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Research Article

Effects of natural environmental drivers and different mobile bottom-contact fishing intensity on infauna communities in NATURA 2000 sites in the German Exclusive Economic Zone of the North Sea

Ramona Ohde[1,2], Ingrid Kröncke[1,2]

1 *Senckenberg am Meer, Department for Marine Research, Wilhelmshaven, Germany*
2 *Institute for Chemistry and Biology of the Marine Environment (ICBM), Carl von Ossietzky University, Oldenburg, Germany*
Corresponding author: Ingrid Kröncke (ingrid.kroencke@senckenberg.de)

Abstract

Three marine protected areas, i.e., Borkum Reef Ground, Sylt Outer Reef, and Dogger Bank, have been established within the European NATURA 2000 program in the German Exclusive Economic Zone of the North Sea. Within them, we analysed the effect of the varying impact of mobile bottom-contact fishing on infauna communities in selected focus areas as a baseline study prior to the exclusion of mobile bottom-contact fishing since 2023. The three focus areas varied significantly in sediment composition and depth. The mobile bottom-contact fishing intensity was lowest at Borkum Reef Ground, but revealed decreasing gradients at Sylt Outer Reef and Dogger Bank.

The infauna communities in the three focus areas were significantly different. Gradients in sediment composition, e.g. sand, mud, gravel and shell contents, revealed significant relationships with the infauna communities in the three areas. But on a small spatial scale also the gradients of mobile bottom-contact fishing intensity correlated significantly with the variations of the infauna communities at Sylt Outer Reef and Dogger Bank. The common agreement of the European Commission for the exclusion of mobile bottom-contact fishing in parts of Borkum Reef Ground and Sylt Outer Reef since 2023 and of Dogger Bank since 2025 will provide the opportunity to study the recovery of the infauna communities in these areas from mobile bottom-contact fishing in future.

Key words: Exclusion mobile bottom-contact fishery, infauna, mobile bottom-contact fishery, Natura 2000 sites, sediment composition

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Introduction

The North Sea is a temperate coastal shelf sea of the north-eastern Atlantic Ocean, located at the north-western borders of the European mainland. Spanning roughly 750,000 km^2 (Otto et al. 1990; OSPAR 2000), the North Sea is bordered by a densely populated coastline that is home to some 80 million people. Much of this heavily industrialised region supports domestic, agricultural, and industrial operations that generate nutrients and chemicals, which primarily enter the sea through river runoff and atmospheric

deposition (OSPAR 2000; Emeis et al. 2014). Meanwhile, its offshore zones are heavily utilised for oil and gas extraction (OSPAR 2000). As one of the world's busiest maritime routes, the North Sea is also increasingly vulnerable to climate change, evident in its rising sea surface temperatures (Drinkwater et al. 2009; Dippner et al. 2025).

Mobile bottom-contact fishing (MBF) is one of the most widespread human disturbances in the southern North Sea (Kaiser et al. 2000; Hiddink et al. 2018, 2020). More than 60% of the sediment surface in the southern North Sea has been trawled once or more per year (Rijnsdorp et al. 1998, 2018; Eigaard et al. 2017), but since 2000 the effort of the MBF generally declined and occurred mainly in the shallower, eastern and south-eastern parts of the North Sea (ICES 2016, 2018; Couce et al. 2020).

While MBF is known to influence the abundance, biomass, and diversity of benthic infauna and epifauna (Hiddink et al. 2018, 2020), the extent of its impact varies depending on the exposure and sensitivity of individual species and habitats (Eggleton et al. 2018; Hiddink et al. 2018). As a result, the current benthic community likely consists largely of species that have developed resilience to sustained MBF. Over recent decades, this pressure has driven a shift in species composition, favoring opportunistic, short-lived organisms over longer-living species (Kröncke 1992; Rumohr and Kujawski 2000). One example was the loss of the extended bivalve patches of the species *Spisula subtruncata* and *Mactra stultorum* in the north-eastern and central part of the Dogger Bank due to MBF (Kröncke 2011).

