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Rating species sensitivity throughout gradient systems – a consistent approach for the Baltic Sea

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ABSTRACT

Evaluating the state of benthic communities has played an important role in water quality assessments. Indices incorporating species sensitivities, richness and densities are commonly applied. In Europe, the importance of benthic indices has increased in the last years with the implementation of the European Marine Strategy Framework Directive (MSFD) which at the same time demands the applicability of an index across regional scales. To date, environmental variability is rarely considered in benthic indices and most sensitivity rankings have the disadvantages of static values (i.e. the same value in all areas), expert judgement and a limited geographical range.

This study presents species sensitivity values calculated along environmental gradients for the Baltic Sea. Sensitivities were calculated according to the procedure of the Benthic Quality Index (BQI). We created a matrix of subregions, classes of salinity, depth and gear to identify comparable subsets for data analysis. Altogether, 19 subsets were defined within the Baltic Sea basins. Sensitivity values were calculated for 329 species out of a total of 678 species that were recorded in this study. Sensitivity values of taxa vary between subsets as it was expected for different environmental conditions. Most sensitivity values can be assigned to species occurring in euhaline and polyhaline waters. Distribution of species with high and low sensitivity values differed along the salinity gradient. In euhaline waters more species with high sensitivity values occurred than species with low sensitivity values, while in mesohaline waters the ratio of high and low sensitivity values among species was almost equal. In oligohaline waters more species with lower sensitivity values were present.

For the first time, sensitivity values were calculated for a large number of species using the same method for the entire Baltic Sea. This results in a Baltic-wide comprehensive set of sensitivity values based on a dataset across subregional borders, and divided along environmental gradients and gear type. The same principles can be applied to transient waters from rivers to coastal lagoons as well as to other environments with gradients of, e.g. hydrodynamic characteristics. Publicly available sensitivity values will increase transparency and support the improvement of state assessments under the MSFD.

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1. Introduction

Integrative ecological assessments are carried out worldwide (Borja et al., 2008) and biological measures should be included to describe water quality (Kotta et al., 2007). Therefore, evaluating the state of benthic communities has played an important role in water quality assessments. In Europe, this role has been even increased with the implementation of the European Marine Strategy Framework Directive (MSFD; 2008/56/EC). The state of benthic communities is considered in Descriptor 6 'sea-floor integrity' and in Descriptor 1 'biodiversity' of the MSFD.

Defining the state of communities is more complex than assessing single species. Here, the implementation of the MSFD will benefit from the work conducted under the Water Framework Directive (WFD; 2000/60/EC) (Van Hoey et al., 2010). In previous assessments in the frame of the WFD, indices incorporating species sensitivities, richness and densities have been applied (Borja et al., 2009): e.g. M-AMBI (Muxika et al., 2007), MarBIT (Marine Biotic Index; Meyer et al., 2008) and BQI (Rosenberg et al., 2004) as modified in Leonardsson et al. (2009).

Two general approaches can be distinguished to evaluate species sensitivity: A mathematical approach as employed in the BQI, where species sensitivity is calculated from sampled data and an expert based approach as for instance in AMBI and MarBIT. Whatever the approach, results from different indices are only comparable after intercalibration.

In an ideal benthic index the evaluation of species sensitivity is transparent (Duarte, 2009) and catering for different environments (Zettler et al., 2013). Still, the assessment of sensitivities should be harmonised among environments to be comparable (Karakassis et al., 2013; Neto et al., 2014) and the index should be based on data stemming from standardised sampling (Neto et al., 2014). The data source should be kept as large as possible to increase statistical power (Duarte, 2009), to obtain a representative cross section of environmental conditions and to ensure a reliable basis for sensitivity values. Sensitivity values should not be calculated based on small datasets, because their range may not be representative (Fleischer and Zettler, 2009). Additionally, the index should be applicable in the whole area of a regional sea (Rice et al., 2010).

