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Cyanobacteria dynamics in a small tropical reservoir: Understanding spatio-temporal variability and influence of environmental variables

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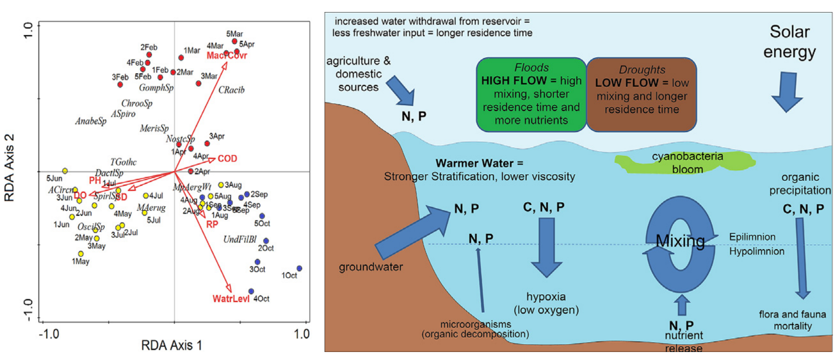
HIGHLIGHTS

- Fifteen cyanobacteria taxa were recorded over the study period.
- *Anabaena circinalis*, *Microcystis aeruginosa* and *Chroococcus* spp. dominated.
- Cyanophyta were the more abundant taxa during the cool-dry (May and July) season.
- Using redundancy analysis, seven variables had significant effect on cyanobacteria.
- Under climate change forecasts, potentially harmful algal species may proliferate.

GRAPHICAL ABSTRACT



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ABSTRACT

Anthropogenic disturbances within or near aquatic ecosystems often contribute to eutrophication events. Cyanobacteria are a key group responsible for environmental problems associated with eutrophication processes. Interest is growing in estimating the threat of cyanobacteria in tropical Africa, however, there is still a lack of understanding regarding temporal drivers of cyanobacteria dynamics in natural aquatic ecosystems given the paucity of relevant fundamental research in this area. To better understand cyanobacteria dynamics, potential drivers of cyanobacteria dynamics were investigated in a model tropical reservoir system, whereby phytoplankton communities and water quality parameters were sampled during the tropical hot–wet, cool–dry and hot–dry seasons. Fifteen cyanobacteria taxa were recorded over the study period. *Microcystis* spp. and *Cylindrospermopsis* spp., known cyanotoxins producers, were the most prevalent bloom-forming taxa found in the study, with overall Cyanobacteria relative abundances being greatest during the cool-dry season. This was likely driven by decreased river inflows and increased reservoir mixing during the cool-dry period. Combinations of macrophyte cover, dissolved oxygen levels, water transparency, reactive phosphorus, water depth and chemical oxygen demand were found to significantly affect cyanobacteria community structure. The study highlights that under climate change forecasts (for much of tropical arid Africa), potentially harmful and problematic algal species may proliferate. Management options, therefore, need to be explored to maintain water quality and potable availability to mitigate against indirect harmful effects of environmental changes on ecosystems and human communities that utilise their services.

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1. Introduction

One of the major problems associated with anthropogenic disturbance of aquatic ecosystems is that of eutrophication. Eutrophication has many undesirable symptoms such as high phytoplankton biomass, oxygen depletion, decrease in water transparency, unpleasant taste and odour, and drinking-water treatment problems (Mhlanga et al., 2006; Chinyama et al., 2016; Mantzouki et al., 2016; Ndlela et al., 2016). Many of the problems associated with eutrophication are, however, caused by the prevalence of Cyanobacteria. Cyanobacteria are a diverse group of organisms that differ widely in their functional traits, many of which are undesirable from a water quality perspective (Brasil et al., 2016; Havens et al., 2017). In the past few decades, many of the world freshwater and marine environments have experienced a steady increase in cyanobacterial blooms due to the algae rapid multiplication as a result of eutrophication (Fastner et al., 2003; Preußel et al., 2006; Liao et al., 2016; Mantzouki et al., 2016; Ndlela et al., 2016). These cyanobacteria can produce a wide range of potent toxins which may have health implications for aquatic life, livestock and wild animals (Mhlanga et al., 2006; Baig et al., 2017; Brient et al., 2017) and even humans (Funari and Testai, 2008; Funari et al., 2017; Rezaitabar et al., 2017).

Recent studies (i.e. IPCC, 2013; Brasil et al., 2016; Walls et al., 2018) have suggested that climate change may further intensify eutrophication symptoms in parts of the world. According to the Intergovernmental Panel on Climate Change (IPCC, 2013) report, many arid and semi-arid regions are likely to become warmer and drier by the end of the current century, partly due to anthropogenic induced climate change. Cyanobacteria within the tropics may show persistent annual dominance with relatively small changes during the year and often being toxic (Duong et al., 2013). High cyanobacterial bloom densities can also create problems associated with aesthetics and odour, lower water quality, increase turbidity and disrupt energy transfer in aquatic food webs as most cyanobacteria are not palatable to primary consumers (Preußel et al., 2006; Liao et al., 2016; Havens et al., 2017).