Within the German Exclusive Economic Zone (EEZ) of the North Sea, three areas have been designated as marine protected areas (MPAs) under the European Commission's NATURA 2000 network since 2017 (Krause et al. 2006; Bildstein et al. 2017). These sites are the "Dogger Bank" (DgB), the "Borkum Reef Ground" (BrG), and the "Sylt Outer Reef–Eastern German Bight" (SAR).

The establishment of the three MPAs aimed to achieve the Good Environmental Status as defined in the European Marine Strategy Framework Directive (EC 2008). Nevertheless, the MSFD assessment of the MPAs in the German North Sea has shown that these sites fail to achieve Good Environmental Status, largely due to the high volume of anthropogenic activities taking place within them (EC 2008; OSPAR 2023).

Given that the NATURA 2000 sites face an increased risk of failing to meet their benthic conservation objectives (Jennings 2009; Greathead et al. 2020), the German Marine Research Alliance (DAM) initiated the project "Exclusion of mobile bottom-contact fisheries in Marine Protected Areas of the German EEZ of the North Sea (MBF-North Sea)" in 2020. This project was designed as a baseline study to assess the effects of existing MBF intensity within the German North Sea NATURA 2000 sites, prior to the eventual fishing bans. These bans were implemented by the EU in March 2023 for SAR and BrG (EC 2022), and are scheduled for November 2025 for DgB (EC 2025).

In order to analyse the impact of natural environmental variables and MBF as potential drivers, the present study was conducted in the three NATURA 2000 sites along gradients of decreasing MBF intensity with two specific objectives: (i) examining the small-scale spatial variability of the infauna communities and natural environmental drivers and (ii) disentangling the relative effects of natural environmental drivers and MBF on the infauna community structure.

Materials and methods

Study area

Borkum Reef Ground (BrG), Dogger Bank (DgB) and Sylt Outer Reef (SAR) are the German NATURA 2000 sites in the south-eastern North Sea (Fig. 1). Within these NATURA 2000 sites, focus areas were defined according to gradients with decreasing mobile bottom-contact fishery (MBF) intensity (Fig. 1).

The Borkum Reef Ground (BrG) is the smallest of the three NATURA 2000 sites with 625 km^2 (BfN 2008a). It is around 40 km away from the coast of the East Frisian Island of Borkum and characterised by a large sandbank and reef structures (Dörjes 1977; BfN 2008a).

The Dogger Bank (DgB) is a shallow sandbank in the central North Sea and a special ecological region, where species from the northern and the southern North Sea meet (Kröncke 1992; Kröncke and Knust 1995). The German part of the DgB covers an area of 1624 km^2 (BfN 2008b). The shallow parts of the Dogger Bank (<30 m) consisted of fine sand with varying amounts of dead bivalve shells, while at the deeper parts, the mud content increased (Kröncke 2011).

The Sylt Outer Reef (SAR) is the largest NATURA 2000 site with 5603 km^2 and is characterised by a high diversity of sediments and habitat structures (BfN 2008c; Michaelis et al. 2019a, 2019b).

