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An adjustment of benthic ecological quality assessment to effects of salinity

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ABSTRACT

In the last decade a politically inspired marine protection movement arose in the European Union. This movement leads to an holistic strategy. Merging the Water Framework Directive (WFD) and the Marine Strategy Directive (MSD) along the European coastline demands sophisticated ecological classification procedures. The 'Benthic Quality Index' (BQI) is one of several indices created in view of the WFD. We used the dynamic species reference system $ES_{50_{0.05}}$ to test the capability of BQI to exclude primary environmental factors including the salinity gradient and depth (a proxy for the oxygen regime) from the ecological quality (EcoQ) assessment.

A macrozoobenthos dataset of the southern Baltic Sea spreading over more than 20 years and over 100,000 km^2 was used for the EcoQ assessment. Quality assurance rules were applied to the record set and an analytical dataset of 936 sampling events with 20,451 abundance records was used in the analysis. We show that the natural salinity gradient has a severe impact on the BQI based EcoQ. We adapted the calculation procedure to reduce the salinity effects to a minimum.

According to the adaptation 503 sensitivity/tolerance values for 87 species were computed. These values were calculated within seven salinity ranges from 0 to >30 PSU and two depth zones. These values can be used as a reference for further investigation in the Baltic and other areas with similar environmental conditions.

1. Introduction

Recent realisation of the extent of ecosystem service provision by marine systems has motivated a politically inspired protection movement over the last decade. The European 'Maritime Policy' and 'Marine Strategy Directive' (MSD) are the most recent attempt to create optimal conditions for sustainable use of the European oceans and seas. The European Commission has already initiated the MSD together with the recommendation of a framework for sustainable development towards a 'Good' marine environmental condition (EC, 2005a,b). Experience with the Water Framework Directive (WFD; 2000/60/EC) has shown that the definition of 'Good' ecological status is not trivial. Natural reference conditions are hard to find in coastal waters and this is also true for off-shore areas as well (Dauvin et al., 2007; Muxika et al., 2007; Borja, 2006). As a consequence of these circumstances there have been several attempts to create references either by modeling or paleoecology (Muxika et al., 2007; Bald et al., 2005; Andersen et al., 2004).

In recent years, a variety of benthic indices has been developed (Grall and Glémarec, 1997; Weisberg et al., 1997; Borja et al., 2000; Simboura and Zenetos, 2002; Rosenberg et al., 2004) most of which are based on the succession model published by Pearson and Rosenberg (1978).

However, the applicability of all these measures to several scenarios needs further investigation. Their aim is to identify anthropogenic impacted sites from reference conditions, but all indices are sensitive to any causal factor either natural or man-made (Borja et al., 2003; Muxika et al., 2005; Reiss and Kröncke, 2005; Labrune et al., 2006; Zettler et al., 2007). Since all these indices will be used to confirm political actions according to the WFD it is crucial to know the influence of natural factors on results of ecological quality indices. Therefore it is necessary to determine the index sensitivity at least on all natural environmental factors (Vincent et al., 2002) occurring within the area of the WFD or MSD. This study was an attempt to ascertain wether it is possible to minimize the influence of salinity (one of the main forces in the Baltic) and depth on the results of Benthic Quality Index (BQI).

The specifications of the WFD share common problems: (1) the reference conditions for the calculation of the ecological quality ratio (EQR); (2) the animal sensitivity references. The use of static reference locations, either from expert judgement or from direct knowledge of pristine conditions, is problematic (Nielsen et al., 2003). A static reference in an evolving and changing environment can cause political decisions not based on any anthropogenic influence (Bonsdorff, 2006; Gröger and Rumohr, 2006). In an environment like the Baltic Sea, still recovering from the last glacial

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period (Bonsdorff, 2006), this shifting baseline (Pauly, 1995) might be more obvious (Rumohr et al., 1996; Jansson and Jansson, 2002) than in other regions. Therefore, even if historic data are available, the selection of a reference site presumed to be representative for pristine conditions is always a judgement call.

In this study, we focused on the problem of defining species references. Static reference lists have more often been used (Borja et al., 2000) than other methods. Even though these lists have been enlarged in recent years, each species is always categorised only once in a distinct ecological group. In areas with strong environmental gradients, like the brackish southern Baltic, it is well known that species can adapt and change their live history (Remane, 1958). The salinity gradient is so strong in the southern Baltic that in the same geographical area a large range of salinity can be measured. As Zettler et al. (2007) found, the fixed ecological species reference list needs reconsideration in the Baltic. This and the adaptive behaviour of species has to be considered in a species sensitivity/tolerance reference list. Therefore, we investigated the impact of salinity on ecological status classification in this study.

