Ecological Indicators 80 (2017) 135–146

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Research paper

Developing a regional diatom index for assessment and monitoring of freshwater streams in sub-tropical Australia

Sue Oeding*, Kathryn H. Taffs

School of Environment, Science and Engineering, Southern Cross University, PO Box 157, Lismore NSW 2480 Australia

A R T I C L E I N F O

Keywords:
Bio-indicator
Ecosystem health
Eutrophication
River assessment
Trophic diatom index
Water quality

A B S T R A C T

The use of borrowed indices to assess stream health has limitations and research suggests a need to develop more reliable regionally based indices that are sensitive to the relationship between taxa and environmental conditions. Implementing this is challenging in the Southern Hemisphere given the scarcity of diatom indices, specifically in sub-tropical areas. The purpose of this study was to develop a regionally based diatom index to assess freshwater lotic systems in sub-tropical eastern Australia and compare the results with borrowed indices to derive meaningful inferences on river health. A total of 119 epilithic diatom and water samples were collected during 2014–2015 from the Richmond River Catchment in Northern NSW Australia. Statistical analysis indicated that total phosphorus (TP) and total nitrogen (TN) were strong variables influencing the data set and subsequently TP was chosen as a nutrient proxy for the index. Analysis of diatoms resulted in TP sensitivity values (1–5) being assigned to 105 species with relative abundance of > 1% in the data set. These species were used to calculate the Richmond River Diatom Index (RRDI) for 45 sites within the Catchment. The index effectively scored sites along the environmental gradient with sites in the upper catchment generally scoring lower (healthier) than the mid and lower catchment sites. The index compared positively with both the Diatom Species Index for Australian Rivers (DSIAR) (r = 0.76) and the Trophic Diatom Index (TDI) (r = 0.65). Further research is suggested to test the RRDI on independent sites in neighbouring catchments and develop class boundaries from the RRDI so that the index can be readily used by water managers to assess and monitor freshwater systems in sub-tropical Australia.

1. Introduction

The declining health of surface waters worldwide has prompted policy makers and managers to improve assessment and monitoring programs in an attempt to quantify the impacts of anthropogenic activities (Bennion et al., 2014; Tan et al., 2013). Extensive land clearing for urbanisation and agricultural enterprises are increasingly affecting riverine ecosystems and biodiversity as a result of high nutrient loads and other pollutants. Over the last few decades, policies and management strategies have evolved to include biological indicators to assess and monitor surface waters (Almeida and Feio, 2012; Birk et al., 2012; Elias et al., 2012). Water managers require reliable information so that realistic goals can be set to improve water quality, thereby ensuring the integrity of these systems. This considerable change in direction was prompted by the implementation of the European Union's Water Framework Directive (WFD) (EC, 2000) which required all member nations to include biological indicators in their water quality evaluation and monitoring programs (Almeida and Feio, 2012; Elias et al., 2012). This direction has spread to other continents and is progressively being implemented through relevant environmental legislation, policies and programs (Biggs and Kilroy, 2000; Gómez and Licursi, 2001; Lavoie et al., 2008; Lobo et al., 2004; Potapova and Charles, 2007; Taylor et al., 2007).

Diatoms are one of the most popular and readily used biological indicators of water quality. As a result, global use of diatoms is increasing (Almeida and Feio, 2012; Elias et al., 2012). Water chemistry assessments offer only a snapshot of water quality at the time of sampling; whereas diatoms respond to a range of physical and chemical parameters providing an indication of environmental conditions over a temporal range, revealing environmental changes (Bere and Tundisi, 2011b; Li et al., 2010; Lobo et al., 2010; Salomoni et al., 2006). Diatoms are easily sampled, processed and preserved on permanent slides for future reference (Almeida and Feio, 2012; Chessman et al., 2007; Elias et al., 2012; Kelly and Whitton, 1998). Diatoms have been extensively researched, tested and proven to be valuable biological indicators of stream health (Kelly and Whitton, 1998; Lobo et al., 2016; Oeding and