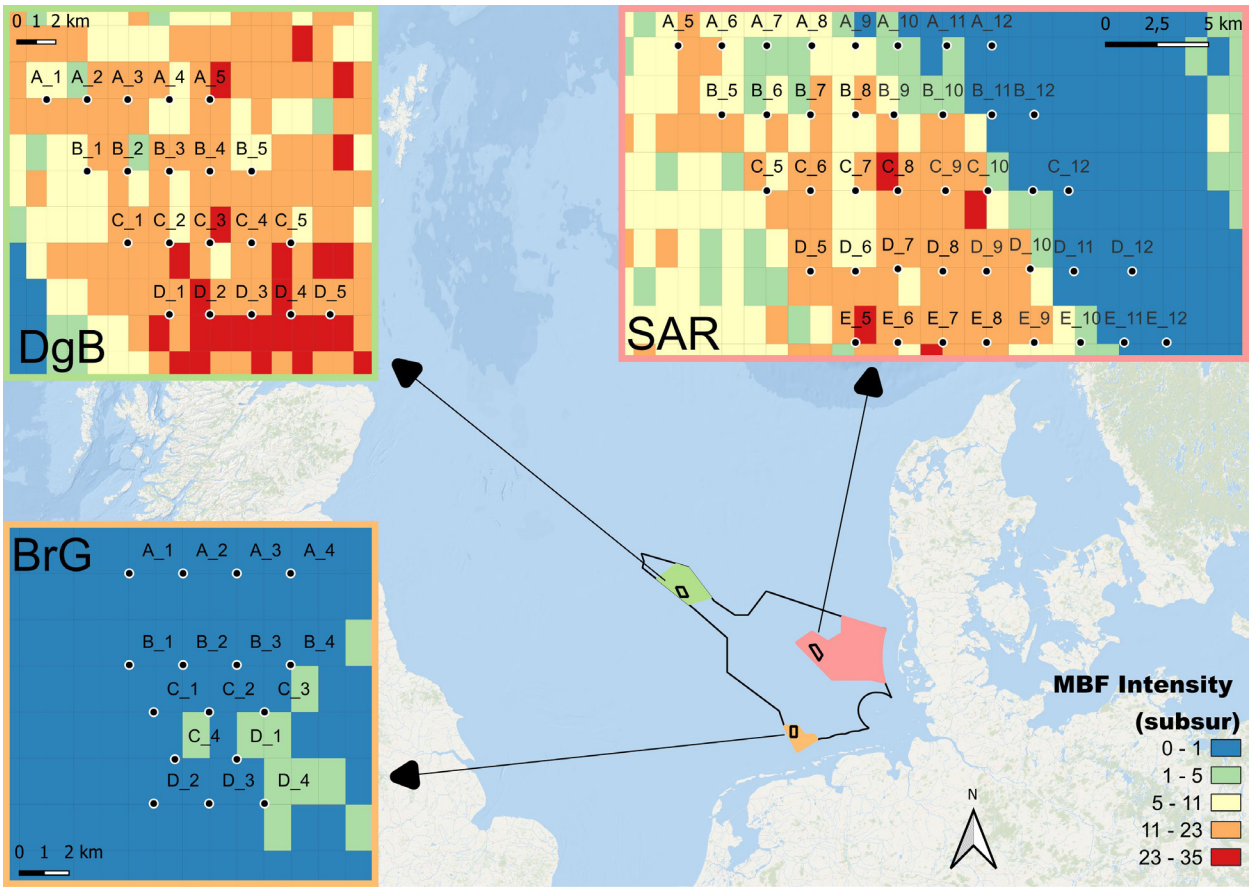

Figure 1. Focus areas and transects sampled during the present study in the North Sea NATURA 2000 sites (coloured polygons) Borkum Reef Ground (BrG), Dogger Bank (DgB) and Sylt Outer Reef (SAR), including mobile bottom-contact fishing MBF intensity (subsurface (>2 cm, subsur) recorded in year 2020 in the German Exclusive Economic Zone based on ICES (2021a, 2021b); red = high MBF intensity; blue = non or low MBF intensity.

Table 1. Sampling with RV "Senckenberg" in the years 2020 and 2021 in the focus areas of the North Sea NATURA 2000 sites, number of sampled stations and sampling months, May and July.

Years and study areas	No. of Stations	Month
2020		
Sylt Outer Reef (SAR)	20	May
Borkum Reef Ground (BrG)	14	July
2021		
Dogger Bank (DgB)	20	May
Sylt Outer Reef (SAR)	20	May

Infauna sampling design

The three focus areas were sampled in 2020 and 2021 onboard the RV "Senckenberg" (Table 1). Samples were collected along station transects following gradients of decreasing MBF intensity affecting the subsurface sediment layer (subsur) (Fig. 1). In SAR, stations 5–8 along every transect were sampled in 2021, stations 9–12 in 2020. For infauna studies, two replicate samples were collected at each station with a 0.1 m^2 van Veen grab and sieved over 1 mm mesh size. All retained organisms were preserved on board in a 4% buffered formaldehyde sea water solution. Later in the laboratory, they were sorted and identified to the lowest possible taxonomic level using a stereomicroscope and microscope. The taxonomy was harmonised following the World Register of Marine Species (WoRMS 2023). Organisms of each taxon were counted and weighed with an analytical balance to estimate abundance and wet-weight (ww) biomass. Data from two replicates were averaged to estimate the mean abundance (Ind./ 0.1 m^2) and biomass (g ww/0.1 m^2) per station.