The BQI uses a variable concept to integrate both the sensitivity/tolerance of a given species and the species richness. This index works best with large datasets that allows values to be calculated from the dataset itself instead of using values from other areas or times. This assumes that large datasets cover either a long period of time and/or of a large area containing all conditions from 'High' to 'Bad'.

We tested the performance of the 'Benthic Quality Index' (BQI) and adapted the calculation procedure along the strong natural salinity gradient in the southern Baltic Sea. This study was based on a very large dataset sampled during the HELCOM monitoring program and further investigations, allowing us to evaluate the influence of salinity on the classification of ecological quality and species sensitivity. In this study we calculated species reference lists for seven salinity ranges and two depth horizons. This constitutes a significant advance on the system of static species reference lists.

2. Material and methods

We have analysed a dataset of 2156 sampling events with 47404 records located in the Baltic Sea for this study. The individual records were selected from the archived data of in-house projects either the Leibniz-Institute for Baltic Research or the Leibniz-Institute for Marine Research IFM-GEOMAR. For quality assurance, we applied the following selection criteria: (1) data recorded during the years 1980–2007, (2) Van Veen grab with 0.1 m^2 sampling area with at least 2 replicates, (3) salinity measured at the sampling event. Using these criteria, we have reduced the dataset to a final set of 936 sampling events from 683 locations and a total of 20,451 records (Fig. 1).

To investigate the influence of salinity and depth (used as a proxy for oxygen supply) on the Benthic Quality Index (BQI), we used the same dataset for Approach I and Approach II. As a common first processing step, we separated the dataset into two depth zones (Fig. 2), with the separation at 20 m depth horizon. By doing so we applied the same depth for separating as used by Rosenberg et al. (2004); it represents the natural thermo-haline stratification of the southern Baltic sea. This first step created two subset with 11579 ($\leqslant$20 m) and 8872 (>20 m) records (Fig. 2). The applied salinity ranges for Approach II were '0–4.$\bar{9}$', '5–9.$\bar{9}$', '10–14.$\bar{9}$', '15–19.$\bar{9}$', '20–24.$\bar{9}$', '25–29.$\bar{9}$' and '$\geqslant$30' PSU.

The depth based datasets (Approach I) and the salinity range based datasets (Approach II) were equally used in the following as source for the calculation of BQI. Beginning with the $ES50_{0.05}$ calculations for each species adapted to specific depth horizons and salinity ranges (according to the applied dataset). The $ES50_{0.05}$ value is the sensitivity/tolerance measure included in BQI and published by Rosenberg et al. (2004). The second step comprised the BQI calculation for each dataset. Following Approach II the five EcoQ classes were evenly distributed in the range of BQI values of each salinity dataset (Rosenberg et al., 2004).

The analytical dataset contained averaged 1 m^2 values from replicated samplings. The sampling effort of the combined data

