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Functional composition of epifauna in the south-eastern North Sea in relation to habitat characteristics and fishing effort

Hermann Neumann [a, *], Rabea Diekmann [b], 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*

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A B S T R A C T

Analysis of ecosystem functioning is essential to describe the ecological status of ecosystems and is therefore directly requested in international directives. There is a lack of knowledge regarding functional aspects of benthic communities and their environmental and anthropogenic driving forces in the southern North Sea. This study linked functional composition of epibenthic communities to environmental conditions and fishing effort and investigated spatial correlations between habitat characteristics to gain insight into potential synergistic and/or cumulative effects. Functional composition of epifauna was assessed by using biological trait analysis (BTA), which considered 15 ecological traits of 54 species. Functional composition was related to ten predictor variables derived from sediment composition, bottom temperature and salinity, hydrodynamics, annual primary production and fishing effort. Our results revealed significantly different functional composition between the Dogger Bank, the Oyster Ground, the West and North Frisian coast. Mobility, feeding type, size and adult longevity were the most important traits differentiating the communities. A high proportion of trait modalities related to an opportunistic life mode were obvious in coastal areas especially at the West Frisian coast and in the area of the Frisian Front indicating disturbed communities. In contrast, functional composition in the Dogger Bank area indicated undisturbed communities with prevalence of large, long-lived and permanently attached species being sensitive towards disturbance such as fishing. Tidal stress, mud content of sediments, salinity, stratification and fishing effort were found to be the most important habitat characteristics shaping functional composition. Strong correlations were found between variables, especially between those which changed gradually from the coast to offshore areas including fishing effort. Unfavourable extremes of these factors in coastal areas resulted in disturbed epibenthic communities, while the relative influence of a single factor on functional composition cannot be quantified. Coastal communities seemed to be well adapted to disturbance and the prevalence of opportunistic trait modalities not necessarily revealed a poor ecological status according to the Marine Strategy Framework Directive (MSFD). The integration of functional aspects into the assessment of ecosystem health is recommended, since widely used structural measures failed in naturally disturbed habitats.

1. Introduction

Spatial and temporal variability of epibenthic communities have long been studied following traditional species-based approaches. However, there is an increasing need to understand not only the structural composition of invertebrate communities, but also functional composition and diversity since ecosystem processes and stability are strongly attributed to functional traits of species and their interactions rather than to species composition and taxonomic identity (Diaz and Cabido, 2001; Grime, 1997; Hooper et al., 2002; Odum, 1969). Functional aspects are therefore acknowledged in international directives such as the Habitat Directive and the Marine Strategy Framework Directive (MSFD) as a key element for the protection of habitats and the ensuring of ecological sustainability (Bremner, 2008; Frid et al., 2008). Functionality has been also suggested as revised criterion for Descriptor 6 (seafloor integrity) of the MSFD in the most recent ICES advice (ICES, 2014).

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

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In this study, we used biological traits analysis (BTA) to describe ecological functioning, which uses a comprehensive set of functional traits of species that are either directly linked to ecosystem processes or are indicators of them (Bremner et al., 2003). Functional traits are defined here as morpho-physio-phenological traits influencing species fitness via the effects on growth, reproduction and survival (Violle et al., 2007) and were chosen in accordance with 10 key aspects of marine system (Frid et al., 2008). The wide range of traits used by BTA, the strong link between them and ecosystem processes (Diaz and Cabido, 2001), as well as the sound theoretical framework (see Bremner, 2008) are a considerable advance over single-trait approaches making BTA to useful analytical tool to describe functioning more completely.

Based on the “habitat templet theory” (Southwood, 1977; Townsend et al., 1997), it is predicted, that the habitat act as selective force for specific life-history strategies of species thereby filtering out unsuccessful traits hampering survival and reproduction under the prevailing conditions. Functional composition of communities therefore reflects habitat characteristics which were given by environmental conditions and anthropogenic factors. Following the classical work of Pearson and Rosenberg (1978), stressed and disturbed habitats were characterised by species revealing an opportunistic life mode such as a short life span, an early onset of sexual maturity or a small size. Against this background, analysis of trait composition is useful by identifying areas exposed (or sensitive) to disturbances, but also by evaluating the success of management strategies. However, environmental and anthropogenic effects were mostly considered separately from each other and interrelationships between factors influencing functional composition remain unclear. Thus, the prevalence of opportunistic trait modalities were found to be the result of hypoxia events (Pacheco et al., 2011), organic enrichment (Marchini et al., 2008), cold winters (Neumann and Kröncke, 2011), low salinity (Darr et al., 2014) and fishing effects (Bremner et al., 2005; Tillin et al., 2006). In order to make functional studies helpful for the state assessment of communities it is necessary to identify habitat characteristics shaping functional composition as well as the spatial correlations between the natural conditions and manageable anthropogenic pressures. To address this issue, our study aims (1) to analyse spatial variability of functional composition and diversity of epibenthic communities in the south-eastern North Sea and (2) to relate functional composition to environmental conditions and fishing effort in the area, which is the most widespread and yet manageable seabed pressure. Additionally, spatial correlations between environmental conditions and fishing effort will be analysed (3) to gain insight into potential synergistic and/or cumulative effects on functional composition of epifauna in the south-eastern North Sea.

