biomarkers. While lignin biomarkers have been widely used to evaluate the composition and source of TOM in aquatic environments (Gordon and Goñi, 2003; Hedges et al., 1986; Onstad et al., 2000; Prahl et al., 1994), and are considered as reliable tracers of TOM (Bélanger et al., 2015; Teisserenc et al., 2010), little is known about lignin transformations during its transit from the vegetal cover to the soil, water bodies and sediments in tropical environments (Bélanger et al., 2015; Feng et al., 2016).

2. Materials and methods

2.1. Study region

The sampling sites are located in the lower Tapajós region (Fig. 1). Historical data indicate that human settlement in the region occurred in successive episodes (Casa Civil, 2006; Oestreicher et al., 2016). The first settlement wave dates back from the 17th to the beginning of the 19th century, during the Portuguese expeditions that were conducted with the aim of taking possession of the land and establishing villages. The cities of Aveiro and Itaituba, in between which the studied lakes are situated (Fig. 1) were founded at this time (1781 AD and 1812 AD respectively). The region experienced a second major settlement wave coinciding with the rubber boom in the 1920s. Automobile industry magnate Henry Ford acquired more than 10,000 km^2 of land between Aveiro and Itaituba to exploit rubber. In the 1970's, the implementation of an integration and settlement policy at the regional level by the Brazilian government brought thousands of new families in the region. Colonists have practiced since then slash and burn subsistence agriculture, exposing cropland, fallow and pasture soils to heavy rains, which radically changed the nature of recent sediments (Farella et al., 2001; Roulet et al., 2000). One last major wave of immigration occurred in the 1980's with the gold rush (Cohenca, 2005) and along with the opening of secondary roads, such as the BR-163 connecting with the *Trans*-Amazonian highway (Fig. 1).

The region experiences alternating wet and dry seasons, and heavy precipitation during the wet season (1800–2200 mm of rain between December and April) (Interministerial, 2006) resulting in a several meter rise in river water levels, flooding the adjacent flatlands (De Oliveira Campos et al., 2001; Salati, 1986) and forming flood lakes. This hydrological system is characterized by an input of water from two separate sources in the wet season, one being the swollen river, and the other being the runoff from immediate surrounding watersheds. As it is difficult to quantify and distinguish water and SPM inputs coming from the river and from the watershed (Bonnet et al., 2008), the studied watersheds were chosen according to a gradient of interconnectivity between the flood lakes and the river (Fig. 2, Table 1a). In particular, Lake 1 (locally called Lake Bom Intento) is primarily fed by the small Watershed 1, being only connected to the Tapajós River in the wet season through a narrow channel. Lake 2 (locally called Lake Demanda)

Table 1
a and b: Location and morphological characteristics of the studied lakes and evolution of combined land use in the three studied watersheds. Percentages of land use exclude water surfaces in the watersheds. DA/LA = drainage area/lake area.

Table 1a	Watershed 1	Watershed 2	Watershed 3
Localization (lat./long.)	03.98S - 55.56W	04.01S - 55.55W	04.06S - 55.54W
Lake area (km^2)	0.27	2.99	2.99
Drainage area (km^2)	3.33	102.15	97.85
DA/LA	12.33	34.16	32.73
Mean slope (%)	10.28	8.14	9.11

Table 1b	Land uses for the three combined watersheds		
Year	1986	2001	2009
Forest (%)	80.6	64.8	48.9
Cropland, pasture (%)	3.7	8.6	16.4
Fallow forest (%)	12.1	21.4	26
Bare soil (%)	2.5	4.1	7.3

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