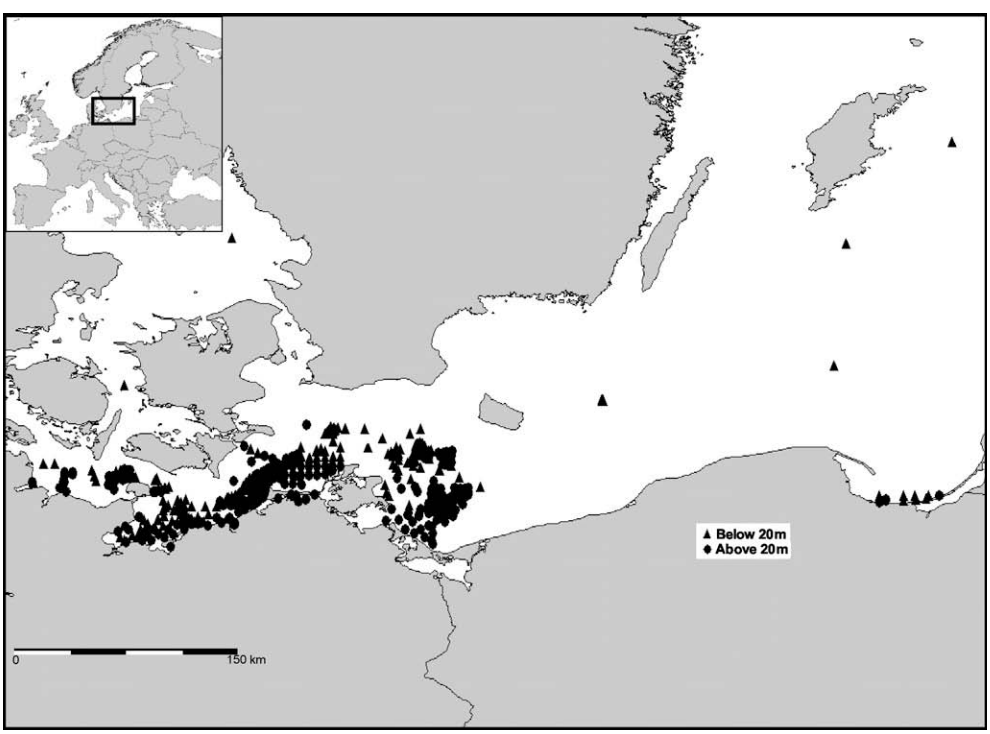

Fig. 1. Distribution map with all sampling event locations included in this study, separated by the 20 m depth horizon.

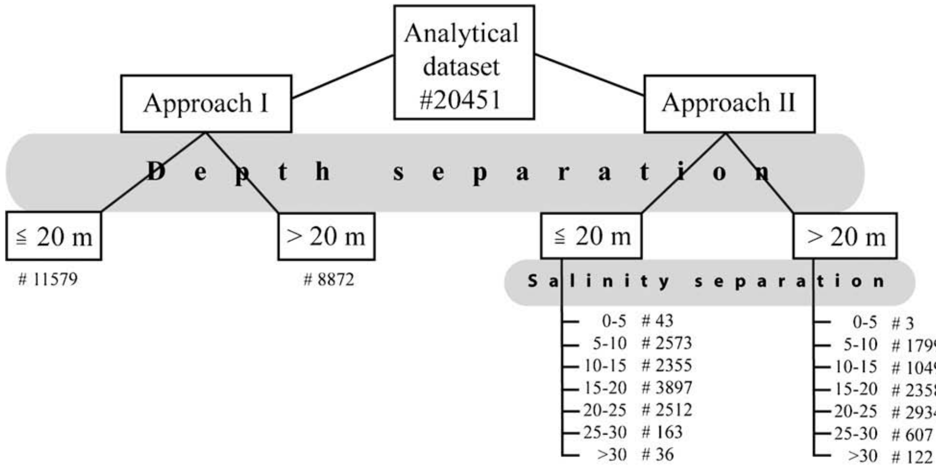

Fig. 2. Schema of the data separation procedure. Approach I included only one separation step. Approach II also separated the dataset into the salinity ranges. The number of records included in each dataset is stated by #.

was heterogeneous in terms of replication. According to this we applied for all further calculations BQI_{ES} (Fleischer et al., 2007) together with the recent adjustments (Blomqvist et al., 2006) (see Eq. (1)). The original version of BQI (Rosenberg et al., 2004) is known to be sampling effort dependent (Fleischer et al., 2007) and was therefore not suitable for this study.

$$BQI_{ES} = \left(\sum_{i=1}^{n}\left(\frac{A_i}{A_{tot}} \times ES50_{0.05i}\right)\right) \times \log(ES_{50}+1) \times \left(1 - \frac{5}{5+A_{tot}}\right) \quad (1)$$

In Eq. (1) above, n denotes the observed species number. A_i stands for the abundance of the species i and A_{tot} is the sum of all individuals within this square meter. Finally, $ES50_{0.05}$ is the sensitivity/tolerance value for species i and ES_{50} denotes the estimated species number for 50 individuals from this square meter.

BQI puts certain requirements on the dataset to which it is applied. First for the computation of ES_{50} (Hurlbert, 1971), more than 50 individuals per sampling event are required. About 24 sampling events, which have 50 or less individuals were therefore discarded as BQI_{ES} could not be computed. These sampling events could not be used for the calculation of $ES50_{0.05}$ either, due to insufficient data available for each species. Too small datasets can lead to a separation bias or render the computation of $ES50_{0.05}$ impossible. These two limiting factors equally account for missing BQI values.