* Corresponding author.
E-mail address: sgoeding@gmail.com (S. Oeding).

http://dx.doi.org/10.1016/j.ecolind.2017.05.009
Received 7 October 2016; Received in revised form 19 April 2017; Accepted 2 May 2017
Available online 15 May 2017
1470-160X/

Taffs, 2015; Salomoni et al., 2006). Diatoms have developed as an integral component of environmental monitoring policy and legislation (Bellinger et al., 2006; Bere and Tundisi, 2011b; Kelly and Whitton, 1998; Salomoni et al., 2006).

The development of diatom metrics and indices for assessment and monitoring has grown substantially, particularly in the Northern Hemisphere (Birk et al., 2012). Indices such as the Trophic Diatom Index (TDI) (Kelly et al., 2008; Kelly and Whitton, 1995), the Pampean Diatom Index (IDP) (Gómez and Licursi, 2001), the Biological Diatom Index (IBD) (Prygiel and Coste, 2000), the Pollution Tolerant Index (Muscio, 2002) are widely used in Europe. Indices used in North America include the Indices of Biotic Integrity (Wang et al., 2005) and the Eastern Canadian Diatom Index (IDEC) (Lavoie et al., 2006). These indices were all developed in temperate zones of the Northern Hemisphere and research has indicated that they may not be applicable to rivers in different regions and climate zones (Besse-Lototskaya et al., 2011; Chessman et al., 2007; Newall et al., 2006; Salomoni et al., 2011).

Increasingly, research is suggesting that regional or catchment focused indices may serve more effectively, providing a better indication of conditions than national or international indices (Besse-Lototskaya et al., 2011; Chessman et al., 2007; Lavoie et al., 2009; Oeding and Taffs, 2015). It has previously been widely accepted that diatoms are cosmopolitan, and have consistent ecological tolerance (Bere, 2011a; Kelly et al., 1998; Lobo et al., 2010; Reid et al., 1995). However, research indicates that some species often have a regional variation of ecological tolerance influenced by a range of environmental processes such as climatic, catchment geology, soils, river geomorphology, topography and vegetation (Bere and Tundisi, 2011b; Besse-Lototskaya et al., 2011; Kelly et al., 1998; Potapova and Charles, 2007). Several studies have noted a need to either calibrate indices to regional conditions or use regionally derived indices that are more sensitive to the relationship between taxa and environmental conditions and consequently be more effective and reliable (Bere and Tundisi, 2011b; Lavoie et al., 2009; Philibert et al., 2006; Potapova and Charles, 2007).

It is paramount that careful consideration should be made concerning the use of borrowed diatom indices in regions in which they were not developed as they may cause uncertainty in results (Besse-Lototskaya et al., 2011; Lavoie et al., 2006; Lobo et al., 2015; Philibert et al., 2006). Spatial and temporal variations in species ecological tolerances and optimums have been reported (Lobo et al., 2015; Salomoni et al., 2011). Additionally, the number of taxa included in an index may limit its performance by underestimating the ecological integrity of a site (De la Rey et al., 2004; Lavoie et al., 2009; Oeding and Taffs, 2015; Tan et al., 2013). Inadequacy of indices to identify the boundaries of pollution gradients across a range of regional/continental contexts is also an issue. For example, sites considered as having poor water quality in one country or continent may not be classified at the same level in another (Kelly et al., 2005; Lavoie et al., 2006, 2009). It has been suggested that in regions without their own index, several indices should be applied and results carefully analysed (Besse-Lototskaya et al., 2011). Justification of results is essential as in many countries there are regulatory and financial implications associated with the classification of rivers, and often, funding for restoration and rehabilitation works is highly competitive (Kelly et al., 2008).

