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Reducing spatial variation in environmental assessment of marine benthic fauna

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ABSTRACT

The Benthic Quality Index, BQI, is widely used for benthic quality assessment. Here, we investigated if spatial variation in the BQI can be reduced by accounting for the environmental factors instead of having different boundaries for different salinity regimes between status classes in the EU Water Framework Directive and Marine Strategy Framework Directive. For this purpose we tested salinity, sediment structure, and depth in a regression model to test their contribution to variations in BQI. The spatial variation in BQI was better explained by depth than by salinity or sediment structure. The proposed assessment method uses the residuals from the regression model between BQI and depth. With this method the variance in BQI between samples was reduced by 50% to 75% in the majority of situations. A method to establish the boundary between *good* and *moderate* status and how to derive EQR-values according to the WFD is presented.

1. Introduction

We live in a changing world and there is a great need to scientifically analyse the temporal and spatial changes we observe and to evaluate how recorded changes affect the ecosystem. Changes in the ecosystem can be beneficial to humans when nutrients have a top-down effect and lead to increased fish catches without significant side effects. In contrast, excess nutrient input can have serious negative effects on ecosystem services and oxygen conditions. It is therefore essential to assess, in a scientific way with accuracy and precision, how ecosystems can cope with various pressures and how resilience can be maintained.

In this study we focus on methods for the assessment of temporal and spatial changes in benthic communities in Swedish marine waters, more specifically in the Skagerrak, Kattegat and the Sound between Denmark and Sweden. Benthic communities are ideal for such assessment studies as the animals are rather stationary and the community structure changes in a rather predictable way to various environmental pressures such as organic enrichment, hypoxia, metal pollution and physical disturbance (Pearson and Rosenberg, 1978; Heip, 1995; Josefson et al., 2009). Along with increased anthropogenic stress, benthic faunal diversity declines and the proportion of tolerant species increases. Similarly, a low or variable salinity reduces the number of benthic species, which has been demonstrated for estuaries and brackish water areas. Elliott and Quintino (2007) described this as the "estuarine quality paradox" and stated that estuarine fauna have features similar to that in anthropogenically-stressed areas, and this makes it difficult to detect anthropogenically-induced stress and separate it from the effect of low and variable salinity.

In year 2000, the European Union introduced the Water Framework Directive (WFD), which was followed by the Marine Strategic Framework Directive (MSFD) in the year 2008, and today both directives provide for the assessment of ecosystem quality. The Benthic Quality Index (BQI) was initially introduced for assessing the ecological status according to WFD in Swedish waters (Rosenberg et al., 2004). BQI was calculated based on individual species sensitivity values, species dominance and number of species. BQI was further evaluated for use in benthic quality assessment by Leonardsson et al. (2009). BQI has proven to be useful for benthic quality assessment in Scandinavian waters (e.g. Perus et al., 2007) and its response to various pressures has been compared and evaluated in relation to Danish and Norwegian indices (Josefson et al., 2009). BQI has also been used for quality assessment in the Mediterranean (Labrune et al., 2006; Dimitriou et al., 2012; Karakassis et al., 2013) and other European waters (Grémare et al., 2009). Recently BQI was also introduced as an indicator for *good* environmental status of open sea and coastal waters for several descriptors within the framework of the MSFD implementation in Sweden (national regulation HVMFS2012:18).

By time, lots of new information about faunal distributions have been added and new assessments have been made. Evidence has also

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been recorded that sometimes and at certain times a strong and occasional recruitment of a particular species can reduce the sensitivity value considerably with additional negative effects for also other species in the same sample. Such events with strong recruitment of species considered as sensitive by expert judgements will flaw the quality assessment. This drawback has been pointed out by Labrune et al. (2006) and Grémare et al. (2009). Therefore, a change in the calculation of the sensitivity values, which have the greatest impact on BQI of all factors, was proposed and statistically evaluated by Leonardsson et al. (2015). They suggested using the observed number of species in each sample instead of the ES50-value as used earlier (ES50 is the estimated number of species among 50 individuals as interpolated from the rarefaction method (Hurlbert, 1971). Despite this improvement there is still a considerable spatial variation in the BQI-values, even within a single waterbody. The existing method to deal with some of this variation in Swedish west coast waters has been to apply different WFD status class boundaries in shallow and deeper waters (Rosenberg et al., 2004; Leonardsson et al., 2009). The halocline had been shown to have a significant impact on the structure of the benthic community composition on the Swedish west coast (Rosenberg and Möller, 1979). Depth-related boundaries between *High, Good, Moderate, Poor* and *Bad* in the WFD were therefore separated by the depth between the influence of brackish water of Baltic origin and oceanic water and was set at 20 m depth, i.e. the deeper distribution of the halocline in the Skagerrak-Kattegat area. An improvement of the index to explicitly account for this type of impact of, e.g. the salinity, would reduce the amount of sampling effort needed for accurate boundary setting and assessment.