3. Results

It was possible to calculate BQI for 912 sampling events across the southern Baltic. This includes 503 new sensitivity/tolerance values in two depth horizons and seven salinity ranges.

3.1. BQI data

Approach I without taking salinity into account and instead focussing on depth separation only resulted in 450 BQI values for samples above 20 m and 462 values for samples below the divide.

Approach II resulted in 338 BQI_{ES} values above 20 m and 462 BQI_{ES} values below 20 m. For 112 sampling events it was not

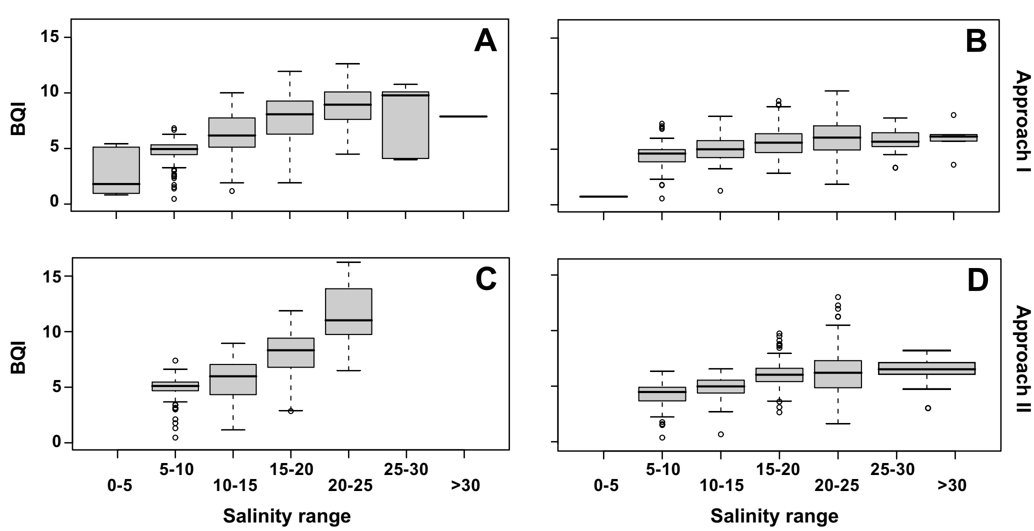

Fig. 3. Box plots showing the BQI_{ES} values calculated from the 937 sampling events data set. (A) BQI values calculated for sampling events with equal or less than 20 m depth and not taking salinity into account. (B) BQI values calculated for sampling events with more than 20 m depth and not taking salinity into account. (C) BQI values calculated for sampling events with equal or less than 20 m depth and taking salinity into account. The missing values in the 0–5, 25–30 and >30 are caused by the reduction of the record set. (D) BQI values calculated for sampling events with more than 20 m depth and taking salinity into account. As in C it was impossible to calculate BQI for the salinity range 0–5, but a calculation on the combined dataset from the ranges 25–30 and >30 has been done.

possible to compute $ES50_{0.05}$ due to the insufficient size of the datasets after salinity separation (separation bias).

The BQI values for the two different approaches show the same pattern (Fig. 3). The BQI values increase along the salinity gradient. For both approaches, the values overlap.

3.2. $ES50_{0.05}$ sensitivity/tolerance data

In this study, we were able to calculate a total number of 503 species related sensitivity/tolerance values (Table 1). For some species we successfully calculated sensitivity/tolerance for all possible salinity ranges, which means a sensitivity/tolerance estimation along the whole salinity gradient. Fig. 4 is an example of changes in $ES50_{0.05}$ along the salinity gradient for the tube-living worm *Pygospio elegans*. The complete list of $ES50_{0.05}$ values can be downloaded from the website of the Leibniz-Institute for Baltic Sea Research Warnemünde www.io-warnemuende.de/bio/workgroups/benthos/en_micha.html.

From sampling events above 20 m we calculated 174 $ES50_{0.05}$ values within the different salinity steps (Approach II) and 117 across the whole gradient (Approach I). $ES50_{0.05}$ values for 56 different species were computed in Approach II. For sampling events below 20 m, we calculated 124 $ES50_{0.05}$ values within the salinity ranges (Approach II) and 88 across the whole gradient (Approach I), thus in total we obtained values for 77 species. In total, 503 sensitivity/tolerance values have been computed in this study (Table 1).