To date, environmental variability is rarely considered in indices and most sensitivity rankings have the disadvantages of static values (i.e. the same value in all areas), expert judgement and limited geographical range (Dauvin et al., 2012). Benthic indices consider environmental variability as for example the fact that reference values need to be habitat specific (e.g. Borja et al., 2007; Van Hoey et al., 2013). Sensitivity rankings do not consider this aspect except in cases where the sensitivity by expert judgement is scaled different for species from different environments (e.g. on a large scale for the Swedish west coast and the Swedish east coast, Leonardsson et al., 2009). Static sensitivity values make an index difficult to be used outside the region it was developed for, especially when certain dominant species have a varying sensitivity along an environmental gradient (Zettler et al., 2013). Species are capable of adapting to changed environmental conditions and change their behaviour (Remane, 1958). Furthermore, not only species distribution or ecology may change along environmental gradients but also the resilience and sensitivity of a species to anthropogenic stressors (Villnäs and Norkko, 2011). An index with static sensitivity values may not be adequate in a gradient system. Also in open sea areas water bodies need to be defined according to environmental characteristics (Villnäs et al., 2015). On the other hand, the application of different indices is not favourable either because comparability is lost or expensive intercalibration procedures are needed afterwards.

In order to overcome these difficulties it is rewarding to calculate species sensitivity values along environmental gradients and thus establish a transparent procedure that could be used across national borders. The Baltic Sea for example covers a wide salinity gradient resulting in a natural species minimum within the brackish range (Remane, 1934; Zettler et al., 2014). Therefore, a flexible index with non-static sensitivity values such as the BQI seems an optimal solution for the region. The BQI was originally developed by Rosenberg et al. (2004) to assess the ecological quality of benthic habitats in Sweden according to the WFD. The sensitivity values of species are calculated directly from the sampled data. Thus, the BQI has the advantage of an objective and transparent procedure to derive species sensitivities combined with the flexibility to expand the area of its application. BQI has also been tested in other areas of the Baltic Sea (e.g. Zettler et al., 2007) and the index formula was later adjusted to better account for the presence of mobile species in less diverse areas (Leonardsson et al., 2009). Fleischer and Zettler (2009) conducted a first study to adjust the BQI to the salinity gradient in the southern Baltic Sea. Still, studies focusing on the Baltic region as a whole are rare (Villnäs and Norkko, 2011).

Not only environmental parameters but also sampling gear affects the number of taxa found and thus gear type may have an effect on index values. We aimed at distinguishing ecologically relevant subsets to calculate species sensitivities and therefore we correct for sampling effects by separating different gear types.

This study presents species sensitivity values calculated along environmental gradients for the Baltic Sea. The study encompasses data from the entire Baltic Sea, from Bothnian Bay to Kattegat, in order to enable a coherent assessment of benthic communities, regarding especially the MSFD. We assembled a large dataset to form a reliable basis for sensitivity values that may also serve as a basis in assessment systems for smaller datasets.

Aims of the study were: (I) to provide species sensitivity lists based upon the same index throughout the Baltic Sea (II) to calculate species sensitivities tailored to each region by considering environmental gradients and gear types, (III) to make the sensitivity lists publicly available free of charge.

2. Materials and methods

2.1. Study area

The study area covers the whole Baltic Sea with a focus on offshore areas and coastal waters but disregarding lagoons and inner coastal waters. The Baltic Sea is a brackish water sea characterised by a strong salinity gradient and temporarily anoxic conditions. In the deeper areas of Kattegat, its westernmost part, almost full marine conditions prevail with a salinity of >30. In the southwestern part the salinity gradient is most pronounced ranging from about 25 in Kiel Bay down to 7 in the Pomeranian Bay. In the central and eastern basins brackish conditions with salinities from 3 to 10 prevail. Close to large river outlets with freshwater discharge and in the northernmost basins salinity only reaches 0.5–3. There is a narrow and shallow connection to the North Sea and irregular inflow of high saline and oxygen rich waters which is the only source for deep water exchange. This inflow contributes to the halocline which in turn prevents the mixing of the upper and the lower water masses leading to severe anoxic conditions in the deep basins of the Baltic Sea (Conley et al., 2009).

According to its evolutionary young age there are few truly endemic species present in the Baltic Sea. Fauna and flora constitute from immigrant marine and freshwater species of surrounding waters (Remane, 1934). As those species stem from very different environments the relatively low or high salinity respectively exert a significant stress. Thus, many species are smaller or change their life strategies compared to their source habitats.