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Morphology-based functional groups as the best tool to characterize shallow lake-dwelling phytoplankton on an Amazonian floodplain

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ABSTRACT

River floodplains are subject to different inundation scenarios, mainly related to the flood pulse. Moreover, the ecology of floodplain lakes is modulated by exchanges of water with the main stream. On Amazonian floodplains, the water level fluctuates seasonally, with four distinct stages during the year: rising, high, falling, and low water. This study evaluated how/which three functional approaches to phytoplankton (FG, functional groups; MFG, morphofunctional groups; and MBFG, morphology-based functional groups) showed the largest relation to the environmental variations in response to rising and falling water periods, using data of the seven lakes sampled during rising and falling water periods, on the Curuaí Floodplain system, Pará state, Brazil. We used a Principal Coordinates Analysis to check for differences in phytoplankton species composition between the rising and falling water periods and a Redundancy Analysis to evaluate the relationship between functional approaches and environmental. Electrical conductivity, silica, and pH were the most important environmental variables to structuring the phytoplankton. The biological dissimilarity was computed using Bray-Curtis index for species biovolume and indicated greater similarity among the species compositions in the lakes during the falling water period. During rising water species is adapted in almost all lentic ecosystems (FG **Y**) and autotrophic organisms typical from the meroplanktonic that can be found in phytoplankton samples of the shallow lakes (FG **MP**); cryptomonads (MFG **2d**), large centrics (MFG **6a**), and large pennates (MFG **6b**); and non-flagellated organisms with siliceous exoskeletons (MBFG **VI**) and unicellular flagellates of medium to large size (MBFG **V**) were predominant. During falling water, species that tolerate eutrophic to hypertrophic environments with low nitrogen content predominated all shallow lakes (FGs **H1** and **M**; MFGs **5e** and **5b**; and MBFGs **III** and **VII)** and *Dolichospermum* spp. formed blooms. Morphology-based functional groups were the larger relation with the environmental variations than did functional groups and morphofunctional groups. MBFGs provides a relatively simple and objective classification and were the best in characterizing phytoplankton dynamics on the Curuaí floodplain. Therefore, we recommend using these groups to study phytoplankton ecology in shallow floodplain lakes.

1. Introduction

Biological classification systems allow study of the various relationships between living organisms, and in general, serve to categorize, group, and sometimes to form hierarchies of organisms (Linnaeus, 1758). The frequent use of functional classifications by

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ecologists is based on the evolutionary perspective that the functional criteria comprise biological processes and characteristics, and consequently generate ecological adaptations. Each functional association reflects the simultaneous responses of the individual species to environmental variations in an ecosystem (Reynolds et al., 2002).

Based on the assumption that species of different taxonomic groups can share ecological characteristics, different functional classifications of phytoplankton have been proposed: functional groups—FGs (Reynolds et al., 2002, Journal of Plant Research 24, updated by Padisák et al., 2009, Hydrobiologia 621); morphofunctional groups—MFGs, (Salmaso and Padisák, 2007, Hydrobiologia 578); and morphology-based functional groups—MBFGs (Kruk et al., 2010, Freshwater Biology 55). Phytoplankton functional approaches allow comparison of environmental studies and facilitate the assessment of biological responses to environmental conditions (Reynolds et al., 2002; Machado et al., 2015). Overall, phytoplankton classification uses morphological, physiological, and ecological traits, and when appropriate, taxonomic relationships (Salmaso et al., 2015). The classification of Reynolds et al. (2002) consists of a system comprising 31 functional groups whose species share ecological affinities based on tolerances and sensitivities under different environmental conditions. Padisák et al. (2009) consolidated the previous classification and updated the list to 40 functional groups (FGs). Salmaso and Padisák (2007), using taxonomic, morphometric, structural, and functional characteristics, developed another classification system, with 31 morphofunctional groups (MFGs). This system separates the cyanobacteria from other groups of algae, but left a classification gap by not including the large filamentous cyanobacteria (oscillatorialeans). Kruk et al. (2010) proposed a new functional approach for phytoplankton: morphology-based functional groups (MBFGs), which resulted in a dichotomous key based exclusively on the morphology of organisms. Although this approach could be considered simplistic, the morphology eventually expresses the physiology of the species (Reynolds, 1988; Naselli-Flores and Barone, 2007). The three approaches differ in the number of groups proposed, the main classification criteria, and the taxonomic and morphological and/or functional refinement used in each analysis (Brasil and Huszar, 2011).

Many studies have used phytoplankton functional groups in analyses of different systems around the world, such as reservoirs (e.g., Rangel et al., 2016; de Souza et al., 2016), rivers (e.g., Abonyi et al., 2012; Devercelli and O’Farrell, 2013), and floodplain lakes (e.g., Stanković et al., 2012a,b; Stević et al., 2013). Floodplain systems consist of flooded areas along the main river that periodically oscillate between the aquatic-terrestrial transition zone (ATTZ). The flood pulse is the structuring force of these ecosystems (Junk et al., 1989); on Amazonian floodplains, the flood pulse generates four distinct hydrological periods (rising, high water, falling. and low water), and leads to high spatio-temporal heterogeneity in the aquatic communities (Ward and Stanford, 1995; Ward et al., 1999). The physical and chemical properties of Amazonian floodplain lakes vary widely depending on the seasonal water level fluctuation (Affonso et al., 2015), soil type, vegetation cover, climate conditions (Junk, 2013; Junk et al., 2015), and human land use and occupation (Junk and Cunha, 2012) and can cause increased nutrients leading to high levels of phytoplankton blooms.

