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Correlations between benthic habitats and demersal fish assemblages — A case study on the Dogger Bank (North Sea)

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ABSTRACT

The interdependence between groundfish assemblages and habitat properties was investigated on the Dogger Bank in the North Sea. Abiotic habitat parameters considered included topography, hydrographic conditions, sediment composition, and the biotic habitat variable the prevailing benthic invertebrates. Distinct epi- and infauna communities occurred at different locations on the Dogger Bank. Fish assemblages were clearly linked to both the biotic and abiotic habitat characteristics.

Overall, fish and benthic communities revealed similar spatial distribution, represented in the respective clusters of characteristic and abundant species. Distribution patterns corresponded with the prevailing abiotic conditions such as depth and sediment composition, which appear to relate to autecological preferences of individual species.

The apparently most generalist species, grey gurnard (*Eutrigla gurnardus*) and dab (*Limanda limanda*) occurred at all stations and dominated in terms of biomass in most cases. The absolute numbers of grey gurnards were related to the abundance of suitable prey, invertebrate and fish species, which stomach analyses revealed as part of the diet in an independent study during the same research cruise. Haddock (*Melanogrammus aeglefinus*) and whiting (*Merlangius merlangus*) were only abundant at deep stations along the flanks of the bank. The occurrence of lemon sole (*Microstomus kitt*), American plaice (*Hippoglossoides platessoides*) and cod (*Gadus morhua*) was also positively correlated with depth, whereas especially lesser weever (*Echiichthys vipera*), sandeel species and solenette (*Buglossidium luteum*) occurred predominantly at the shallower sites. At the same time, individual fish species such as solenette and lesser weever were associated with high densities of selected epi- or infauna species.

1. Introduction

Distribution patterns of fish often depend on the spatial extent of appropriate habitat. This is particularly clear where complex habitats such as coral reefs or sea mounts lead to local accumulations of habitat-specific fish (e.g., Fock et al., 2002; Parrish and Boland, 2004). For the North Sea, habitat effects on small-scale distribution of fish have been studied around prominent physical structures, especially oil platforms (Løkkeberg et al., 2002; Soldal et al., 2002). However, for the more typical sand-bottom habitats of the North Sea, fewer investigations exist that report on the importance of particular in- and epifauna communities providing a biotic habitat for groundfish (Ellis et al., 2011; Kaiser et al., 2004; Reiss et al., 2010; Ryer et al., 2004).

Sandbank habitats have attracted greater interest recently, when some EU member states designated Natura 2000 sites under the Habitats Directive (European Commission, 1992), aimed at the protection of this particular type of benthic habitat with its associated marine communities. The Dogger Bank is the largest sandbank in the North Sea, covering sections of the Exclusive Economic Zones of four bordering states (UK, NL, GE, DK). Most of the bank's area has been declared as Natura 2000 sites, for which possible protection measures are presently being debated at the time of writing. The installation of appropriate management measures, geared to protect the structure itself and its associated typical fauna, calls for a detailed analysis of the interdependence of species and habitats, including invertebrate fauna and fish.

The Dogger Bank is a sandbank with distinct ecological features (Kröncke and Knust, 1995; van Moorsel, 2011). Different salinities, temperatures and seasonal variability in both parameters distinguish the different water masses around the Dogger Bank. Waters in shallow areas on top of the bank are nearly permanently mixed, whereas seasonal stratification occurs in the deeper areas. Both, morphological heterogeneities as well as the co-occurrence of different water masses are known to support the development of fronts (Otto et al., 1990) with a related potential for enhanced primary and secondary production (Hill et al., 1994). Primary production on the Dogger Bank occurs throughout the year with higher values in winter (January and February)

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than in any other area in the southern North Sea (Brockmann and Wegner, 1985; Howarth et al., 1994; Richardson and Olsen, 1987). The benthic infauna communities on the Dogger Bank have been studied since the 1920s by Danish, British and German scientists (e.g., Sell et al., 2007; Wieking and Kröncke, 2005; reviewed in Kröncke, 2011).

In the present study, our objective was to build upon the initial analyses of fish and invertebrate communities presented in Sell et al. (2007) in order to evaluate how strongly the spatial structure of groundfish assemblages on the Dogger Bank depend on the different local habitat features. We characterize benthic habitats based on abiotic parameters as well as the biotic components and relate these habitat properties to the composition of groundfish communities. Two hypotheses are being tested:

(1) Groundfish assemblages depend primarily on bank topography (association with abiotic habitat parameters), and
(2) The distribution of groundfish assemblages is related to the composition of benthic in- and/or epifauna communities, which provide potential prey resources (association with biotic habitat parameters).

2. Methods

2.1. Sampling and sample treatment

Bottom fish assemblages on the Dogger Bank (North Sea) were analyzed during a research cruise with FRV "Walther Herwig III" from April 28–May 9, 2006, using the GOV otter trawl and sorting the catch, both as described in the manual for the International Bottom Trawl Survey (IBTS) (ICES, 2006). All the sampling was conducted during daytime. During the cruise WH 287, 35 stations across the bank's area were sampled for the fish assemblages, benthic epifauna and abiotic habitat parameters; infauna was sampled at 24 of those stations (Fig. 1, Supplementary Table S1). The depth intervals sampled were: <30 m, 6 stations; 30 < 40 m, 11 stations; 40 < 50 m, 8 stations, and >50 m, 10 stations.

