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Variation partitioning of benthic diatom community matrices: Effects of multiple variables on benthic diatom communities in an Austral temperate river system

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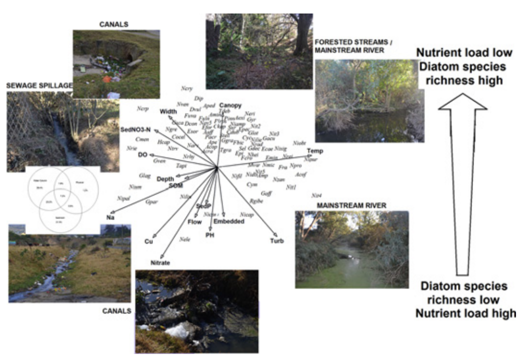
HIGHLIGHTS

- We explored diatom dynamics in modified river system with inconsistent river flow.
- Seasonal diatom composition was driven by nutrient loads and metal concentrations.
- Temporal variation in communities was observed in smaller systems over time.
- Differences in stream and mainstream sites were pronounced than canals and streams.

GRAPHICAL ABSTRACT



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ABSTRACT

This study explores diatom community dynamics in a highly modified semi-arid temperate region river system characterised by inconsistent river flow. Various water and sediment environmental variables were assessed using a multi-faceted analysis approach to determine the spatio-temporal drivers of benthic diatom communities in the river system. Overall, the diatom community was generally dominated by pollution tolerant species, reflecting the anthropogenic intensity and activities on the river system. Diatom community composition was found to be largely determined by water column chemistry variables particularly nutrient concentrations in comparison to sediment chemistry and physical variables. Strong seasonal diatom species composition was also observed and this was driven by strong seasonal variations in nutrient loads and metal concentrations, a result of the variable water flow across the two seasons. However, the greater temporal variation in communities was observed in the smaller systems with the mainstream river system being more homogenous over time. In addition, diatom community composition and environmental variables were found to be different and more pronounced between streams and mainstream sites, than between canals and streams. The study highlights the complex interaction between water column, sediment and physical variables in determining the diatom species

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composition in small river systems. It also highlights the importance of river flow inconsistency as an indirect variable that alters primary drivers such as nutrient concentrations in the water column and heavy metal levels in the sediment.

1. Introduction

Understanding how ecological processes are interconnected over multiple spatial scales, from global patterns to local community structure, is of paramount importance for fundamental and applied ecological research (Thomson et al., 2001). In freshwater ecosystems, key ecosystem components are hierarchically organised in space (Heino, 2011; Tudesque et al., 2014). Such spatial hierarchy may be perceived as an unforeseen composition of unidirectional relationships between abiotic and biotic components, whose dynamic balance between the different components can be maintained by top-down or bottom-up cascading effects (Heino, 2011). In the scope of environmental monitoring, understanding at which scale the surrounding landscape and human disturbances affect water quality at a given point is essential to adapt scale-appropriate strategies to protect and rehabilitate aquatic ecosystems (Tudesque et al., 2014).

Globally, it is estimated that some 65% of all freshwater habitats (i.e. lakes, ponds/pools, rivers, streams and reservoirs) are moderately to severely threatened (Dudgeon et al., 2006; Schowe and Harding, 2014). Human population increase and high water demand exacerbate the threat to these systems (Dalu et al., 2016a, 2016b; Nhiwatiwa et al., 2017; Petersen et al., 2017). Increased water consumption, industrial and agricultural activities or urbanisation, and inorganic processes, degrade surface waters. These anthropogenic impacts affect the ecological integrity and functioning of freshwater ecosystems, subsequently impairing their use for domestic, industrial and agricultural purposes (Wu et al., 2012; Venkatachalapathy and Karthikeyan, 2015). This is particularly relevant for river ecosystems as disturbances at one location often have far-reaching downstream implications for ecosystem functioning and management (Teittinen et al., 2015; Bere et al., 2016a, 2016b; Dalu et al., 2016a; Dalu and Froneman, 2016).

