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Evaluating the performance of benthic multi-metric indices across broad-scale environmental gradients

Anna Villnäs[a,*], Judi Hewitt[b], Alf Norkko[a,c]

[a] Tvärminne Zoological Station, University of Helsinki, J.A. Palménin tie 260, 10900 Hanko, Finland
[b] National Institute of Water and Atmospheric Research, P.O. Box 11-115, Hillcrest, Hamilton, New Zealand
[c] Marine Research Centre, Finnish Environment Institute (SYKE), P.O. Box 140, 00251 Helsinki, Finland

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ABSTRACT

The usefulness of benthic multi-metric indices when assessing seafloor integrity across broad environmental gradients should be deliberated, as their lack of transparency might hide important sources of variation and fail to identify environmental change. This study compares the performance of two multi-metric indices; the Benthic Quality Index (BQI) and the Brackish water Benthic Index (BBI) between three sub-basins in the Baltic Sea. Both indices reflect the salinity-driven gradient in macroinvertebrate diversity and composition as well as changes in bottom water oxygen concentrations. The relative contribution of predictor variables for explaining index variation does, however, differ between sub-basins, resulting in the indices representing different aspects of the benthic community along the environmental gradient. This context-dependency is caused by inherent differences in benthic community characteristics between the sub-basins of the Baltic Sea, and how the communities are portrayed by the indices. An increased transparency of the importance of the different predictors for directing index values is needed for coherent classifications over broad environmental gradients, such as those occurring in large estuarine water bodies. Use of a weight of evidence table to combine multiple indicators would preserve transparency and be more likely to provide a robust assessment method that would detect seafloor degradation at an early stage.

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1. Introduction

Healthy marine environments with diverse biological components and good environmental status provide valuable ecosystem services and support a wide range of human activities. Marine ecosystems are, however, exposed to an increasing number of disturbances such as eutrophication, shipping, over-fishing and pollution (Lotze et al., 2006). In face of increasing pressures, appropriate environmental guidelines are needed to enable a sustainable management of marine waters. An accurate assessment of environmental condition is a prerequisite for establishing environmental targets and securing good environmental health (Borja et al., 2013).

Recent national and international legislations have recognized benthic invertebrates as an important element when evaluating the condition of coastal and marine environments (Rice et al., 2012; Van Hoey et al., 2013). This has resulted in a rapidly growing number of multi-metric benthic indices used for evaluating ecosystem health (Diaz et al., 2004; Borja and Dauer, 2008; Pinto et al., 2009; Rodil et al., 2013). The indices generally strive to convey an easily understandable assessment of complex ecological data to resource users and decision makers, by combining several benthic variables into a single number (Borja and Dauer, 2008). As environmental conditions, habitat properties and disturbances all influence benthic community composition, multi-metric indices produce an integrated measure of change in the biota, enabling a separation of degraded vs. non-degraded benthic conditions (Diaz et al., 2004; Pinto et al., 2009). Still, the use and interpretation of indices is not self-evident or straightforward (Borja et al., 2009). Green and Chapman (2011) call for increased deliberation on the suitability of indices for representing the complex data usually describing communities and ecosystems, as the lack of transparency in multi-metric indices (i.e. the combination of several measures blurring the importance of individual predictor variables), might hide important sources of variation and thus fail to identify environmental change.

Most of the current multi-metric indices developed are based on variables describing benthic community structure and the

* Corresponding author. Tel.: +358 2941 28090.
E-mail addresses: anna.villnas@helsinki.fi (A. Villnäs), Judi.Hewitt@niwa.co.nz (J. Hewitt), alf.norkko@helsinki.fi (A. Norkko).

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relative abundance of sensitive and tolerant species (Puente and Diaz, 2008). An increased caution is especially required when applying multi-metric indices developed for coastal areas (i.e. the seaward limit of one nautical mile from the baseline of territorial waters; EC, 2000) to assess the status of benthic communities in transitional estuarine areas (Diaz et al., 2004; Borja and Dauer, 2008; Puente and Diaz, 2008; Rodil et al., 2013). Transitional waters can be considered as ecotone ecosystems, which encompass markedly different hydrodynamic and physico-chemical dimensions (Basset et al., 2013). They are often characterized by distinct spatial and temporal environmental gradients (e.g. in salinity, temperature, dissolved oxygen and water residence time; Dauvin, 2007; Elliott and Quintino, 2007; Villnäs and Norkko, 2011). Benthic biodiversity and community composition changes markedly along these gradients, and the community can be represented by a mix of species of marine and limnic origin. The typical estuarine communities are characterized by a few dominant, often r-strategic species, with high abundances and low individual biomasses (Puente and Diaz, 2008; Basset et al., 2013). The resident species can be euryhaline and adapted to cope with environmental stress, or be at their margin of distribution and highly sensitive to further stressors. Consequently, estuarine species are likely to express wide differences in sensitivity toward anthropogenic disturbances and it is possible that natural differences in benthic biodiversity and community composition across estuarine environmental gradients may change the underlying importance of the variables included in multi-metric indices. However, if multi-metric indices are to be used for producing coherent classifications across estuarine gradients, these natural sources of variation must be identified in order to know what the indices actually represent and to increase the transparency and rigor of environmental assessments.