Abiotic habitat parameters measured included CTD profiles from a Seabird probe and sediment samples taken with a van Veen grab. In the lab, sediment fractions of gravel (grain size > 2 mm), sand (>63 μm–2 mm) and mud (<63 μm) were separated by wet-sieving over the respective mesh sizes. Two replicates per station of benthic infauna were taken with 0.2 m^2 van Veen grabs as well and were processed independently before averages of the results were taken. Epifauna and small bottom fish at the sea bed were sampled with a 2-m beam trawl, equipped with a mat of tickler chain and a net with 20-mm mesh size and a liner with 4-mm knotless mesh as described in Jennings et al. (1999). The net was applied at the same stations at which the GOV hauls were taken and towed for 5 min at a speed of 2 knots over ground. In the smaller fraction of fish caught with the 2-m beam trawl minimum length of fish caught was 3–4 cm and maximum length typically around 25 cm — outliers and elongated species like *Entelurus aequoreus* excepted. In the GOV, fishes with less than 4 cm length may occur, but in low numbers, and maximum lengths of fishes caught can reach 2 m, but were during this cruise around 60 cm. For easier phrasing, these two groups are in the following also called "small fish" from the 2-m beam trawl and "large fish" from the GOV. Epifauna species were counted and weighed on board ship, infauna samples were preserved in 4% formaldehyde and were post-processed in the laboratory.

2.2. Data analysis

GOV haul target duration was 30 min, but in a few cases where haul duration differed by 1 min, count data of demersal fish were standardized to 30 min for comparison. For purposes of visualizing the numbers of individuals caught, data were transformed to the swept area based on the net geometry (wingspread) of the individual GOV hauls and towed distance. Epifauna and fish data from catches with the 2-m beam trawl were also standardized to 1000 m^2 (roughly three times the area covered per haul), and for infauna data sampled with the van Veen grab to 1 m^2. For statistical analyses, abundance data were square-root transformed to reduce the impact of very abundant over the rarer species. The vast majority of the epifauna was identified to species level, only few taxa to a higher taxonomic level. Pelagic fish species present in the GOV hauls were excluded from the analyses (herring — *Clupea harengus*, sprat — *Sprattus sprattus*, Atlantic mackerel — *Scomber scombrus*, and European anchovy — *Engraulis encrasicolus*) because their abundance is not expected to be directly related to benthic habitats. None of these taxa was present in the beam trawl. Although sandeel species (Ammodytidae) feed in the pelagial, they were not excluded here, as they are a dominant element of sandbank communities (Ellis et al., 2011; Kaiser et al., 2004), while they are unlikely to be dependent on the benthic invertebrate fauna in their habitat, they can themselves be expected to form a critical habitat component as prey. Sandeel are known to be hunted by many predatory fish species, forming a significant part of their diet, and aggregative responses to sandeel have been observed (Engelhard et al., 2008; Weinert et al., 2010).

Initial data exploration and canonical correspondence analyses (CCA) of the relations between fish assemblages and habitat parameters were performed with BRODGAR (Highland Statistics Ltd., version 2.6.6) and CANOCO, version 4.5 (ter Braak and Smilauer, 1998). Further statistical calculations were performed using the software package PRIMER — Plymouth Routines In Multivariate Ecological Research, version 6 (Clarke and Gorley, 2006).

Cluster analyses were performed on the level of individual functional groups, e.g., benthic infauna, and with pre-treatment of the data in the form of Bray–Curtis similarity matrices of square-root transformed species abundances. Similarity profile permutation tests (SIMPROF) were applied to test for significant differences between groups identified through cluster analysis in the a priori unstructured set of samples (stations with their specific species assemblage). The SIMPER routine within the PRIMER program was used to examine the contribution of each species to the similarity within a group of assemblages, and to identify the dissimilarities between the groups. Relationships between the assemblages of larger groundfishes (GOV catches, clusters with 60% similarity) and the characteristics of their abiotic and biotic habitats were investigated. Analyses of similarities (ANOSIM) or RELATE routines were performed to reveal potential differences between the fish assemblages depending on a number of abiotic factors, particularly each station's depth, temperature, salinity and sediment properties. Similarity matrices used in these routines were based on Bray–Curtis ordination for abundance data and on Euclidean distance for (normalized) abiotic environmental data. ANOSIM was applied to test *whether* a particular parameter (e.g., sediment category) is significantly correlated to the composition of assemblages. It was used in analogy to a univariate ANOVA as a method of permutation-based hypothesis testing to look for differences between a priori defined groups of samples. RELATE measures how closely related two sets of multivariate data are, for a matching set of samples by calculating a rank correlation coefficient between all the elements of their respective (dis)similarity matrices. RELATE was used here for relation of species assemblages to multiple abiotic data, including both categorical and continuous data, or to compare two sets of abundance data from different taxa for the same stations. For all SIMPROF, ANOSIM or RELATE analyses, 999 permutations were conducted. BEST analyses employ rank correlation between two resemblance matrices and were used to investigate relationships between faunal communities and a suite of environmental data – here, the combination of the factors depth, temperature and salinity – for which with resemblance matrices were prepared based on Euclidean distance.