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Full-coverage spatial distribution of epibenthic communities in the south-eastern North Sea in relation to habitat characteristics and fishing effort

Hermann Neumann [a,*], Rabea Diekmann [b], Kay-Christian Emeis [c], Ulrike Kleeberg [c], Andreas Moll [d], Ingrid Kröncke [a]

[a] Senckenberg am Meer, Department for Marine Research, Südstrand 40, 26382 Wilhelmshaven, Germany
[b] Thünen-Institut für Fischereiökologie, Palmaille 9, 22767 Hamburg, Germany
[c] Helmholtz Zentrum Geesthacht, Institute of Coastal Research, Max-Planck-Str. 1, 21502 Geesthacht, Germany
[d] Institute of Oceanography, University of Hamburg, Bundesstraße 53, 20146 Hamburg, Germany

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ABSTRACT

Full-coverage spatial data of occurrence and a detailed description of habitat requirements of epibenthic communities are needed in many conservation and management contexts. In the North Sea the focus has so far been on small benthic infauna, whereas structure and ecosystem functions of larger epifaunal communities have been largely ignored. This study provides a comprehensive analysis of epibenthic community structure in the south-eastern North Sea, including a detailed inventory of species, diversity and spatially contiguous distribution of communities. Data from nearly 400 stations were compiled for the study, enabling us to describe epibenthic community structure at unprecedented spatial resolution. Eight distinct epibenthic communities were found in the south-eastern North Sea by using multivariate analysis. Distribution modelling with eight environmental variables (bottom temperature and salinity, temperature differences between summer and winter, mud content of sediments, maximum bottom shear stress, stratification, water depth and annual primary production) and one human pressure (fishing effort) was used to extrapolate probable spatial distributions and to identify associated habitat characteristics of the communities in the south-eastern North Sea. Three large epibenthic communities “Coast”, “Oysterground” and “Tail End” reflect a gradual habitat change from the coast towards offshore regions, expressed in gradients of bottom salinity, seasonal temperature differences and stratification as the dominant environmental factors. Five smaller communities (“Amrum Bank”, “Frisian Front”, “Deeps”, “Dogger Bank” and “Dogger Slope”) outline specific habitats in the south-eastern North Sea. The “Dogger Slope” community has not been recognized before, but has a predicted spatial extent of 7118 km^2. Due to the high occurrence of long-lived, sessile species such as sponges this community is very sensitive to demersal fishing.

1. Introduction

Analysing spatial distribution of benthic communities in the North Sea has been a major focus for benthic ecologists since Petersen's fundamental work about benthic communities in the early 20th century (Petersen, 1914). In contrast to benthic infauna, it took more than 70 years – until the early 1980ies – before the first quantitative studies on spatial patterns of epibenthic communities in the North Sea were conducted (Dyer et al., 1982, 1983). The epifauna, which spend the majority of their life on the surface of the seafloor, are an important component of the benthic ecosystem. It includes highly mobile predators and scavengers, but also sessile and habitat-forming taxa such as sponges or bryozoans, which significantly enhance habitat complexity. Epibenthic species represent a major food source for higher trophic levels, are a key link between the benthic and pelagic ecosystem, and provide essential ecosystem functions by modifying biogeochemical processes (Reise, 2002; Norkko et al., 2013). On the other hand, the epifauna has shown to be vulnerable to human impacts such as

* Corresponding author.
E-mail address: hneumann@senckenberg.de (H. Neumann).

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demersal fishing, and the loss of larger epifauna through fishing resulted in decreasing fish productivity (Jennings and Kaiser, 1998; Collie et al., 2000a; Kaiser et al., 2000; Kenchington et al., 2007; Lambert et al., 2011).

Epibenthic community structure, species diversity and relative abundance of epibenthic species have been described on regional (Basford et al., 1989; Rees et al., 1999; Neumann et al., 2013b) and North Sea wide scales (Frauenheim et al., 1989; Jennings et al., 1999; Zühlke et al., 2001; Callaway et al., 2002; Reiss et al., 2010). However, earlier studies have lacked dedicated sampling effort and resolution when it comes to epibenthic community structure in the south-eastern North Sea, although such information is essential for regional management requirements in the face of rapid industrialisation of sea space (Emeis et al., 2015). Callaway et al. (2002) and Reiss et al. (2010), for instance, only described two, respectively three epifauna communities in the south-eastern North Sea by analysing approximately 50 samples. Neumann et al. (2013b) distinguished five epibenthic communities by analysing 75 samples from the German Exclusive Economic Zone (EEZ). Epibenthic data from nearly 400 stations in the south-eastern North Sea are used in this study, which include the German, as well as large parts of the Dutch and Danish EEZs. Our study is based on data from about eight times more stations than the most comprehensive study so far, enabling us to describe the epibenthic community structure on significantly finer spatial scales than before. The data are part of Senckenberg's LTER North Sea Benthos Observatory and have previously and in part been used to analyse temporal variability (Neumann et al., 2009b), as well as functional aspects (Neumann et al., 2016) of epibenthic communities in the south-eastern North Sea. The former analyses revealed an unexpectedly complex and diverse epibenthic community structure in the south-eastern North Sea and suggested that communities are more susceptible to direct fishing impacts than anticipated (Neumann et al., 2016).

