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The Zambian Macrophyte Trophic Ranking scheme, ZMTR: A new biomonitoring protocol to assess the trophic status of tropical southern African rivers

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ABSTRACT

The Zambian Macrophyte Trophic Ranking system (ZMTR) is a new bioassessment scheme to indicate the trophic status of tropical southern African river systems. It was developed using a dataset of 218 samples of macrophytes and water chemistry, collected during 2009–2012, from river sites located in five world freshwater ecoregions primarily represented in Zambia. A typology based on these ecoregions, and three stream order categories, was used to determine soluble reactive phosphate (SRP) reference conditions. Zambian Trophic Ranking Scores ($ZTRS_{sp}$) were calculated for 156 species, using direct allocation from SRP data for 80 species, in samples for which sufficient available SRP data existed. An indirect quantitative procedure, based upon occurrence of species in six sample-groups, of differing mean SRP status, produced by TWINSPAN classification, allocated provisional $ZTRS_{sp}$ values for the remaining 76 species. Additional data for nitrate, pH, alkalinity and conductivity were used to help assess the trophic preferences of macrophyte species showing differing $ZTRS_{sp}$ values. $ZMTR_{sample}$ values were calculated as the mean $ZTRS_{sp}$ score of species present per sample. ZMTR indicated trophic status reasonably accurately for 83.1% of Zambian samples, and for all samples within a test dataset from Botswanan rivers. Examples of application of the methodology, and its potential for hindcasting river trophic status are provided. The scheme currently underestimates highly-enriched conditions, and, to a lesser extent, overestimates the trophic status of some very low-nutrient rivers, but at this pilot stage of development it generally predicts the trophic status of tropical southern African river systems quite well.

1. Introduction

Freshwater biomonitoring uses organisms that live in freshwater systems as indicators of ecosystem health (or "biointegrity": Norris and Hawkins, 2000), and also potentially of specific ecosystem characteristics which provide an indication of biointegrity status, such as nutrient conditions (e.g., Holmes et al., 1999).

The maintenance of good quality, clean rivers, supporting high-quality biodiversity, is universally recognised as a vital element of societal wellbeing. The successful development and implementation of inexpensive but effective biomonitoring schemes to assess river biointegrity is crucial to improving human and environmental welfare in all developing countries, including those in tropical

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Africa. However, despite their obvious low-cost advantages for water quality monitoring in low-income tropical countries, to date river biomonitoring schemes have been developed for only a few tropical African countries (e.g., South Africa, Zimbabwe, Namibia and Tanzania), and are usually based on the use of benthic invertebrates, rather than macrophytes, as indicator organisms (e.g., Dickens and Graham, 2002; Palmer and Taylor, 2004; Bere and Nyamupingidza, 2014; Kaaya et al., 2015). A major reason for this state of affairs lies with the general dearth of baseline information about the freshwater biota and environmental conditions occurring in tropical African rivers, and their associated waterbodies, which is obviously needed as a prerequisite for bioassessment scheme development.

It is in Europe (or to be more precise, in European Union (EU) nations) that a major effort has been made to develop macrophyte-based river biomonitoring protocols, which are currently in routine use for river biomonitoring, after macrophytes were recognised as biological quality elements for the implementation of the European Water Framework Directive (Birk and Willby, 2010). Three examples of the many different macrophyte-based national river bioassessment schemes in use in EU countries include LEAFPACS in the UK (WFD-UKTAG, 2014), Macrophyte Biological Index for Rivers (IBMR) in France (Haury et al., 2006) and TIM (Trophic Index of Macrophytes) in Germany (Schneider and Melzer, 2003). The national protocols vary quite considerably in detail, but tend to utilise a similar basic approach, and are usually reference-condition based schemes (e.g., Ferreira et al., 2002; Pardo et al., 2012). In addition to development and implementation of these biomonitoring protocols, much work in Europe has been done on comparison, critical assessment, and intercalibration of macrophyte-based river bioassessment schemes using a range of metrics (e.g., Birk et al., 2006; Aguiar et al., 2014).