It was possible to calculate 125 $ES50_{0.05}$ species values in the depth separated dataset. For 80 species it was possible to calculate sensitivity in both depth horizons, whereas for 45 species sensitivity could only be calculated in one of the two depth ranges.

Table 1
Number of calculated $ES50_{0.05}$ values of species produced by the different approaches. In this study a total of 503 sensitivity/tolerance values were computed. Most species have more than one $ES50_{0.05}$ value.

Salinity ranges	<20 m	>20 m	Approach
0–5	–	–	II
5–10	27	23	II
10–15	42	13	II
15–20	59	37	II
20–25	46	42	II
>25	–	9	II
All ranges	117	88	I
Sum	291	212	503

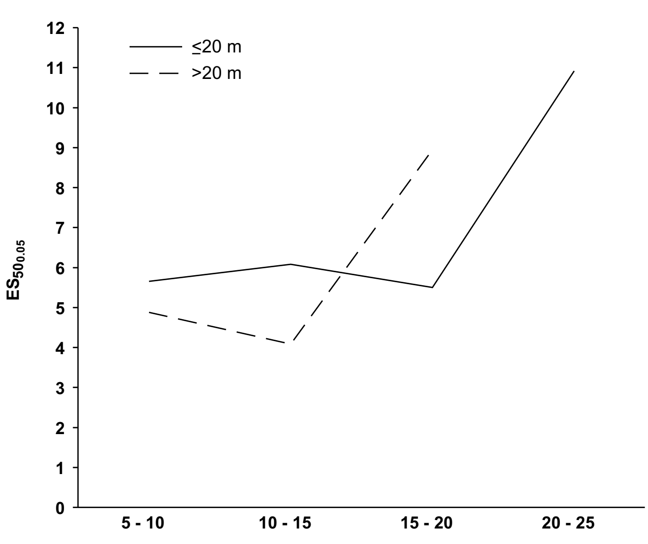

Fig. 4. Sensitivity/tolerance change across the salinity range of *Pygospio elegans* in the southern Baltic Sea. $ES50_{0.05}$ values according to the second approach.

3.3. The EcoQ classification

The two approaches produced contrasting EcoQ classifications (Fig. 5). Approach I, using the entire data set with no regard to the salinity gradient, results in low values for all sampling events with low salinity ranges. High salinity stations resulted in higher BQI values. The salinity effect can be seen in Fig. 5; it is more obvious below the 20 m depth horizon.

The EcoQ classification of records based on BQI values is presented in Fig. 5. Without relation to salinity, only 'Bad', 'Poor' and 'Moderate' classifications for records were found in the lower salinity ranges of '0 to 5' and '5 to 10' in both depth zones (Fig. 5A and B). In contrast, higher salinity ranges showed no 'Bad' classification at all and the salinity range '>30' featured only 'Good' conditions (Fig. 5A and B).

When taking the salinity gradient into account, the whole range of ecological quality classes can be found in each salinity range (Fig. 5C and D).

Fig. 5E and F shows a possible but overly simplistic classification procedure. The calculation of BQI values according to Approach I (same BQI values as in Fig. 5A and B), but the boundaries (minimum and maximum BQI values) for each salinity range were adjusted as in Approach II. The results are a mixture of the approaches evaluated in this paper and do not fully implement the salinity based calculation.

Figs. 6 and 7 show maps of the southern Baltic with all calculated sampling events. Fig. 6 shows the EcoQ classification according to Approach I, while Fig. 7 shows also the EcoQ classification based on Approach II.

4. Discussion

In the process of our study, it became clear to us that the increase in species richness and individual numbers from east to west (Bonsdorff, 2006; Remane, 1958) still affect the BQI, regardless of whether or not salinity is taken into account (Fig. 3).

The second stage, the classification procedure, does make a difference to the final EcoQ. Within this study we presented the results of three possible procedures to assess the EcoQ from one dataset. Fig. 5E and F shows some differences in comparison to Fig. 5A–D in EcoQ classification. These differences are based on the salinity adjusted $ES50_{0.05}$ sensitivity/tolerance values used in the second approach. Nevertheless, the influence of salinity on EcoQ can be reduced by a simple boundary adjustment. However, this adjustment is not without problems. Geographical separation according to environmental conditions is the backbone in the implementation of the WFD (Bald et al., 2005). The crucial point is that this separation needs to be done entirely from water bodies down to species reference lists.