The application of statistical distribution models for benthic analyses has been of increasing importance in recent years, since spatial information is commonly based on point observations, whereas detailed full coverage spatial data are needed to support an ecosystem-based management (Reiss et al., 2015). Initially, statistical distribution models related species occurrence and environmental predictor variables to predict the potential habitat of species (Elith and Leathwick, 2009). But modelling approaches were also used on community level, since environmental factors also determine benthic community structure. Degraer et al. (2008) and Gogina et al. (2016), for instance, modelled the distribution of benthic infauna communities in the Belgian part of the North Sea and the Baltic Sea, respectively. It is known from the multivariate analysis of observational point data that the most influential environmental factors for epibenthic community structure in the North Sea are depth, temperature, salinity, mud content of sediments, seasonal temperature differences as well as beam trawling (Jennings et al., 1999; Callaway et al., 2002; Reiss et al., 2010). However, these analyses basically compare similarity matrices of biological and environmental data to investigate community-environment relationships (i.e the multivariate grouping of all biological sampling sites with the multivariate grouping of environmental factors). In contrast, statistical distribution models correlate environmental factors with each community separately and therefore provide more useful insights into the causal relationships between the spatial distribution of a single community and the underlying environmental factors (Moritz et al., 2013).

This study focuses on (1) a comprehensive analysis of epibenthic community structure in the south-eastern North Sea including a detailed description of species composition and diversity. Furthermore, a modelling approach was used (2) to provide the full-coverage spatial distribution of the epibenthic communities in the south-eastern North Sea and (3) to determine the environmental factors that drive their spatial distribution. These information are needed in the context of international directives such as the Marine Strategy Framework Directive (MSFD), since epibenthic community structure is insufficiently studied in the south-eastern North Sea and conservation and management effort is so far mainly focusing on the small benthic infauna, ignoring ecosystem functions and services of larger epifauna.

2. Materials and methods

2.1. Study site and epibenthic data

Epibenthic invertebrates and demersal fish were sampled at 398 stations in the south-eastern North Sea from 53°30′N to 56°00′N and 3°00′E to 8°00′E. The study area includes the inner German Bight with the shallow West and North Frisian coasts, the deeper Oyster Ground, and the shallow northeast Dogger Bank. Water depth generally increases from the coastal areas towards the northwest rectangles, with exception of the Dogger Bank, and varies from 18 m to 55 m.

Epifauna data were analysed from catches taken during surveys with the Fisheries Research Vessel “Walther Herwig III”. Sampling took place within the framework of the 3rd quarter International Bottom Trawl Surveys (IBTS) coordinated through the International Council for Exploration of the Seas (ICES). Epifauna was sampled in July/August from 2000 to 2015 (except 2001 and 2002) with a standardized 2 m beam trawl made of galvanized steel with a chain mat attached. The beam trawl was fitted with a 20 mm net and a cod end of 4 mm mesh size. A Scanmar depth finding sonar was attached to the top of the net just behind the steel beam to determine the exact time and position of contact with the seabed. From the moment of contact with the ground, the beam was towed at a speed of about 1.5–2 knots for 5 min. Usually, 30 samples per year were taken unless bad weather conditions or ship problems precluded sampling. Samples were sieved through 5 mm mesh size and the epibenthic fauna was separated from the remains. Species were identified on board to the lowest possible taxonomic level and abundance data were standardized to a tow length of 250 m (area sampled = 500 m^2).

2.2. Multivariate community analysis

In total, 119 species/taxa were used for epibenthic community analysis. Eleven small fish species such as the goby *Pomatoschistus* spp. or the solenette *Buglossidium luteum* were included in the analysis since they are known to be sampled effectively by the used gear (Neumann et al., 2013b). Additionally, colonial taxa such as *Flustra foliacea, Alcyonium digitatum, Alcyonidium diaphanum* and sponges were included. Abundance of colonial species was given as “number of colonies”.

Hierarchical cluster analysis (group-average linking) and nonmetric multidimensional scaling (nmMDS) were applied on square-root-transformed abundance data to separate groups of stations with similar community structure. Similarities were calculated using the Bray-Curtis coefficient. Similarity profile (SIMPROF) tests and an average similarity of at least 40% were used as criteria for defining groups with similar community structure. SIMPROF is a permutation test to identify statistical significance of clusters in samples that are not *a priori* divided into groups (Clarke et al., 2014). Finally, similarity percentage analysis (SIMPER) was used to identify species/taxa predominantly responsible for the similarity within groups. Shade plots were used for visualization of characteristic species within groups, whereby species were ordered