The Southern African River Assessment Scheme, SAFRASS, developed during 2010–2014, following preliminary work in Zambia from 2006 onwards, aimed to produce a pilot set of river-quality biomonitoring protocols for use in tropical southern Africa (Kennedy et al., 2012a,b; Kennedy et al., 2014,2015; Lowe et al., 2013). SAFRASS uses three biotic indicator groups (benthic diatoms, benthic macroinvertebrates, and macrophytes) that variously respond to changes in river conditions over time-scales from weeks to years (e.g., Smith et al., 1999; Harding et al., 2005; Schneider, 2007; Dallas et al., 2010; US EPA, 2012; Moore and Murphy, 2015). Zambian rivers, and their closely-associated floodplain waterbodies, were selected as the target systems for this study because of the naturally-wide range of ecological conditions occurring in the country. There is also a widely-varying scale of impacts from human-associated activities, across the country, including nutrient enrichment, pollution by heavy metals and other toxins, flow changes, catchment degradation, sedimentation, and impacts of invasive aquatic weeds (e.g., Kennedy et al., 2012a,b; Kennedy et al., 2014, 2015).

No river biomonitoring protocols existed for Zambia prior to development of the pilot SAFRASS procedures. Water chemistry testing had been conducted at a few sites over past years by government institutions but data are both extremely limited, and spatially and temporally sporadic. The combination of lack of capacity to monitor water resource quality, and the potential for increased impacts on these resources, as well as likely impacts upon the people who rely on them, made the need for development of appropriate freshwater biomonitoring tools in Zambia particularly pressing.

Here we outline the basic features of the SAFRASS monitoring approach, and describe in detail its macrophyte-based biomonitoring protocol, the Zambian Macrophyte Trophic Ranking (ZMTR) system. This was developed using a subset of the data (utilising vascular macrophytes only: lower plants are not currently included in the scheme), collected from the first-ever extensive survey, during 2006–2012, of Zambian rivers and associated high-connectivity floodplain standing waters (Kennedy et al., 2015). The SAFRASS approach aimed to bring together, modify as necessary, and recalibrate appropriate features of similar schemes developed for use in non-tropical parts of the world. In particular we made use of (in the case of the SAFRASS macrophyte element, ZMTR) the UK Macrophyte Mean Trophic Ranking system (MTR: Holmes et al., 1999), and the Swedish Environmental Quality Criteria for Lakes and Rivers (Swedish Environment Protection Agency, 2000), as well as relevant baseline aspects of the South African Scoring System (SASS: Dickens and Graham, 2002). The work reported here was, in large part, based on results obtained during fieldwork undertaken during 2010–2012 for development and testing of SAFRASS. The data were supplemented by information from previous and subsequent surveys of Zambian rivers and closely-associated waterbodies, including riverine floodplain lakes, backwaters and dambos (seasonal standing waterbodies), undertaken by the authors during 2006–2012. A further test dataset was obtained for riverine sites independently surveyed during 2006–2007 in Botswana (Mackay et al., 2011; Davidson et al., 2012). The outcomes reported here update and replace previously-published provisional findings for the ZMTR protocol (Kennedy et al., 2012a,b; Kennedy et al., 2014).

2. Material and methods

Macrophyte surveys (with collection of supporting physico–chemical data) were conducted during 2006–2012, with 271 samples being collected from 228 sites in Zambia, located on rivers and closely-associated (high connectivity) floodplain waterbodies, including riverine lakes, backwaters and dambos (seasonal standing waterbodies). From this dataset a subset of 218 samples collected during 2009–2012 was primarily used for the purposes of this study. Surveys followed the guidelines of the international standard EN 14184 (European Committee for Standardization, 2003), including emergent vegetation due to its importance in Zambian rivers (Dallas et al., 2010). The survey protocol (as outlined in Kennedy et al. (2015) and briefly summarised here) required a standard 100 m stretch of waterbody to be sampled at five random points within the stretch. All macrophyte species present within the waterbody were recorded per sampling point, and frequency (as %F per stretch) was calculated as a measure of abundance for each species, based on number of hits out of 5 maximum possible. Records for emergent and floating species were supplemented by the use of a standard macrophyte-sampling grapnel (attached to a 5 m long cord, and thrown from bank or boat as appropriate) to collect submerged species, which were generally less conspicuous compared to life forms which projected above or resided at the water surface. The high risk of attack by dangerous animals (particularly crocodile and hippopotamus) largely precluded entry into the water for plant sampling purposes, except in small shallow clear-water streams, or where (rarely) armed guards were available to provide protection.

Where feasible, plant samples were retained as herbarium-sheet specimens for subsequent identification. This was a major issue in Zambia at the time of the project, as no appropriate identification guides for aquatic vegetation pre-existed for the country. Consequently, identification was carried out using other aquatic and wetland plant identification and distribution source material, currently available for other parts of southern Africa and tropical Asia (e.g., Cook, 1996, 2004; Gerber et al., 2004; Weyl et al., 2016), as well as guides to identification of riverine macrophytes in Zambian rivers, produced as outputs from the SAFRASS project