Variation due to environmental factors is in part reduced by the characterization of water bodies into types and associated type specific status class boundaries as specified in the WFD. Types are two dimensional compromises between practical aspects related to the number of types and demands on narrow ranges in environmental factors for reduction of uncertainty in different indicators. Thus, there may still be significant variations in environmental factors within each type, a variation that is especially important for benthic biota dependent on factors related to depths. The effects of this variation can be reduced by stratification of types into subtypes, e.g. based on depths as in the current Swedish assessment system or salinity as in Muxika et al. (2007), or even stratification of water bodies into ecotopes based on salinity and depth (intertidal/subtidal) as in van Loon et al. (2015). As a consequence, optimizations of monitoring programmes have to take subtypes into account, which requires enough data from each subtype. For countries with a long and topographically complex coast as few subtypes as possible would be desired. An alternative has been to include environmental factors when setting reference values for separate metrics within the indicator formula as in the Danish DKI_{v2} (Carstensen et al., 2014), or the British IQI_{vIV} (Phillips et al., 2014).

Here we investigate an alternative approach where we remove as much as possible of the spatial variation in BQI by means of a regression model that includes the main factor(s) that contribute to the spatial variation. Having a regression model that successfully takes the environmental variables into account will simplify the sampling and the assessment since there is no need to divide the types into subtypes. With this approach the final assessment will not be based on the index values per se, but on the residuals from the regression model. This way of dealing with the BQI makes it transparent how the different environmental factors contribute in the model to improve the precision of the assessment. The aim is to reduce as much as possible of the variation, which means that there is also a need to analyse the contribution of each of the components of BQI to the uncertainty. One of the components, the sensitivity factor, has been analysed separately (Leonardsson et al., 2015), which leaves the species number and the abundance factor (see Eq. (1) below) for analyses in this paper. The environmental variables considered to be of relevance for the regression model were salinity, depth, and sediment characteristics. In this paper we evaluate how BQI is related to depth, salinity and sediment structure in Swedish marine waters.

2. Material and methods

2.1. Study area

The distribution of benthic data used in the analyses in this publication originates from Swedish coastal and open waters, more specifically from the Skagerrak, Kattegat and the Sound between Denmark and Sweden (Fig. 1). All samples are from the years 1965 through 2013, and encompass 855 stations from depths between 4 and 153 m. All samples were obtained by a 0.1 m^2 Smith–McIntyre grab and the samples were sieved on 1 mm meshes. Stations from areas with known impact were marked as impacted and excluded from most of the analyses. Impacted areas were occasionally or frequently exposed to hypoxia, physical disturbance or toxic substances. Fishing pressure was not included in our analysis because of lack of suitable data for this pressure and its effects on benthic communities.

2.2. Sediment characteristics

Each station was given a sediment class based on a transformation of static marine geological maps to seafloor surface sediments made by Hallberg et al. (2010). The underlying data for the marine geological maps are of different quality since investigation methods have developed over time resulting in better quality in Kattegat and the Sound compared to northern and outer parts of Skagerrak. The sediment classes are not always matching sediment information associated to each benthic sample, e.g. free text sediment description or sample volume. Since objective ways of classifying sediments from each benthic sample were lacking, e.g. data of grain size or organic content, the surface sediment map was the only way to achieve a sediment classification for all stations.

2.3. Salinity

Median salinity from nearby depths and areas during the period April–June and five years prior to benthic sampling was used as a salinity value for each benthic sample. Measured salinity data downloaded from SMHI (www.smhi.se), ICES (www.ices.dk) and AU (dce.au.dk) was primarily used. If such data were lacking for a sampling occasion, modelled salinity data from SMHI (vattenweb.smhi.se) was used, or as a last option from the EUSeaMap project (jncc.defra.gov.uk/page-5020). Selecting the median salinity during the five year period prior to benthic sampling was done to overcome differences in hydrographic sampling efforts between areas and years. The months April through June were chosen since they generally represent the lowest salinity values during the year. Different species and life stages might be affected by different values (min, max, median, range, etc.), but the choice of the median was because it is less sensitive to the number of values available.

2.4. Statistical analyses

To reduce the uncertainty in the BQI, the underlying sources contributing to the uncertainty need to be identified and explained. One way of doing this is by finding reliable and explicit relationships between the independent variables causing, direct or indirect, the variation in the index. These independent variables need to have measurable values at all possible sites in order to apply to the adjusted index anywhere in the region. Here we use a regression approach to find the environmental variables that will reduce the variation of the index substantially. Three variables were included in these analyses: depth, salinity and sediment type. All these variables have the potential to directly or indirectly affect the benthic community structure.

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