4.1. $ES50_{0.05}$ sensitivity/tolerance

Given the size of the analytical dataset we applied different salinity boundaries to the dataset than those recommended for transitional waters by Bulger et al. (1993). The intention was to achieve a better resolution in the sensitivity/tolerance assessment (Fig. 4).

The sensitivity/tolerance measure used in BQI is based on ES_{50} values (Hurlbert, 1971) that are affected by species dominance. Therefore, dominant species will be rated as being more tolerant than they actually are. It is necessary to understand that not only a few sampling events from one locality determine the final $ES50_{0.05}$ value of a species in this study. In our study the $ES50_{0.05}$ value can be interpreted as a sensitivity/tolerance measure in terms of salinity. In fact, using the applied separation procedure

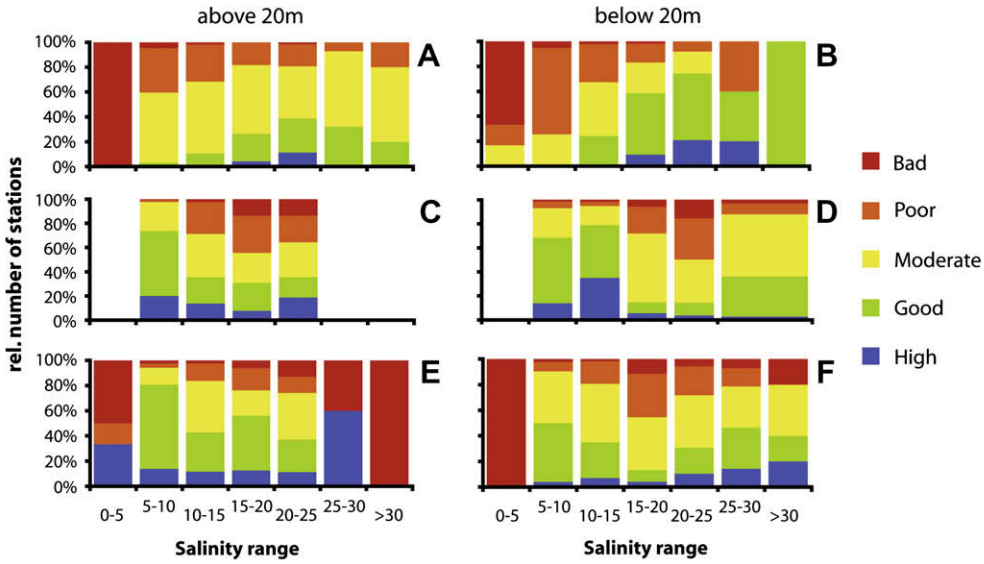

Fig. 5. Classification of EcoQ based on the BQI values shown in Fig. 3. The left column is for sampling events with equal or less than 20 m and the right column is for sampling events below 20 m. (A and B) show the EcoQ based on the BQI calculation for all stations (without salinity) while (C and D) show the results from the separated salinity ranges. (E and F) present a special classification approach based on the same data as (A and B), but the boundaries (minimum and maximum values) for the EcoQ classifications are adjusted to the salinity ranges (see Section 3.3).