In Australia, biological assessment has been focused primarily on macroinvertebrates, with programs such as the Australian River Assessment System (AUSRIVAS) (Davies et al., 2000) and the Ecosystem Health Monitoring Program (Abal et al., 2006) of South East Queensland Healthy Waterways Partnership. Diatoms have been under-utilised in Australia (Reid et al., 1995), and it has been suggested that this is possibly due to a lack of metrics, diatom expertise, indices and taxonomic keys, specific to regional or catchment scale (Chessman et al., 2007). To date there is only one Australian diatom index available. The Diatom Species Index for Australian Rivers (DSIAR) (Chessman et al., 2007) was developed predominantly from temperate zone data. The authors of this index noted that further research and evaluation was needed to test its applicability in other regions of Australia.

The main purpose of this study was to develop a diatom index suitable for sub-tropical Australian rivers with data sourced from the Richmond River in northern NSW and compare results with the TDI and DSIAR indices to derive meaningful inferences on sub-tropical health. To evaluate the performance of the Richmond River Diatom Index (RRDI), four criteria were used following methods similar to Lavoie et al. (2009); (1) percent of total taxa present used to calculate the RRDI compared with the TDI and DSIAR, (2) comparison of sensitivity values to a range of borrowed indices, (3) comparison of index scores in regards to inferences on river health, and (4) the ability of each of the indices to identify both ends of the nutrient gradient.

2. Methods

2.1. Study area and sampling design

The Richmond River Catchment (RRC) is located in the sub-tropical Northern Rivers Region of NSW, Australia (Fig. 1). The RRC covers an area of approximately 6900 km^2. It is the sixth largest river catchment in NSW, with two major tributaries; the Richmond and Wilson Rivers which merge at Coraki. The dominant geology of the Catchment is basalt (31%), alluvial deposition (30%) and sandstone (28%) (Hossain and Eyre, 2002). The upper reaches are characterised by smaller tributaries draining steep valleys, many of which have been cleared for agriculture (approximately 78%), resulting in minimal riparian zones, unstable banks and subsequent high erosion rates (Dawson, 2002; Eyre, 1997). The lower reaches have been extensively cleared of native vegetation for agriculture and urban development (Dawson, 2002; Lott and Duggin, 1993; Williams, 1987). Land use is dominated by grazing (53%) in the upper floodplain areas, sugar cane cropping in the lower reaches and coastal zones, and horticulture (tropical fruits and nurseries) in the mid and upper reaches of the Wilson River and its tributaries (Hossain and Eyre, 2002; Ryder et al., 2015). National Parks and reserves make up approximately 11.5% of the Catchment (Ryder et al., 2015). As a result of extensive land clearing, the surface waters of the region have experienced declining water quality through both point and diffuse sources (McKee et al., 2001; Williams, 1987).

Sites ($n = 45$) were selected with the main criterion reflecting a disturbance gradient, ease of sampling and appropriate diatom habitat such as riffle and run zones and water depth. Sites located in upper catchment areas have little anthropogenic disturbance with extensive riparian zones, mostly within or immediately downstream of protected areas such as National Parks. Sites in the mid and lower catchment areas are highly disturbed due to agriculture enterprises such as macadamia plantations, grazing, nurseries and sugar cane, as well as urban developments. These sites had minimal riparian zones consisting mainly of pasture grasses and both woody and herbaceous weed species. Three data sets are included in this study as identified by the site codes CC (Coopers Creek), RR (Richmond River) and MC (Micro catchments of the Richmond River). The eight CC sites were sampled monthly from March to December 2014, the 20 RR sites were sampled in May 2015 (autumn) and the 20 MC sites were sampled in December 2015 (summer).

2.2. Water quality

Water quality was measured at the same time as diatoms during stable flow conditions. Physicochemical parameters (temperature, pH, dissolved oxygen (DO) and electrical conductivity (EC)) were taken with a YSI 556 MPS Multi Meter at each site. A 1L water sample was taken at each site and transported on ice for further processing at a National Association of Testing Authorities (NATA) accredited labora-