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Original Article

A regional benthic fauna assessment method for the Southern North Sea using Margalef diversity and reference value modelling

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ABSTRACT

The aims of this study are to develop an optimized method for regional benthic fauna assessment of the Southern North Sea which (a) is sensitive and precise (quantified as the slope and the R^2 value of the pressure-impact relationships, respectively) for the anthropogenic pressures bottom fishing and organic enrichment, (b) is suitable for estimating and modelling reference values, (c) is transparent, (d) can be efficiently applied using dedicated software; and to apply this method to benthic data from the Southern North Sea.

Margalef diversity appeared to be the best performing benthic index regarding these criteria, even better than several Multi-Metric Indices (MMIs) containing e.g. AMBI (AZTI Marine Biotic Index) and ITI (Infaunal Trophic Index). Therefore, this relatively simple and very practical index, including a new reference value estimation and modelling method, and BENMMI software were selected as a common OSPAR (Oslo Paris convention) method for the benthic fauna assessment of the Southern North Sea. This method was applied to benthic fauna data from the Southern North Sea collected during the period 2010–2015. The results in general show lower normalized Margalef values in coastal areas, and higher normalized Margalef values in deeper offshore areas.

The following benthic indices were compared in this study: species richness, Margalef diversity, SNA index, Shannon index, PIE index, AMBI, ITI. For each assessment area, the least disturbed benthic dataset was selected as an adjacent 6 year period with, on average, the highest Margalef diversity values. For these datasets, the reference values were primarily set as the 99th percentile values of the respective indices. This procedure results in the highest stable reference values that are not outliers. In addition, a variable percentile method was developed, in which the percentile value is adjusted to the average bottom fishing pressure (according to data from the International Council for the Exploration of the Sea, ICES) in the period 2009–2013. The adjusted percentile values were set by expert judgement, at 75th (low fishing pressure), 95th (medium fishing pressure) and 99th (high fishing pressure) percentile. The estimated reference values for Margalef diversity correlate quite well with the median depth of the assessment areas using a sigmoid model (pseudo-R^2 = 0.86). This relationship between depth and Margalef diversity was used to estimate reference values in case an assessment area had insufficient benthic data

For testing the effects of bottom fishing pressure, normalized index values (NIV; index value divided by reference value) were used. The rationale for using NIVs is the assumption that, although a certain level of bottom fishing pressure will have a larger absolute effect on more biodiverse benthic communities in deeper waters than on more robust and less biodiverse coastal benthic communities, the relative effects (tested using NIVs) are comparable. A clear exponentially decreasing relationship (R^2 = 0.26–0.27, $p < 0.00001$) was found between both bottom surface and subsurface fishing activity (penetration depth < 2 cm and > 2 cm, respectively) and normalized Margalef diversity values, with an asymptotic normalized Margalef value of 0.45 at a

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subsurface fishing activity > 2.3 sweeps/year. This asymptotic value is predominantly found in coastal waters, and probably shows that the naturally more robust coastal benthic communities have been transformed into resilient benthic communities, which rapidly recover from increasing fishing pressure.

1. Introduction

There is a need for the European Marine Strategy Framework Directive (MSFD) to develop indices able to detect differences and changes in benthic fauna condition in relation to anthropogenic pressures. A wide variety of benthic fauna multi-metric indices (MMIs) exist, mainly developed for the European Water Framework Directive (WFD), in particular the m-AMBI (Muxika et al., 2007), the BAT (Teixeira et al., 2009), the BEQI2 (Van Loon et al., 2015), the BQI (Rosenberg et al., 2004), the IQI (Borja et al., 2007), the DKI (Borja et al., 2007) and the SN index (Rygg, 2006). In these MMIs, the benthic indices species richness, Margalef diversity (Margalef, 1958), SN, Shannon index (Shannon and Weaver, 1963), Simpson measure of concentration (λ, Peet, 1974), Probability of Interspecies Encounter (1-λ, Hurlbert, 1971), Total Abundance (N) and AMBI (Borja et al., 2000) have been used one or more times. These indices all showed a useful sensitivity to anthropogenic pressures in a broad European study (Borja et al., 2011), and were therefore selected for testing in this study. In addition, the Infaunal Trophic Index (ITI) was selected because it is a relevant biological trait index that has yielded useful results (Maurer et al., 1999).

For the assessment of the condition of macrobenthic communities in a marine area, it is common practice to assign the benthic data to specific benthic habitat types. This approach is essential for improving the comparability of the benthic data, by reducing the benthic variation due to differences in habitat types and anthropogenic pressures (Van Hoey et al., 2013). A currently available and widely applicable habitat classification is the EUNIS system. EUNIS level 3, which discriminates Sand, Mud, Coarse and Mixed as sediment types, is often applied (Long, 2006). In addition, depth is an important environmental variable which can be used as a proxy for several natural pressures (including salinity, flow and wave pressure and light limitation) on the benthic habitats and the associated benthic communities (Leonardsson et al., 2016, Armonies et al., 2014). According to Kröncke et al. (2011), clearly discernible benthic communities can be found in the depth ranges < 50 m, 50–100 m, and > 100 m. In the Southern North Sea depths of < 50 m occur most frequently, and in the Northern North Sea deeper areas (> 100 m) are found. Coastal areas are usually defined by depths of < 20–25 m.

