Ecological Indicators 38 (2014) 90–103

Contents lists available at ScienceDirect

Ecological Indicators

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

A pilot macroinvertebrate index of the water quality of Singapore's reservoirs

Esther Clews[a,b], E-wen Low[c], Christina C. Belle[a], Peter A. Todd[a,*], Hans S. Eikaas[d], Peter K.L. Ng[a]

[a] Department of Biological Sciences, National University of Singapore, 14 Science Drive 4, Blk S1 #02-05, Singapore 117543, Singapore
[b] Ecological Monitoring Informatics and Dynamics Group, TMSI, National University of Singapore, 18 Kent Ridge Road, Block S2S, Singapore 119227, Singapore
[c] Public Utilities Board, Technology & Water Quality Office, 40 Scotts Road, #22-01, Singapore 228231, Singapore
[d] Public Utilities Board, Catchment and Waterways Department, 40 Scotts Road, #22-01, Singapore 228231, Singapore

ARTICLE INFO

Article history:
Received 13 May 2011
Received in revised form 21 October 2013
Accepted 23 October 2013

Keywords:
Biotic indices
Index
Freshwater
Macroinvertebrate
Tropical
Lentic
Singapore

ABSTRACT

Biomonitoring using benthic invertebrate community indices is well established in the assessment of the ecological status of temperate streams but less often applied to lakes, particularly in the tropics. The aim of this study was to identify a suitable bioindicator of the water quality of Singapore's reservoirs for further development and application in ecological monitoring. First, potential physicochemical stressors were identified from pre-existing monitoring data. Next, we developed, adapted and applied potential biotic indicators using both data-driven and knowledge-driven approaches. The former involved derivation of weights representing faunal response to stress from local data to create a new benthic quality index (a data-driven approach). Pre-existing metrics were adapted to reflect local taxonomic composition and resolution. The suitability of each of these indices as well as metrics describing the diversity, abundance and proportions of taxa as biotic indicators of water quality was then assessed. Of the metrics evaluated, the BQI_{SING} index based on data-derived tolerance/sensitivity of local taxa to stressors was best able to discriminate among water bodies representing different levels of stress, represented here by their trophic state. The relative success of this metric in reflecting potential ecological stressors was attributed to the derivation of data-driven weights applied in this index in contrast to indices applied 'off the shelf' which may not have reflected local faunal response to stress.

1. Introduction

Biomonitoring is used extensively in marine and temperate stream systems to assess ecological status and track changes within water bodies (Sládeček, 1973; Rosenberg and Resh, 1993). Ecological indicators have evolved from the use of simple metrics describing indicator taxa or measures of biological diversity to targeted quality indices weighted on taxon sensitivity to specific stressors (e.g. Hawkes, 1997; Reynoldson et al., 1997; Barbour et al., 1999). These indices enable integration of water quality and environmental changes over ecologically relevant timescales, capturing cumulative effects as well as rare or episodic disturbances which may be either missed by point sampling or masked by high frequency 'online' monitoring (Rosenberg and Resh, 1993; Spellerberg, 1991). In addition, biotic community-based metrics offer composite indicators that condense complex ecological responses that account for combined effects of correlated suites of potential stressors. This reduces reliance on multiple single-parameter threshold values for physicochemical parameters in routine screening. Macroinvertebrate indices of ecological health and water quality are particularly well established and adopted in stream assessment world-wide (Rosenberg and Resh, 1993; Reynoldson et al., 1997; Barbour et al., 1999; Smith et al., 1999; Davy-Bowker et al., 2005; Bunn et al., 2010).

Despite the benefits outlined above, macroinvertebrate-based indices are relatively underutilised in lakes and rarely applied to tropical freshwater systems in general. Biotic indices for standing waters are only now being developed—primarily in the USA and Europe (Blocksom et al., 2002; Verneaux et al., 2004; Solimini et al., 2006; Rossaro et al., 2007) but with recent developments on the use of macroinvertebrate communities in the ecological assessment of tropical reservoirs in Brazil (Molozzia et al., 2012). The application of indices to aquatic environments (such as lakes rather than streams) or biogeographical regions other than where they were developed benefits from modification to account for (a) the faunal composition within those systems; and (b) sensitivities to stressors (weights) within the environment they have adapted to. Approaches to the development of locally relevant weights may be

* Corresponding author.
E-mail address: dbspat@nus.edu.sg (P.A. Todd).

1470-160X/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ecolind.2013.10.030

based on expert opinion on ecological requirements of taxa occurring locally (e.g. Mustow, 2002) or through a data-driven approach whereby weights representing sensitivities to stressor(s) are elucidated for local taxa (e.g. Rossaro et al., 2007). Adaptation of indices becomes increasing critical where species assembly and sources of major ecological stress differ markedly from the place where the index originated (Resh, 2007). Error may be exacerbated in the tropics, where there is greater specialisation, niche differentiation and therefore diversity than in temperate regions (Krebs, 1994).

Within the Southeast Asian region, there is a marked shift from monitoring of water quality for municipal use towards ecological monitoring, similar to the transition seen in Europe and the North America over the last 20–30 years (Hilsenhoff, 1987; Hawkes, 1997; Barbour et al., 1999) and more recently in Australasia (Bunn et al., 2010; ANZECC, 2000). The major challenge in establishing ecological indices within the tropics is the paucity of information on the taxonomy and ecology of faunal groups. In Southeast Asia, many of the larval forms of insects, such as dragonflies, mayflies and caddisflies are described only to family-level and few studies have been undertaken to investigate their ecological requirements or functions (Morse et al., 2007; Dudgeon, 1999; Yule and Yong, 2004; Orr, 2005; Norma-Rashid et al., 2009). “Generic” diversity metrics or taxal abundance provide some description of faunal assembly, but do not take into account of the stress sensitivities/tolerance of taxa. Alternatively, metrics based on the percentage, abundance or ratios of higher order indicator taxa such as Oligochaete:Chironomid or the number of EPT (Epemereoptera Plecoptera Trichoptera) taxa, might be applied directly, with the assumption of consistency in within-group sensitivities. Diversity metrics and the EPT have been applied directly in the region to classify the condition of water bodies, but rarely have they been assessed against stressors to evaluate their effectiveness in reflecting local conditions (see Parnrong, 2002 for a review of metrics applied in Thai streams).

