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Morphology-based functional groups as effective indicators of phytoplankton dynamics in a tropical cyanobacteria-dominated transitional river–reservoir system

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ABSTRACT

Cyanobacteria dominance is often associated with economic, ecological and health problems. The potential production of toxic compounds calls for frequent monitoring of cyanobacteria and their toxin production in many aquatic systems. Methods to simplify this process and facilitate management responses to sudden environmental changes are needed to improve the capability of risk-assessment. We tested the effectiveness of two different functional approaches (Functional Groups – FG, Reynolds et al., 2002; and Morphology-Based Functional Groups – MBFG, Kruk et al., 2010) as well as single species and taxonomic classifications as the best proxy of spatio-temporal phytoplankton dynamics and dominance of toxic algae in an impacted transitional river–reservoir system in the tropics. The Paraíba do Sul River and Funil Reservoir are located in one of the most heavily impacted regions of Brazil, and the latter system has a history of intense, long-lasting toxic cyanobacteria blooms. Sampling was conducted over the two climatological periods of the region: warm-rainy (October/2011 and January/2012) and cold-dry (July/2011 and May/2012), with stations in the following areas: tributary, reservoir and river (downstream from the dam). Our results showed that the MBFG classification was the most effective approach, i.e., best explained the response of the phytoplankton community to environmental variations. Environmental factors including light, nutrients, water temperature and hydrology increased the occurrence of different MBFGs on both spatial and temporal scales. The lotic areas showed a more diverse composition of MBFGs, including species with high to moderate tolerance to light limitation and flushing conditions (MBFGs **I**, **III**, **IV**, **V** and **VI**). In Funil Reservoir, phytoplankton biovolume was dominated by bloom-forming cyanobacteria (MBFGs **III** and **VII**) and remained high throughout the study. This dominance was related to the overall eutrophic conditions, low light availability and increased water-column stability of the reservoir. The seasonal dynamics in the reservoir was mainly related to changes in temperature and hydrology. Our results show for the first time that morphology captures efficiently eco-strategies of bloom-forming cyanobacteria and the MBFG approach can be used to predict and monitor the development of cyanobacteria HABs in temporal and spatial scales.

1. Introduction

Eutrophication and the subsequent dominance of bloom-forming cyanobacteria are expected to reduce phytoplankton species diversity in many freshwater systems (Borics et al., 2012; Mantzouki et al., 2015). Many tropical and subtropical reservoirs, especially those located in areas of high population density and with greater human influence, are subject to frequent cyanobacterial blooms (Jiang et al., 2014; Silva et al., 2014). The high input of nutrients from impacted rivers, combined with a stagnant water column due to high temperatures during most of the year, provide advantageous conditions for some bloom-forming cyanobacteria species (Rangel et al., 2012; Soares et al., 2013). The potential effects of these events extend beyond the reservoir itself, as the impoundment of water may strongly influence limnological features and the phytoplankton community in dammed rivers (Tornés et al., 2014). For instance, these impoundments may contribute to the

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development of bloom-forming cyanobacteria in lotic regions, where they are rarely dominant under normal conditions (Soares et al., 2007; Webster et al., 2000).

The proliferation of bloom-forming cyanobacteria usually causes economic losses, and also leads to risks to aquatic biota and human health (Paerl and Huisman, 2008; Smith and Schindler, 2009). A number of cyanobacteria species are potential producers of highly potent toxins, which can be harmful to mammals (including humans), affecting the hepatopancreatic, digestive, endocrine, dermal, and nervous systems (Dittmann and Wiegand, 2006; Paerl and Otten, 2013). In response to this potential threat to public-health, in Brazil as in many countries, legislation on water quality includes mandates for monitoring cyanobacteria and cyanotoxins (Brasil, 2011; Chorus and Bartram, 1999). Due to the high cost of frequent monitoring for cyanotoxins and tracking the genes responsible for toxin production (Codd et al., 2005), detection of potential cyanotoxin production is commonly based on total phytoplankton biomass, measured as chlorophyll-*a* concentrations, and/or on the quantification of the entire phytoplankton community at the species level (Kong et al., 2014; Sinang et al., 2013). While chlorophyll-*a* concentrations does not generate sufficient information on the dominance of potentially toxic species and risk assessment (Hu et al., 2015; Kruk et al., 2011), phytoplankton quantification is a complex and laborious task and is highly dependent on expert taxonomic knowledge (Cottingham and Carpenter, 1998).