Environmental drivers

Available environmental drivers used were depth (m) and sediment composition (mud, sand, shell and gravel contents (%). For sediment analysis, a separate 0.1 m^2 van Veen grab was taken at each station. The samples were frozen at -20 °C. In the lab, the sediment samples were wet sieved. The mud content (<63 µm), sand content (>63 µm) and gravel and shell contents (%) (>2 mm) were determined. The water depth was recorded for each grab sample.

Mobile bottom-contact fishing (MBF) data

Data describing MBF intensity originated from ICES for 2009 to 2020 for the North Sea (ICES 2021a, 2021b). The intensity of the MBF was calculated based on the Vehicle Monitoring System (VMS) and linked logbook data submitted by EU member states to ICES and aggregated consistently across years and quarters for 2012–2016 for the North Sea. The data-set was used because of the small-scale resolution (1 × 1 nautical miles) of the MBF intensity in the small-scale focus areas. According to ICES definition, a value of subsur 1 implies that the sediment of the entire area was trawled once during this specific period with the subsurface penetration at depths ≥ 2 cm of gears such as beam trawls (Rijnsdorp et al. 2016; Hiddink et al. 2017, 2023; van der Reijden et al. 2018), which harms infauna communities.

Statistical community analysis

For the analyses of the spatial variability of the infauna community a cluster analysis with a similarity profile analysis (SIMPROF) and multidimensional scaling (MDS) was conducted for each NATURA 2000 site, based on a Bray-Curtis resemblance matrix of the square root transformed abundance data, using Primer v7 (Clarke and Warwick 2001). SIMPROF is a permutation test, analysing the statistical significance of groups. Characteristic taxa for each cluster per study area were identified by similarity percentage analysis (SIMPER). These clusters were confirmed with an Analysis of Similarities (ANOSIM) that is a permutation test, analysing the statistical significance of *a priori* divided clusters (Clarke and Warwick 2001). Boxplots (Frigge et al. 1989) were also created with Primer v7.

To test the relationships between the natural environmental variables (sediment composition and depth) and MBF intensity with the infauna community structure, a RELATE-analysis, based on a Bray-Curtis similarity matrix of the infauna data was conducted. Based on a significant RELATE-analysis, distance-based linear models (DistLM) were processed, based on the resemblance matrix. A step-wise procedure and the AIC (Akaike information criterion) as the evaluation measure was used to extract the natural environmental parameters and MBF, fitting significantly (Marginal Test: p-value < 0.05) with the infauna data of each focus area. To visualize the DistLM, a distance-based redundancy analysis (dbRDA) was carried out. The dbRDA is a multivariate multiple regression of a principal coordinates analysis on predictor variables that is used to find linear combinations of the predictor variables, which explain the greatest variation in the data set.

Results

Spatial variability of natural environmental drivers and MBF

The median depth (m) was about 30 m BrG and 43 m in SAR and DgB (Fig. 2F). The depth in SAR and BrG decreased from transect A to transect E, while in DgB, the depth decreased from west to east.

The median sand content reached 98% in BrG and DgB, 78% in SAR (Fig. 2A). It decreased from transect A to transect D in BrG, while it increased towards transects C and D at DgB. The median mud content was highest in SAR with about 17% distributed along all transects (Fig. 2C). Gravel was found in BrG only, with median content < 2% (Fig. 2B). The median shell content was highest (6%) in SAR, although in BrG also high contents were found (Fig. 2D). In DgB and BrG, the shell content decreased from transect A to transect D.

The median MBF intensity (subsur) was lowest in BrG (1) and highest in DgB (16) (Fig. 2E). It increased from west to east in the eastern part of SAR (station numbers 9 to 12) and from north to south in the western part along transects A to E, which showed the highest MBF (Fig. 1). In DgB, the MBF intensity increased from transect A towards transect D (Fig. 1).