The Baltic Sea is one of the largest brackish water basins in the world. Its large drainage basin is heavily populated (1 633 290 km^2, inhabited by 85 million people; Leppäranta and Myrberg, 2009), exposing this sea area to a range of anthropogenic disturbances. As for other impacted seas, international recommendations and legislations require an assessment of ecological status in the Baltic Sea through, among other things, evaluating benthic community condition (e.g. the Baltic Sea Action Plan (BSAP: HELCOM, 2007), the European Water Framework Directive (WFD: EC, 2000), and the Marine Strategy Framework Directive (MSFD: EC, 2008)). Especially the WFD (EC, 2000) has promoted the development and use of multi-metric indices in coastal areas, which account for the relative abundance of sensitive and tolerant species, together with benthic diversity measures and abundance. The MSFD broadened the description of what benthic attributes are important to account for when assessing seafloor integrity in marine areas (EC, 2008; Rice et al., 2012). Still, the European Commission put considerable emphasis on using multi-metric indices also in open waters (EC, 2010). Since the main objective of the MSFD is to achieve a good environmental status in European marine waters by 2020, it requires all countries per regional sea to define common indicators for benthos as a quality descriptor (Van Hoey et al., 2010; Rice et al., 2012). Although the performance of multi-metric indices, developed within the framework of the WFD, has been tested in transitional areas of the open Baltic Sea (e.g. Zettler et al., 2007), to date only a basic measure of average regional diversity has been applied over the entire estuarine gradient to assess benthic community status (Villnäs and Norkko, 2011).

This study examines how two multi-metric indices, developed or adapted to coastal brackish waters, perform along the environmental gradient of the open Baltic Sea. Specifically, three sub-basins along the biodiversity gradient are compared to (1) explore changes in index values and (2) the relative importance of variables predicting the index values. If the contribution of predictor variables is observed to differ between sub-basins, it will highlight the need for an increased transparency in efforts to evaluate and assess environmental change in the marine environment.

2. Material and methods

2.1. Study area

The Baltic is a semi-enclosed sea and its restricted water exchange with the North Sea causes a gradient of decreasing salinity in a south-to-north direction. Due to its topography, the Baltic Sea can be divided into several different sub-basins. In this study, three sub-basins along the salinity gradient, i.e. the Bornholm Basin, the Gulf of Finland and the Bothnian Bay (Table 1) were chosen to

Table 1
Dimensions and typical salinity and temperature values of the studied sub-basins (mod. from Leppäranta and Myrberg, 2009). The number and coordinates of benthic sampling stations, the total number of samples and minimum sampling depth is given for the studied sub-basin. Oxygen concentrations represent conditions in bottom waters during the sampling occasions for each sub-basin.

	Bornholm Basin	Gulf of Finland	Bothnian Bay
Area (km^2)	38 942	29 498	36 260
Mean depth (m)	46	37	41
Max depth (m)	105	123	146
Volume (km^3)	1782	1098	1481
Min. station depth (m)	>50	>55	>60
Bottom water salinity (‰)	13–17	5–9	4–4.5
Bottom water, °C[a]	7–9	3–5	3–5
O_2 (mg l^{-1}) min–max	0–9.9	0–8.2	4.6–10.4
O_2 (mg l^{-1}) avg. ± SD	2.7 ± 2.6	3.9 ± 2.3	8.3 ± 0.7
Number of stations	8	8	8
Total no. of benthic samples[b]	92	204	188
Total no. of water samples[b]	54	156	130
Station coordinates	55° 15′ N, 15° 59′ E	59° 38′ N, 23° 39′ E	64° 18′ N, 22° 21′ E
	55° 13′ N, 17° 04′ E	59° 35′ N, 23° 18′ E	64° 25′ N, 22° 55′ E
	55° 21′ N, 15° 44′ E	60° 04′ N 26° 21′ E	64° 42′ N, 23° 05′ E
	54° 49′ N, 15° 45′ E	60° 00′ N 26° 05′ E	65° 00′ N, 23° 15′ E
	54° 41′ N, 15° 45′ E	59° 55′ N, 25° 36′ E	65° 14′ N, 23° 34′ E
	55° 29′ N, 15° 19′ E	59° 55′ N, 25° 02′ E	64° 42′ N, 22° 04′ E
	55° 33′ N, 15° 07′ E	59° 51′ N, 24° 50′ E	64° 56′ N, 22° 21′ E
	55° 41′ N. 14° 42′ E	59° 42′ N, 24° 02′ E	64° 48′ N, 23° 29′ E

[a] October.
[b] Period 1965–2006, one benthic sample includes 3 replicate van Veen grabs.

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