Studies using single functional group approach to analyze floodplain phytoplankton have used FGs, such as in Brazil for the Upper Paraná River (Bovo-Scomparin and Train, 2008; Bovo-Scomparin et al., 2013; Zanco et al., 2017), Pantanal (Loverde-Oliveira and Huszar, 2007), the Araguaia River (Nabout et al., 2006; Nabout and Nogueira, 2007), in the Amazon basin (Huszar and Reynolds, 1997). In other countries still using FGs, for the middle stretch of the Paraná River in Argentina (Devercelli, 2006), for northern Australia, in Mary River (Townsend, 2006) for Cross River in Nigeria (Okogwu and Ugwumba, 2012) and for the shallow lake Sakadaš, situated on the floodplain of the Danube River in Croatia (Mihaljević et al., 2009; Mihaljević et al., 2010; Stević et al., 2013). MFGs were used in Europe by Mihaljević et al. (2013) and in Argentina by Devercelli (2010), and MBFGs to study the spatial patterns of the Danube River (Mihaljević et al., 2015). Studies applying two functional approaches, FGs and MFGs, were used in the Mura, Drava, Danube, and Sava rivers in Croatia by Stanković et al. (2012a,b); and FGs and MBFGs were used as indicators of the environmental variation in the floodplain of the Upper Paraná River (Bortolini et al., 2014). Three functional approaches to understanding phytoplankton dynamics were used in human-impacted shallow lakes of the Argentine Pampas plain (Izaguirre et al., 2012), for phytoplankton changes in the Danube River (Mihaljević et al., 2014), and in deep karstic lakes (Žutinic et al., 2014).

This study evaluated which of three phytoplankton functional approaches (functional groups-FGs, morphofunctional groups-MFGs, and morphology-based functional groups-MBFGs) showed the largest relation to the environmental variations during of rising and falling water periods in Amazonian floodplain lakes. Our hypothesis was that different functional classifications (FGs, MFGs, and MBFGs) have different capacities to characterize phytoplankton dynamics; and we also evaluated if the disconnection of the lakes due to the falling water period led to greater heterogeneity of the functional groups. The research questions included: (i) Which of the functional approaches best characterize phytoplankton dynamics on this Amazonian floodplain, composed predominantly of shallow lakes?; (ii) Do the functional and morphological characteristics reflect the environmental variability during rising and falling water periods?; and (iii) Which environmental variables modified by the flood pulse are more influential in the structuring of the phytoplankton community in these environments?

2. Materials and methods

2.1. Study area

The study was conducted on the Curuaí Floodplain (01°50′16″S – 02°15′12″S and 055°00′51″W – 056°05′00″W), Pará state, Brazil (Fig. 1). It is located on the right bank of the Amazon River, 900 km upriver from the Atlantic Ocean. The floodplain extends approximately 130 Km along the main course of the Amazon River, and is composed of more than 30 lakes that are temporarily or permanently connected to each other and to the Amazon River by several channels (Maurice-Bourgoin et al., 2007; Bonnet et al., 2005, 2008). The largest lake, Lago Grande, is approximately 50 km long (Barbosa et al., 2006).

The maximum river level occurs between May and June, and the minimum is in November and December. The flooded area varies between 575 and 2090 km^2 for water levels between 3.0 and 9.6 m (Barbosa et al., 2006; Bonnet et al., 2008), and in years of extreme floods such as 2009, the flooded area can reach up to 2500 km^2 for a water level reaching 11 m. The main lakes have the characteristics of a white-water system (Lago Grande, Poção Grande, Salé, Poção, Santaninha, Piedade, and Piraquara) (Sioli, 1984; Junk et al., 2012).

According to the Köppen and Geiger (1928) classification, the climate is humid tropical (Af), marked by rainfall in all seasons and annual mean temperature between 24 and 26 °C (Fisch et al., 1998). The mean annual precipitation in the eastern Amazon basin is 2460 mm (Amanajás and Braga, 2012).

2.2. Environmental variables

Sampling data were taken on parallel transects in seven lakes along the length of the Curuaí Floodplain. We collected from 26 sampling points during the rising water period (March 2013) and 25 during the falling water period (September 2013).

Water temperature (WT), water depth (WD), pH and electrical conductivity (EC) were measured *in situ* using a YSI EXO 2 multiparameter probe. Turbidity (TB) was estimated by absorbance in a spectrophotometer (Varian Cary 1-E), considering a ratio between low- and high-molecular-weight compounds (Strome and Miller, 1978).