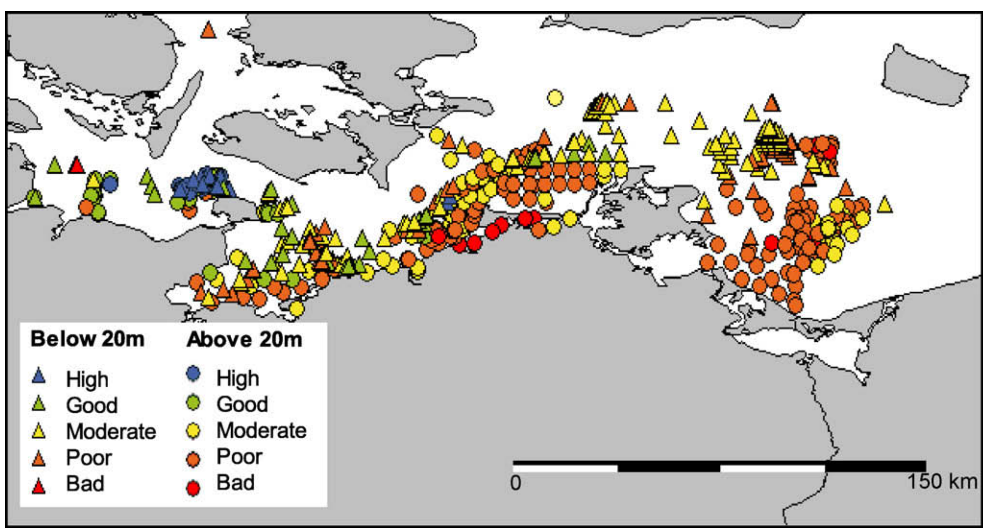

Fig. 6. The sampling area with indication of ecological status per sampling location based on the BQI values from first analysis approach. This map shows an east to west gradient of the EcoQ classification from 'Bad' to 'Good' (see also Zettler et al. (2007)).

(Fig. 2) implies that the $ES_{50_{0.05}}$ value is salinity controlled (see the example of *Pygospio elegans* in Fig. 4). This feature with its data-based approach and the calculation without an a-priori interference can be an advantage. The chance to calculate sensitivity/tolerance values for several stressors is tempting and needs further investigation and comparison to the static sensitivity/tolerance lists.

The use of static species lists editable by the user needs guidelines (Borja and Muxika, 2005, 2004) for documentation of these lists. Otherwise results might turn out to be irreproducible.

The most recent changes in the $ES_{50_{0.05}}$ and EcoQ classification have been published in a Swedish national report (Naturvårdsverkets, 2008). According to this report there have been slight modifications in the calculation of $ES_{50_{0.05}}$ (M. Blomqvist personal communication). These adjustments need to be tested for their real effects to the final sensitivity/tolerance values but seem to be of minor effect. This study here revealed that there is the need for a final clarification how to deal with samples low species numbers as a common index problem (including these samples with the real species number or excluding these samples completely) (Borja et al., 2004).

The calculated sensitivity/tolerance values in this study are solely based on the actual dataset. It was thus possible to derive a baseline for further experimental investigations on species sensitivity/tolerance, which is needed, at least for some species, to verify the evidence gained from distribution data analysis. Although, there are few experimentally checked sensitivity/tolerance data for macrobenthic species, recent autecological studies in the Baltic show that selected species from the whole species inventory can be highly indicative or descriptive of the macrozoobenthos community (Glockzin and Zettler, 2008).

4.2. The EcoQ classification

We used the procedure published by Rosenberg et al. (2004) with five equal classes for the conversion of BQI to EcoQ categories.

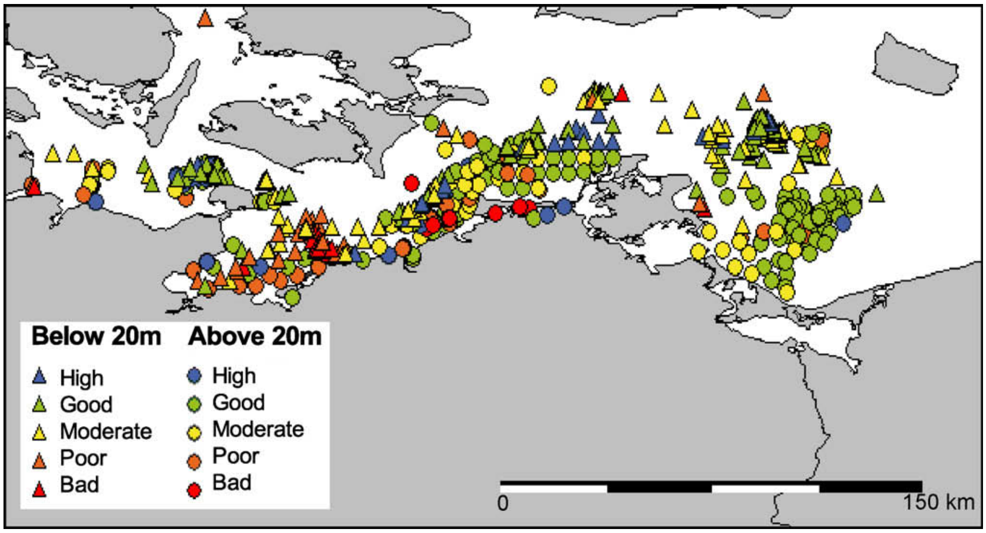

Fig. 7. The sampling area with indication of ecological status per sampling location based on the BQI values from the second analysis approach. Unlike Fig. 6, this map does not show the east–west gradient of EcoQ classification. It is visible that this approach excluded the effects of the natural salinity gradient from the assessment.