River ecosystems dynamics are driven by multiple natural and anthropogenic factors operating at different temporal and spatial scales, causing biotic assemblage variation depending on which factor is at play (Soininen, 2009; Bere et al., 2016a; Fidlerová and Hlúbiková, 2016; Virtanen and Soininen, 2016). Small streams are particularly vulnerable to land use changes and non-point source pollution as they have a greater watershed to stream area contribution than larger streams (Hlúbiková et al., 2014). Small streams may also experience high relative nutrient inputs than larger rivers owing to atmospheric deposition, allochthonous input and/or sediment mobilisation from the surrounding catchment (Hlúbiková et al., 2014; Bere et al., 2016b; Teittinen et al., 2015, 2016). Furthermore, given that these environments are directly connected to downstream habitats, streams as headwaters of river systems have been identified as areas that require special consideration for conservation and management (Abell et al., 2007).

Compared to biological indicators, water quality assessments based on water chemistry alone are generally poor determinants of freshwater ecosystem pollutant impacts (Bere and Tundisi, 2010). A major limitation for water chemistry assessments as a standalone measure is that it does not integrate water quality temporally (Bellinger et al., 2006; Teittinen et al., 2015). However, sediment chemistry parameters could give information about past pollution events, especially in some water body types. Water chemistry changes have implications for biotic communities as they inhibit recruitment of some species while encouraging others, thereby changing the relative contributions of biotic groups (Cholnoky, 1960). It is possible that the changes in species compositions can be used to reflect water quality changes in a more integrated manner than traditional water chemistry monitoring (Taylor et al., 2007a; Tan et al., 2015). Diatoms have been identified as a useful biotic group in this regard as they respond rapidly to environmental changes (Korhonen et al., 2013; Dalu and Froneman, 2016; Fidlerová and Hlúbiková, 2016).

Diatoms species typically have relatively narrow preferences for several environmental variables and their community structure responds to changing environmental conditions rapidly (Stevenson et al., 1996; Lavoie et al., 2014; Noga et al., 2014; Tan et al., 2014a, 2014b; Teittinen et al., 2015). The use of diatoms for biomonitoring is thus due to their cosmopolitan nature, rapid cell cycle and the ability to provide a relatively rapid indicator for disturbance. Moreover, unlike other aquatic biota, diatoms do not have specialised habitat niches (Stevenson et al., 1996; Walsh and Wepener, 2009; Noga et al., 2014; Rimet et al., 2015).

Urban areas represent key environmental change hot spots (Teittinen et al., 2015; Bere et al., 2016a, 2016b; Dalu et al., 2016a). Due to the generally low availability of surface waters and elevated demand in Austral temperate regions, much of the utilised water within these regions eventually return as effluent waters to rivers, streams and reservoirs (Taylor et al., 2007b). Effluent return and diffuse discharges may significantly alter the natural state of receiving aquatic ecosystems, often resulting in changes in ion concentrations, nutrient status and turbidity. These changes will in turn, to some extent alter the structure of aquatic communities in these systems (Taylor et al., 2007b). The use of diatoms in environmental water status assessment on a routine basis, is less common in the Austral temperate regions, even though diatoms have been demonstrated to serve as valuable indicators (Tan et al., 2015; Dalu and Froneman, 2016 and references therein). Hence, the effects of multiple drivers on diatom communities have not been explicitly evaluated in Austral temperate ecosystems, with only a handful of studies having been carried out (e.g. Dalu et al., 2015, 2016a, 2016b; Snow, 2016). Previous studies conducted in Northern Hemisphere temperate and tropical regions have shown that stream diatom communities are affected by agriculture and urbanisation (e.g., Tan et al., 2014a, 2014b; Wu et al., 2012; Teittinen et al., 2015; Fidlerová and Hlúbiková, 2016; Virtanen and Soininen, 2016).

The main aim of this study was to explore and describe the diatom species assemblages of the Bloukrans River system covering the primary environmental gradients in an urbanised and agricultural intensive Bloukrans River system, Eastern Cape, South Africa, with the view of improving and understanding diatom-based water quality assessment systems. We also aimed to assess the importance of analysed variables of water column, sediment, as well as physical properties of the sites and their contributions in explaining diatom community structure and species richness variation in the system. We hypothesized that: 1) based on previous studies conducted elsewhere, water column variables particularly nutrient concentrations would emerge as key determinants of diatom communities 2) diatom species composition would vary across seasons depending on the prevailing environmental factors such as water flow, nutrient load and metal concentrations; and 3) diatom assemblages variation would be strongly determined by ecosystem type i.e. canals, mainstream river and streams. We modelled diatom species richness using a boosted regression trees model which is capable of revealing important ecological relationships for environmental management and conservation planning so as to identify the main drivers for benthic diatom species richness.