Spatial variability of infauna communities

A total of 215 infauna taxa (mainly species) were identified in the three focus areas (Suppl. material 1). A minor percentage of them (25.58%) were found in

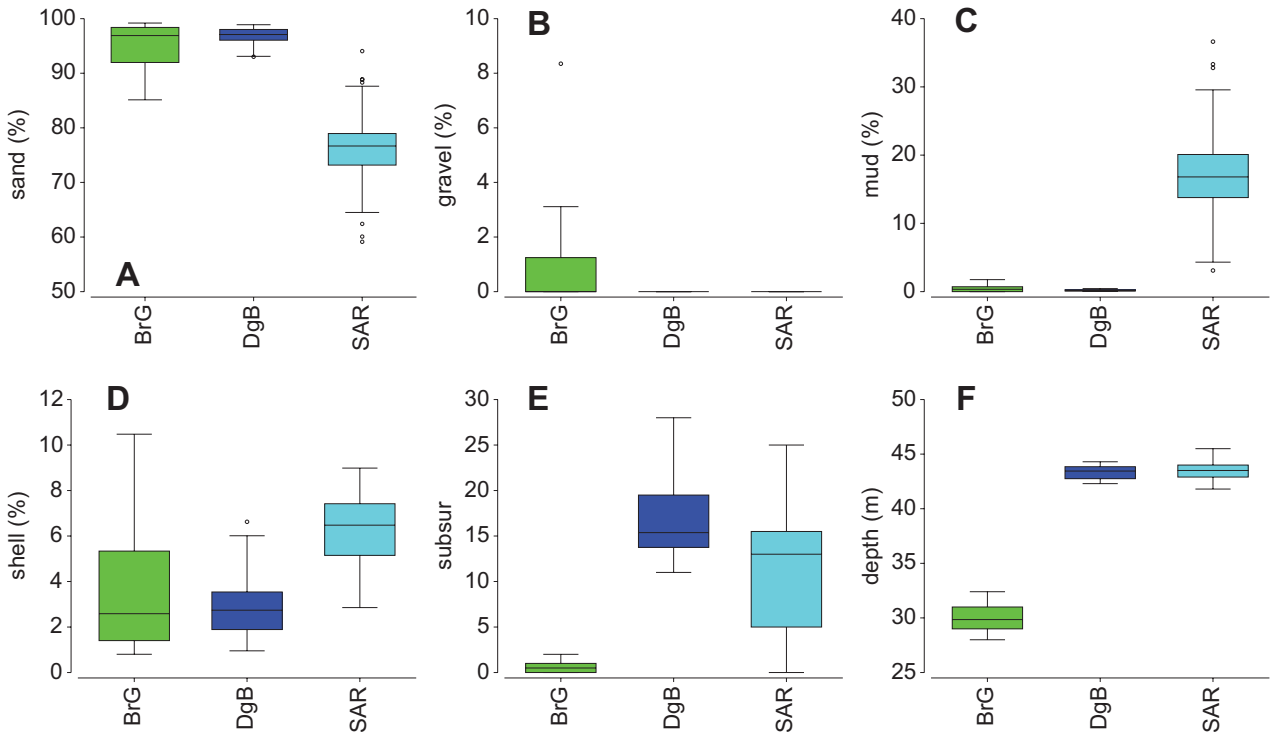

Figure 2. Box plots for sediment characteristics sand (%) (**A**), gravel (%) (**B**), mud (%) (**C**), shell (%) (**D**) contents, the mobile bottom-contact fishery intensity (subsur) (**E**) and depth (m) (**F**) in Borkum Reef Ground (BrG - green), Dogger Bank (DgB – dark blue) and Sylt Outer Reef (SAR – light blue).

all three areas, for example the bivalve *Abra alba*, the polychaete *Lagis koreni* and the amphipod *Tryphosa nana*. Most of the species (47.91%) were found in one of the three focus areas only; for example, the amphipod *Harpinia antennaria* was present only in SAR, the bivalve *Spisula elliptica* in BrG and the polychaete *Clymenura lankesteri* in DgB. Total infauna species number reached 106 taxa/0.1 m^2 in Brg, 94 in DgB, and 147 in SAR.