The recent adjustment to the EcoQ classification conversion includes a complete new procedure (M. Blomqvist personal communication). The classification method has been changed due to intercalibration meetings. The changes are substantial and were again only published in the national Swedish report (Naturvårdsverkets, 2008).

The overly simplistic classification conversion (Fig. 5E and F) will reduce the necessary calculation effort, but is only an interim solution between the single calculation (Approach I) and the gradient based approach (Approach II). These results are not complete. The reduced effort may be tempting while it is very time consuming to calculate all sensitivity/tolerance and BQI values for the salinity ranges. The publication of Reiss and Kröncke (2005) is an example for a comparable effort reduction. Instead of calculating $ES50_{0.05}$ values themselves, these authors used the already existing sensitivity/tolerance values from the Swedish west coast published by Rosenberg et al. (2004). Reusing these values was intended by Rosenberg et al. (2004), but this is comparable with a static species reference list and so should be avoided especially on larger geographical scales. The lists presented here are instead adapted to one major environmental factor. This factor adaptation makes these calculations appropriate in the Baltic Sea for use on smaller datasets.

The changed boundaries have more impact on the final EcoQ then the salinity range specific $ES50_{0.05}$ values. Nevertheless there is a difference between adjusted boundaries with a static sensitivity/tolerance table and the full dynamic second approach (Fig. 5C and D) with changing species reference lists as can be seen in Fig. 5. The presentation of three different procedures for EcoQ assessment from one dataset gives a hint of comparability problems between studies from different areas and scientists. To take the special situation of a transitional area like the Baltic Sea (Glockzin and Zettler, 2008) into account, we customized an assessment procedure to exclude the main natural impact parameters (e.g. salinity). Using this approach, it is now possible to increase the level of certainty for detection of anthropogenic influences.

4.3. Reference conditions

We used our expert judgement in terms of macrozoobenthic communities in the southern Baltic Sea for evaluation of the results. We consider the second approach to be the more reasonable for this variable and dynamic environment. Our dataset covers more than twenty years and more than 100,000 km^2; it is large enough to include all quality levels (Rosenberg et al., 2004) in the southern Baltic and is too wide-ranging to be locally influenced (e.g. by sewage outlets or factories).

A clear and transparent convention for the definition and use of reference conditions in the estimate of ecological quality has yet to be established (Muxika et al., 2007). The reference conditions need to facilitate reproduction and comparison between regions and studies.

It may be necessary to combine habitat quality indices (Hyland et al., 2005) as a reference for ecological habitat conditions. There is a need for further investigations as we do not yet know enough about biodiversity, biological function and eutrophication (Nielsen et al., 2003). We consider the influence of sediment carbon content on EcoQ classification to be very interesting in combination with the results presented here.

'Shifting baselines' have been described by Pauly (1995) for fish stocks. Exploitation is one cause of such shifts, but there is also the shift in community patterns caused by all kinds of environmental factors (Glockzin and Zettler, 2008). Communities in a dynamic environment like the southern Baltic Sea do change over long time scales (Bonsdorff, 2006). These changes may not be completely natural, but even with all survey data available from the Baltic Sea this question can not be comprehensively answered. Therefore, static or historical reference datasets may result in efforts to restore communities to inappropriate or unachievable conditions. When the whole ecosystem is changing and evolving according to its evolution (Bonsdorff, 2006) it is not wise to use a static, historical dataset as a reference for the future.

5. Conclusion

With this study we present data for the very dynamic macrozoobenthos of the southern Baltic Sea. The consideration of salinity and depth in the calculation of BQI made it possible to provide reference values for species sensitivity/tolerance. These values can be used in the whole southern Baltic and with adaptations in the rest of the Baltic too.

This study demonstrates ecological misclassification based on a natural gradient. Ecological quality indices calculated for large sampling regions need to take strong natural gradients into account. The need for range-adapted references in these environments is now more important then ever and this study provides sensitivity/tolerance references for the dynamic environment of the southern Baltic.

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