2. Materials and methods

2.1. Study site and epibenthic data

Epibenthic invertebrates and demersal fishes were sampled at 460 stations in the south-eastern North Sea, covering 24 ICES rectangles (30 × 30 nautical miles) from 53°30′N to 56°00′N and 3°00′E to 8°00′E (Fig. 1). The study area included the inner German Bight with the shallow West and North Frisian coasts, the deeper Oyster Ground, and the shallow northeast Dogger Bank. The depth generally increased from the coastal areas towards the northwest rectangles, with the exception of Dogger Bank, and varied from 18 m (rectangle 38F7) to 55 m (rectangle 40F5).

Epifauna data were analysed from catches taken during surveys with the Research Vessel “Walther Herwig III”, which were part of the ICES-coordinated International Bottom Trawl Survey. Epifauna was sampled in July/August from 1998 to 2013 (except 2001 and 2002) with a standardized 2 m beam trawl made of galvanized steel with a chain matt 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. One sample was taken per rectangle and year with exception of rectangle 37F7 where 9 replicates were taken. Samples were sieved through 5 mm mesh size and the epibenthic fauna was separated from the remains. Species were identified onboard to the lowest possible taxonomic level and abundance/biomass data were standardised to a tow length of 250 m (area sampled = 500 m^2). Data were averaged over time representing the “mean community” from 1998 to 2013.

2.2. Environmental and fishing effort data

Seven environmental variables were selected, which are known to be important factors influencing the spatial variability of epibenthic species in the North Sea (Callaway et al., 2002; Neumann et al., 2009, Reiss et al., 2010): Mean annual bottom temperature and salinity, temperature differences between summer and winter, mud content of sediments, hydrodynamic parameters (tidal stress and stratification) and annual primary production.

Data on bottom temperature and salinity were derived from the hydrodynamic Hamburg Shelf Ocean Model (HAMSOM) (Pohlmann, 1996). The model's horizontal resolution is 12 min of latitude and 20 min of longitude with a vertical resolution of 19 layers. Data from the year 2001 were exemplarily used for analysis. Mean annual bottom temperature and salinity as well as differences between summer (September; warmest month) and winter (February; coldest month) were calculated for each rectangle.

Ecological North Sea Model Hamburg (ECOHAM1) was used to estimate the primary production of the water column. ECOHAM1 is based on a simple phosphorus/nitrogen cycle and takes four state variables into account, three pelagic variables [phytoplankton, phosphate (DIP), and nitrogen (DIN)], and one for benthic detritus. The horizontal grid size of the numerical model is 20 × 20 km, the vertical resolution is 5 m for the upper 50 m. For a detailed description of the model, see Skogen and Moll (2000, 2005).

Sediment data were taken from the Senckenberg sediment database and covers the period from 1999 to 2013 including sediment samples of almost all biological sampling stations of this study (373 stations in total). Sediment composition was analysed by sieving the wet sediment over 63 μm and 2 mm sieves, weighting the dried material with a METTLER fine scale and calculating the percentages from the complete sediment sample. Only mud content (<63 μm sieve fraction) were used as sediment variable because the calculated sieve fractions were not independent of each other resulting in high colinearity between variables.

Data of tidal stress and stratification were provided by the Proudman Oceanographic Laboratory (Liverpool, U.K.) and generated using a three-dimensional hydrodynamic model (Davies and Aldridge, 1993). Tidal stress was calculated from a one-year model run covering the period September 1999 to September 2000, on an approximately 12 km grid. The stratification parameter ‘S’ was derived from the formulation presented in Pingree and Griffiths