The median species number was highest in DgB, followed by BrG and SAR (Fig. 3A). In BrG, the mean species number per station increased from transect A (44 taxa/0.1 m^2) to transect D (38 taxa/0.1 m^2), while in DgB and SAR the mean species number decreased from transect A (44 or 41 taxa/0.1 m^2) to transects D (39 taxa/0.1 m^2) or E (32 taxa/0.1 m^2).

High median abundance was found at BrG (200 ind./0.1 m^2), low at SAR (100 ind./0.1 m^2) (Fig. 3B). In Brg and DgB, the mean abundance per station decreased from transect A (188 or 166 Ind./0.1 m^2) to transect D (135 or 109 Ind./0.1 m^2), while in SAR, the mean abundance increased along the transects from west (station 5, 44 ind./0.1 m^2) to east (station 12, 66 ind./0.1 m^2).

The median biomass was high in SAR and low in DgB (Fig. 3C). In DgB, the mean biomass per station (g ww/0.1 m^2) decreased from transect A (2.23 g ww/0.1 m^2) to transect D (1.11 g ww/0.1 m^2).

Multivariate infauna community analyses

Multidimensional Scaling results showed that on a large spatial scale the infauna communities of the three focus areas were significantly different on a 35% similarity level (ANOSIM R = 0.98; $p < 0.1$) (Fig. 4). The same analyses

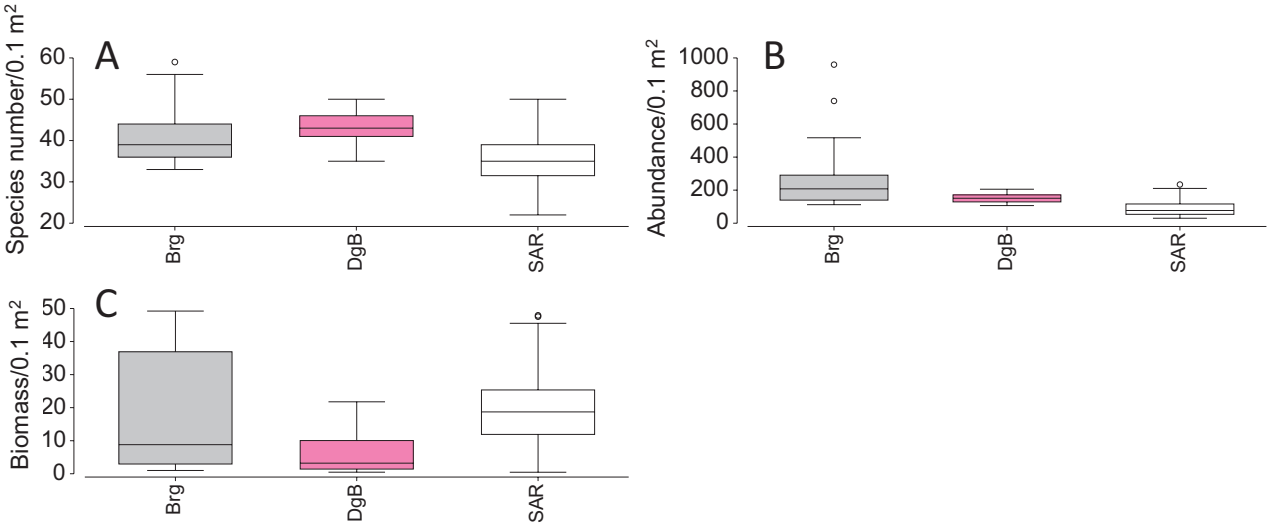

Figure 3. Box plots for species number /0.1 m² (**A**), abundance /0.1 m² (**B**) and biomass g wet weight/0.1 m² (**C**) in Borkum Reef Ground (BrG - grey), Dogger Bank (DgB - pink) and Sylt Outer Reef (SAR – white).

