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Assessment of the spatial and temporal variations in periphyton communities along a small temperate river system: A multimetric and stable isotope analysis approach

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ABSTRACT

Periphyton community structure and stable isotope values have been identified as potential indicators of anthropogenic nitrogen pollution, an increasingly important challenge in aquatic systems. The aim of the study was to assess the spatio-temporal changes in periphyton characteristics to identify potential anthropogenic nitrogen pollution sources such as agricultural and sewage discharge within the Kowie River catchment, South Africa. Periphyton was collected once a season from five sites between September 2012 and May 2013. Diversity indices, multimetric and stable isotope analyses were employed for describing the spatial and temporal dynamics of periphyton community assemblages. Water depth, salinity, resistivity, oxygen reduction potential, nitrates, water velocity and conductivity were the major factors affecting periphyton community structure. Eighty-seven periphyton taxa belonging to 43 genera were recorded throughout the study sites and periods. Periphyton species richness, abundance and stable isotope signatures differed significantly among sites but not among seasons. The lower sections of the Kowie River were polluted by anthropogenic sources as indicated by the high periphytic isotopic nitrogen values (7.9–15.2‰) compared to the pristine upstream sites (4–8‰). We recommend that researchers use a combination of community structure and stable isotope measurements to monitor the periphyton in lotic systems.

1. Introduction

Periphyton consists mainly of algae, bacteria, protozoa and fungi that grow on rock substratum in all lotic systems, with algae making up the largest proportion (Ewart-Smith and King, 2012). This complex organic pool plays an important role in aquatic ecosystems as a main source of food for higher trophic level organisms (Azim et al., 2005). Assessments of periphyton communities can provide information on the trophic structure and ecological status of a system. As such, periphyton is widely used for monitoring purposes because of its value for indicating acidification, eutrophication and organic pollution (Azim et al., 2005; Morin et al., 2010).

Intensive research has been devoted towards understanding periphyton community structure in relation to biotic and abiotic factors (Suren et al., 2003; Uehlinger et al., 2003; Larned, 2010; Ewart-Smith and King, 2012; Tan et al., 2014). A complex interplay of physico-chemical and biological factors such as velocity, temperature and nutrients regulates these complex communities (Biggs and Thomsen, 1995; Jowett and Biggs, 1997; Vis et al., 1998; Chételat et al., 1999; Passy et al., 1999; Murdock et al., 2004). Water chemistry, current velocity, temperature, flood disturbance, grazing pressure, and the anthropogenic factors such as agricultural runoff and sewage discharge all influence periphyton community structure (Chételat et al., 1999; Passy et al., 1999; Ferragut et al., 2010; Larned, 2010; Bere and Tundisi, 2011a).

Periphyton is particularly responsive to water flow and nutrient concentration changes (Azim et al., 2005), hence it is suitable for monitoring environmental changes in lotic systems. An improved understanding of how these communities respond to environmental changes will greatly improve our ability to efficiently manage water resources. Despite the rich abundance of literature on freshwater algae, and some available information on the application of periphyton for assessing ecosystem integrity in European and Australasian countries (Biggs and Thomsen, 1995; Vis et al., 1998; Biggs and Kilriy, 2000; Suren et al., 2003; Finlay, 2011), little related research is available in other parts of the world, particularly Africa. In many African countries, for instance, periphyton is currently not a recognized tool in environmental monitoring programmes.

Recent studies have indicated that stable nitrogen isotope signatures ($\delta^{15}N$) of periphyton can be useful for tracing nitrogen sources in river systems (Anderson and Cabana, 2005, 2006; Vander Zanden and Rasmussen, 2001; Diebel and Vander Zanden, 2009; Ning et al., 2013). Different anthropogenic nitrogen sources have different initial isotope values (Anderson and Cabana, 2005, 2006; Vander Zanden

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and Rasmussen, 2001), thus allowing their identification from $\delta^{15}N$ values observed in inorganic nitrogen fractions, algae, plants and finally, consumers. For example, human wastewater and livestock wastes have high $\delta^{15}N$ values of >10‰, while synthetic fertilizers typically have low $\delta^{15}N$ of −3 to 3‰ (Vander Zanden and Rasmussen, 2001; Anderson and Cabana, 2005, 2006). Biogeochemical transformations of nitrogen such as denitrification and ammonia volatilization can result in substantial isotopic fractionation. When periphyton or other plants in aquatic ecosystems take up dissolved organic nitrogen, their tissues reflect the nitrogen source (Lake et al., 2001). Stable carbon isotopes ($\delta^{13}C$) are widely used to discriminate periphytic from terrestrial production in lotic ecosystems (Finlay et al., 1999; Ishikawa et al., 2012). While the use of $\delta^{13}C$ has many advantages as a natural tracer, there is a growing awareness of large spatial and temporal variability in $\delta^{13}C$ values of lotic periphyton (Ishikawa et al., 2012), and this variability can introduce uncertainty when determining the isotopic baseline of a food web (Finlay et al., 1999; Ishikawa et al., 2012). As such, caution must be used when applying $\delta^{13}C$ values of periphyton in ecological studies.