Additionally, broad comprehension of phytoplankton dynamics and their drivers on different scales may be particularly important in reaching management decisions and facilitating responses to sudden environmental changes in impacted waters subjected to recurrent toxic blooms (Wang et al., 2011). This understanding can be simplified and achieved by grouping phytoplankton species with similar ecological characteristics into fewer categories (Carneiro et al., 2010; Gallego et al., 2012; Weithoff, 2003). Several phytoplankton functional classifications have been proposed, based on the understanding that the selection of groups of species with similar ecological characteristics is driven by environmental variability, regardless of their taxonomic affiliation (Salmaso et al., 2015). It is expected that groups of functionally similar species will simultaneously increase or decrease in biomass in response to particular environmental conditions, thus making it possible to predict the distribution and dynamics of natural phytoplankton populations (Brasil and Huszar, 2011). The functional-groups (FGs) approach proposed by Reynolds (Reynolds, 1997; Reynolds et al., 2002) is one of the most tested and validated phytoplankton functional classifications (Crossetti et al., 2013; Padisák et al., 2009). It divides phytoplankton into groups of species that share ecological affinities, tolerances and sensitivities to different environmental conditions. This approach has been tested successfully in a variety of aquatic systems (lakes, reservoirs, rivers, estuaries) and regions (temperate, tropical and subtropical) (Padisák et al., 2009). A major advantage of this scheme is that it can provide a clear characterization of the habitat (Salmaso et al., 2015). However, it requires identification at the species level and a thorough knowledge of the autecology of species (Brasil and Huszar, 2011; Hu et al., 2012).

Another promising phytoplankton functional scheme that has been recently proposed is based solely on the morphology of phytoplankton species. The authors showed that seven morphology-based functional groups (MBFGs) could effectively capture much of the phytoplankton functionality in a scheme that was built based on analysis of data from 700 phytoplankton species in 211 lakes along a climatic gradient (tropical to subpolar) (Kruk et al., 2010). This classification has proven to be robust and a series of multivariate and regression analyses showed that the MBFGs can be predicted better from environmental conditions than other classifications (FGs, taxonomic groups, and individual species) in these lakes (Kruk et al., 2011). More recently, the MBFGs faithfully simulated phytoplankton succession in two different kinds of waterbodies at different latitudes (Reynolds et al., 2014). One of the main advantages of this scheme is its independence from both taxonomic affiliations and knowledge of the physiological and ecological traits of species (Izaguirre et al., 2012).

Until this moment, only few studies have tested and compared these classifications, indicating which one would be most effective in predicting phytoplankton dynamic from the environmental variability (Salmaso et al., 2015). As each classification present different advantages and disadvantages, the purpose of the study, to identify the best scheme for the question, should be considered (Izaguirre et al., 2012). This choice may also depend on the type of aquatic environment (Stanković et al., 2012). Particularly in impacted aquatic environments, understanding the variability of functional responses of potentially toxic bloom forming cyanobacteria may be central to predicting and managing harmful events (Litchman et al., 2010; Mantzouki et al., 2015).

The Paraíba do Sul River and Funil Reservoir are located in one of the most heavily impacted regions of Brazil (Rangel et al., 2012; Soares et al., 2008). This river drains and receives waste from a highly populated and industrialized region (Soares et al., 2008) and is the main tributary of Funil Reservoir, which acts as a natural sink for pollutants and sediments from the river (Branco et al., 2002). The catchment area of the Paraíba do Sul River is inhabited by approximately 2 million people, all of whom depend on it for water supply, and about 46% of the sewage dumped in the river is untreated (Pacheco et al., 2015). Due to the strong influence of the Paraíba do Sul River, Funil Reservoir has become eutrophic in recent decades (Pacheco et al., 2015; Torres et al., 2016). At the end of the 1970s, it was characterized by low primary production and phosphorus concentrations, and a phytoplankton community dominated by green algae (Rocha et al., 2002). Beginning in the late 1980s, high inputs of nutrients, toxic heavy metals and polycyclic aromatic hydrocarbons, and cyanobacteria blooms have been continually recorded in the reservoir (Ferrão-Filho et al., 2009a). *Cylindrospermopsis raciborskii*, *Dolichospermum circinale* and *Microcystis aeruginosa* dominate the phytoplankton biomass in this system throughout the year (Soares et al., 2012, 2009), and microcystins and saxitoxins have been recorded in the reservoir (Ferrão-Filho et al., 2009b; Guedes et al., 2014).

In this study, we tested the effectiveness of functional approaches (FG of Reynolds et al., 2002 and MBFG of Kruk et al., 2010), and taxonomic classifications in explaining phytoplankton responses to the environmental variability in a tropical impacted transitional river–reservoir system, with history of long-standing cyanobacteria blooms. Our hypothesis is that functional (FG and MBGF) rather than taxonomic (taxonomic classes and individual species) classifications is the best proxy of phytoplankton dynamics and their response to environmental change, in agreement with other observations (Kruk et al., 2011).

2. Materials and methods

2.1. Study area

The Paraíba do Sul River and Funil Reservoir are located in the southern part of Rio de Janeiro State, with warm-rainy conditions during summer, and cold-dry during winter (Cwa in the Köppen system). Funil Reservoir (22°30′S, 044°45′W, altitude 440 m) has a catchment area of 16,800 km^2, surface area of 40 km^2, mean and maximum depth of 22 and 70 m, respectively, and total volume of 890×10^6 m^3. For more details see Soares et al. (2008, 2009, 2012) and Rangel et al. (2012).