Approaches which modify existing indices through the incorporation of new taxa and tweaking of weights are heavily reliant on information on the taxonomy and ecology of these faunal groups. Family-level indices such as the BMWP index are most commonly adopted wholesale in studies reporting stream conditions within the Southeast Asian region (Rahayu et al., 2009; Sangpradub et al., 2010; Parnrong, 2002). Modifications to the BMWP index for streams based on expert local knowledge have been established and applied in Thailand, $BMWP^{THAI}$, and Vietnam, $BMWP^{VIET}$ (Mustow, 2002; Nguyen et al., 2004) to categorise levels of pollution in water bodies. These modifications took the form of inclusion of additional local taxa, exclusion of “redundant taxa” from the original scoring system and a reassignment of weights. Even though Mustow’s assessment of the $BMWP^{THAI}$ demonstrated no advantage in the accuracy of the modified score over the original, its application was advocated for ease of use and to remove redundancy in the original scoring system (Mustow, 2002).

A data-driven approach to creating a biotic index removes reliance on *a priori* ecological information and weights developed for systems elsewhere. Typically, key stressors are first identified through exploration of local pressures on aquatic ecosystems and/or derived from an investigation of physicochemical data to identify potential stressor gradients (e.g. Rossaro et al., 2007; Davy-Bowker et al., 2005). Weights representing stress sensitivity/tolerance are then calculated for each taxon, based on the underlying response of fauna to the stress gradient(s) (Ter Braak and Prentice, 1988). This approach therefore determines faunal responses to local conditions, addressing some gaps in ecological understanding, but it requires data of sufficient quality at ecologically relevant scales of detection and spatiotemporal resolution.

In this study, we trial these various approaches to establishing biotic indices of ecological water quality in reservoirs of Singapore. For more than 20 years, monitoring of Singapore’s reservoirs has been focused on municipal use and maintenance of raw water quality for drinking water supply. Now, there is a move to encompass recreational and ecological quality indicators as national initiatives to naturalise urban waterways are implemented alongside adoption of the ‘Singapore Cities Biodiversity Index’ which promotes the biodiversity of cities internationally (Convention of Biological Diversity, 2010; Public Utilities Board, 2011).

Our aim was to select a suitable pilot bioindicator of the water quality of Singapore’s reservoirs for further development and application in ecological monitoring. This was executed in three stages. First, potential physicochemical stressors were identified from pre-existing monitoring data. Next, we developed, adapted and applied potential biotic indicators using both data-driven and knowledge-driven approaches. The former involved derivation of weights representing faunal response to stress from local data to create a new benthic quality index (a data-driven approach). Pre-existing metrics were adapted to reflect local taxonomic composition and resolution. Finally, the suitability of each of these indices as well as metrics describing the diversity, abundance and proportions of taxa as biotic indicators of water quality was assessed.

2. Materials and methods

2.1. Identification of potential physicochemical stressors

2.1.1. Study sites

Potential physicochemical stressors within 13 of Singapore’s reservoirs (Fig. 1) were investigated. These reservoirs are managed primarily for drinking water supply by the Public Utilities Board (PUB). All of the reservoirs are man-made, constructed by digging and damming rivers and estuaries (Tan et al., 2007, 2009). MacRitchie and Lower Peirce reservoirs were created in the late 19th century and early 20th century, respectively, whilst the remainder were built after 1950. Upper and Lower Peirce, Upper Seletar and MacRitchie were previously swamplands, while Bedok used to be a sand quarry. The remaining reservoirs were once estuarine rivers. Singapore’s reservoirs are generally shallow, most with an effective depth below 8 m, ranging from 2 to 8 m deep. Exceptions are Murai, Upper Seletar, Bedok and Upper Peirce which reach depths of 16, 17, 18 and 22 m respectively. The surface areas of the reservoirs range from 59 to 750 ha, draining relatively small predominantly urban catchments of 360–5400 ha. Nine reservoirs are situated within lowland dipterocarp forest. Tengeh, Murai, Sarimbun, Poyan and Tekong Reservoirs are within military protected areas while MacRitchie, Upper Seletar, Upper and Lower Peirce Reservoirs are located within the ‘Central Nature Reserve’. Beyond the reserves, much of the native forest has been lost: replaced by a ‘municipal’ habitat often dominated by exotic vegetation (Corlett, 1992). Central Singapore overlies a range of plutonic rocks known as Bukit Timah granite. Elsewhere on the mainland and Pulau Tekong the underlying geology is largely comprised of sedimentary rocks of the Jurong, Kallang and Sajahat formations (Gupta and Pitts, 1993; Lu et al., 2005).

2.1.2. Physicochemical data

A suite of physicochemical parameters were analysed monthly from surface-water samples collected at 50 cm below the water surface monthly from a single fixed location in each reservoir by the national water agency, PUB (see Low, 2010; Table 1). On collection, water samples are placed in a cooler and transported directly to the laboratory. Physiochemical analyses were undertaken according to American Public Health Association (APHA)’s Standard Methods for the Examination of Water and Wastewater (Clesceri et al., 1998; as detailed in Table 1). Data for the year antecedent to the collection of invertebrates (October 2007 to September 2008) were extracted