Our aim was to assess periphyton community structure in relation to local environmental factors. We explored whether shifts in community structure or biomass supported the principles of the River Continuum Concept (RCC) (Vannote et al., 1980). We also investigated the spatial and temporal patterns in periphytic $\delta^{15}N$ and $\delta^{13}C$ values along a river relative to potential sources of nitrogen pollution. We postulate that measures of periphyton community structure and stable isotope ratios can act as complementary indicators of anthropogenic nitrogen inputs to aquatic ecosystems.

2. Materials and methods

2.1. Study area

The Kowie River is classified as an intermediate permanently open river system which drains a catchment area of approximately 800 km^2 (Heydorn and Grindley, 1982; Whitfield et al., 1994). The river has a total length of approximately 93 km (Fig. 1), it flows in a south-east direction draining the Bathurst region, and its source is in the Grahamstown Heights Hills. Mean annual rainfall is 650 mm, and rainfall is distributed evenly over the catchment (Heydorn and Grindley, 1982). Minimum and maximum air temperatures are 1.5 °C and 43 °C, respectively, with a mean daily temperature of 12.6 °C (Heydorn and Grindley, 1982). Citrus (pineapples, citrus and chicory) and livestock (fodder crops, beef cattle and goats) farms occur mostly in the middle to the lower sections of the river. A major flooding event in October–November 2012 produced a record discharge of 699.14 $m^3\ s^{-1}$, changing the geomorphology of the Kowie River; a detailed description of the flooding is highlighted in Dalu et al. (2014a).

The study was conducted on 10–14 September 2012 (early spring), 26–30 November 2012 (late spring), 20–24 February 2013 (summer) and 25–29 May 2013 (winter). Periphyton samples were collected along the Kowie River at five different sites: 2 sites (F1 and F2) in the relatively pristine forested headwaters were reference sites, and 3 sites (F3, F4 and F5) were polluted due to the Bloukrans River which drains Grahamstown (population 125,000) and intensive farmlands along the Belmont Valley area (Fig. 1). The sampling sites were chosen to study the pollution gradient from the relatively unpolluted headwaters (pristine) to the polluted downstream sites (Dalu et al., 2014a,b,c). No samples were collected in early spring at site F3 due to accessibility problems.

2.2. Physico-chemical factors

Water depth and velocity were measured at each site and season using a Flo-mate portable flow meter Model 2000 (Marsh McBirney, Maryland). Conductivity, dissolved oxygen, pH, resistivity, salinity, total dissolved solids and water temperature were measured using CyberScan Series 600 portable probes (Eutech Instruments, Singapore). Water samples (500 mL) were collected in triplicate and placed on ice for further processing in the laboratory. Nutrient concentrations in the water samples were analysed using an HI 83203 multiparameter bench photometer (Hanna Instruments Inc., Rhode Island) upon return to the laboratory: ammonia (photometer range of 0–10 mg $L^{-1} \pm 0.05$ mg L^{-1} accuracy),

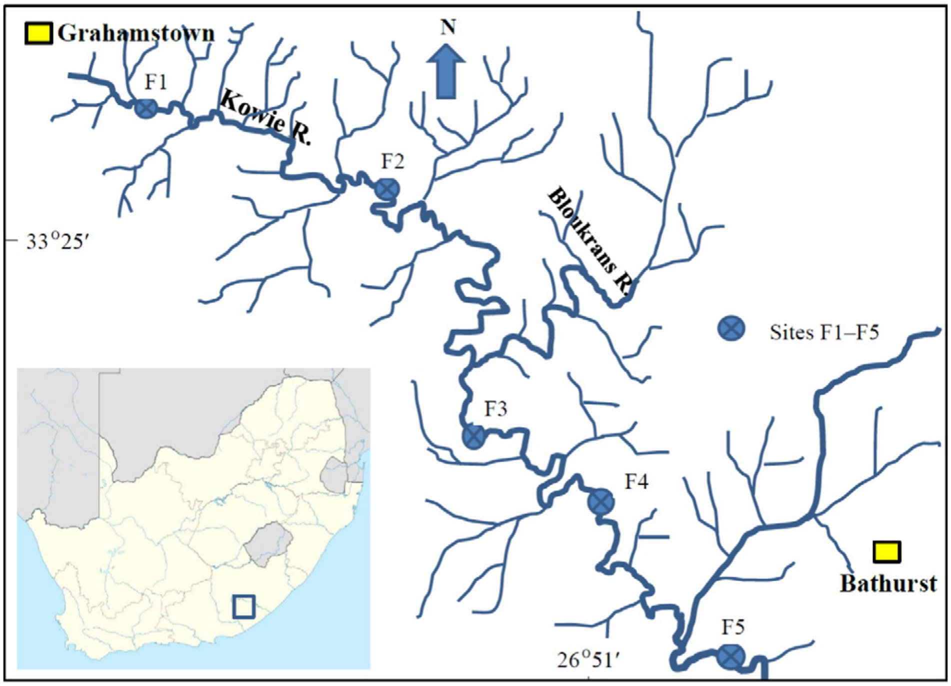

Fig. 1. Location of the study sites along the Kowie River.