Although cyanobacteria blooms are typically associated with nutrient enrichment, their appearance has been related to several factors, such as adaptation to low carbon dioxide concentrations, high temperature and pH levels, low light conditions, and water column stability, ability to store phosphorus, nitrogen limitation, production of allopathic substances and resistance to herbivory (Havens et al., 2017). Phosphorus has been considered as the most important limiting nutrient in freshwater ecosystems and identified as being the main cause of eutrophication (Brasil et al., 2016). However, most investigators have advocated for the consideration of both nitrogen and phosphorus as the major causes of eutrophication and cyanobacterial blooms (Conley et al., 2009; Funari et al., 2017; Cremona et al., 2018). Hence, the concept of nutrient limitation is therefore considered key for cyanobacteria research, as it is in eutrophication research in general.

Despite the growing interest in estimating the threat of cyanobacteria in tropical Africa, there is still a lack of regular monitoring, management and even fundamental research (Ndlela et al., 2016). Therefore, the current study focussed on small tropical water-body cyanobacteria dynamics. Small water bodies are particularly interesting given their high surface area to volume ratio, and increased susceptibility pollution effects because of their small size. Given the need for potable water, small rivers are often impounded in arid regions, increasing the number of small standing water bodies at the regional landscape level. These water bodies become important for local communities that invariably come to rely on the services provided by more permanent water availability. To better understand cyanobacteria dynamics in these ecosystems, we assessed the composition and potential drivers of cyanobacteria in a small tropical reservoir used for recreational activities and water supply in the semi-arid region of Zimbabwe. The overall trends of cyanobacterial blooms were studied in relation to the variation in environmental variables in order to understand how the communities respond to hydrodynamic and thermal stratification events with regards to changes in community structure. This study facilitates our current understanding of the diversity and ecology of cyanobacteria within small tropical reservoirs with implications for effective management of such reservoirs.

2. Materials and methods

2.1. Study area

Malilangwe Reservoir is located in the south-eastern lowveld of Zimbabwe (20°58′–21°02′ S, 31°47′–32°01′ E), with a mean annual rainfall of 562 mm. Approximately 84% of the rainfall occurs between November and March and the area is prone to droughts due to erratic rainfall patterns. Summer temperatures are high, with a daily maxima of >32 °C and peak temperatures of >45 °C. Winters are generally cool, with temperatures ranging from 5 °C to 26 °C (Zimbabwe Meteorological Office, 2007). Malilangwe Reservoir is mostly used as a water supply and it is a gravity section masonry dam, with a surface area of 211 ha, maximum depth is 14.3 m (mean depth 4.5 m) and a maximum volume of 12×10^6 m^3.

The reservoir is vegetated with at least seven plant species belonging to five families (i.e. Cyperaceae (2 spp.), Poaceae (2), Onagraceae (1), Potamogetonaceae (1), Salviniaceae (1)) occurring in patches along the littoral zone (Dalu et al., 2012a) and is inhabited by eight fish species belonging to five families i.e. Cichlidae (4 spp.), Alestidae (1), Clariidae (1), Cyprinidae (1) and Gobiidae (1) being recorded (Dalu et al., 2012b). Sampling was carried out once a month at five selected sites throughout the three main seasons for the region; hot–wet (February to April), cool–dry (May to August) and hot–dry (September to October).

2.2. Environmental variables

Conductivity, dissolved oxygen (DO), pH, temperature and total dissolved solutes (TDS) were measured on-site at 1 m depth intervals using a multiparameter meter (HACH, LDO, Germany). Water transparency and level were measured using a Secchi disk and tape measure with an anchor, respectively. Integrated water samples were further collected using a Ruttner water sampler (KC Denmark) at each site at 1 m depth intervals for nutrients and chemical oxygen demand (COD) analysis in the laboratory (Dalu et al., 2013a). The COD was determined using the closed-reflux digestion method (EPA method 410.4; HACH method 8000; Standard Methods 5520D), with a precision of $\pm$ 2.7 mg L^{-1}. Nutrients i.e. total nitrogen (TN) were determined using the persulphate digestion method (HACH method 10,071) at a precision level of <1 mg L^{-1}, ammonium using the salicylate method (HACH method 10,023) at a precision level of $\pm$0.03 mg L^{-1}, reactive phosphorus using the PhosVer 3 method (HACH method 8048; USEPA method 365.2; Standard Methods 4500 P-E) at a precision of $\pm$0.02 mg L^{-1} and total phosphorus was determined using the PhosVer 3 with acid persulphate digestion method (HACH method 8190; Standard Methods 4500 P-E), at an estimated detection limit of 0.04 mg L^{-1}.

2.3. Phytoplankton sampling

Phytoplankton samples for determination of cyanobacteria were collected using vertical hauls with a phytoplankton net (20 μm mesh size, 40 cm diameter) at a speed of ~0.6 m s^{-1}. The concentrated samples were collected in 250 mL bottles and preserved in Lugol's iodine solution. The cyanobacteria samples were identified and scored under an inverted microscope (Olympus CKX41) using the Utermöhl's sedimentation method (Utermöhl, 1958) with the density of cyanobacteria being determined by counting the numbers present in five 10 mL subsamples from each site (~60–100 cells of the dominant species; Mhlanga et al., 2006) and with the mean value being recorded. All