Benthic habitats and associated benthic communities are submitted to natural as well as anthropogenic pressures. The latter pressures act on top of the natural pressures, and induce a certain amount of degradation of the benthic communities, leading to decreases of benthic index values compared to reference values. In order to be able to clearly discriminate between natural and anthropogenic pressures, useful estimates of reference values, as well as quantitative pressure data and pressure-impact relationships, are needed.

The main environmental variables driving the natural variation are salinity, currents, wave and storm activity in tidal areas (Van Loon et al., 2015), primary production, light limitation and temperature. Some of these variables are influenced by climate driven processes such as the North Atlantic Oscillation (Kröncke et al., 2011). Higher natural pressures in the coastal zone result in lower reference index values than in the deeper offshore areas, where natural pressures are lower (Leonardsson et al., 2016; Armonies et al., 2014; Van Denderen et al., 2015). Because of higher natural stress levels in coastal areas the local benthic communities are probably more robust by nature (Duineveld et al., 1991). Common anthropogenic pressures in the North Sea are fishing (Collie et al., 2000; De Groot 1984; Kaiser et al., 2006; Tillin et al., 2006; Rumohr and Kujawski, 2000), organic enrichment and eutrophication (especially in the coastal zone, Borja et al., 2011), dumping of harbour sludge, sand extraction (in the coastal zone), and pollution e.g. Total Organic Hydrocarbons and heavy metals (in the coastal zone and near oil platforms; Olsgard and Gray, 1995; Hiscock et al., 2005). Fishing is a broadly occurring pressure in the Southern North Sea. In the coastal zone, organic enrichment is the second most widely occurring pressure. These often more or less chronic anthropogenic pressures have led to a certain degree of degradation of the benthic condition in the past. This degradation can be assessed by dividing the current benthic index assessment values with the estimated reference values, resulting in normalized index values (NIV; analogous to ecological quality ratios (EQR)). It is also known that restoration of coastal benthic communities after the cessation of fishing pressure proceeds slowly, and can take more than 8–10 years (Bergman et al., 2015; Coates et al., 2016; Lambert et al., 2014).

An important step in a benthic assessment method is the estimation of reference values under natural conditions. There are several methods to estimate these reference values: (OSPAR, 2012; Borja and Tunberg, 2011): (a) collection or use of a reference benthic dataset from a pristine or high quality area within the same ecoregion (such as the Southern North Sea). The high quality of this area must be demonstrated using a set of appropriate pressure data (fishing, organic matter, oxygen, suspended matter, heavy metals, etc.), (b) use of historical data from the least impacted areas or period, i.e. with the lowest level of anthropogenic disturbance (see OSPAR, 2012), (c) modelling and (d) expert judgement. Although method (a) is in principle preferable, it appears that in the Southern North Sea, which is broadly and chronically impacted by fishing activity (ICES 2016), pristine or high quality areas are in general not available any more (Kröncke et al., 2011; Kröncke and Bergfeld, 2003). Therefore, a combination of methods b, c and d was used in this study, similarly as in the WFD MMIs for marine benthos (Van Hoey et al., 2013; Van Loon et al., 2015). A commonly used WFD method is to estimate reference values as 95th or 99th index percentile values of a sufficiently large set of index values obtained for the least disturbed (baseline) period (Van Hoey et al., 2013; Van Loon et al., 2015). In addition, the variable percentile method of Hering et al. (2006) is a relevant method in which the height of the index percentile value used is adjusted to the known amount of anthropogenic pressure.

The aims of this study are to develop an optimized regional benthic fauna assessment method for the Southern North Sea which (a) is sensitive and precise (quantified as the slope and the R^2 value of the pressure-impact relationships, respectively) with regard to the anthropogenic pressures fishing and organic enrichment, (b) is suitable to estimate and model reference values, (c) is transparent, (d) can be efficiently applied using dedicated software; and to apply this method to benthic data from the Southern North Sea.

2. Methods

2.1. Benthic and pressure data

The Southern North Sea (SNS) is the central part of the Greater North Sea (Fig. 1). Benthic fauna data (species-abundance) were delivered by Belgium, Germany, the Netherlands and the United Kingdom for the Southern North Sea (SNS) area outside the 1 M Water Framework Directive (WFD) zone, and for three UK areas just above the Northern SNS borderline (Farnes East, North East of Farnes Deep, Swallow Sand; Fig. 2). Each national area, e.g. the German Dogger bank, is given an area code, e.g. DE_DoggerBank. In addition, each national area is divided in the relevant EUNIS 3 habitats (Long, 2006),