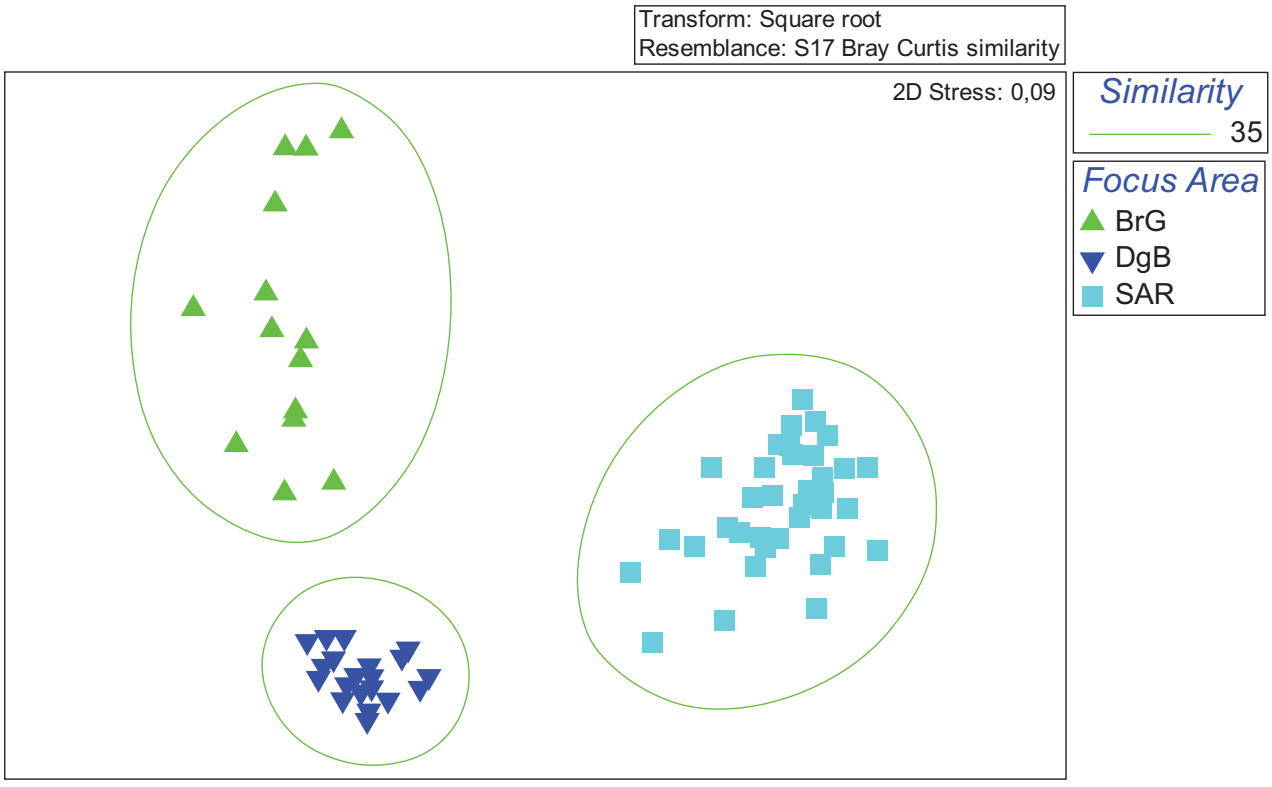

Figure 4. A. MDS plot for infauna communities in Borkum Reef Ground (BrG - green); **B.** Dogger Bank (DgB – dark blue) and **C.** Sylter Outer Reef (SAR – light blue) based on mean abundance/0.1 m². Green contour represents 35% similarity level.

were carried out for abundance data on spatial scale of the respective focus areas. The SIMPER results yielded two infauna communities significantly separated each for SAR, BrG and DgB (ANOSIM: R-value = 0.92, 0.5, 0.78; $p < 0.001$) (Table 2).

In BrG, high mean abundances of the acrania *Branchiostoma lanceolatum* and the polychaete *Lanice conchilega* were found in community 1. Commu-

Table 2. Contribution of characteristic taxa to the average similarity of infauna communities in the focus areas in Borkum Reef Ground (BrG), Dogger Bank (DgB) and Sylter Outer Reef (SAR).

Focus Area	Community 1 - Average similarity: 58.91			Community 2 - Average similarity: 57.03		
	Species	**Av. Abund**	**Cum (%)**	**Species**	**Av. Abund**	**Cum (%)**
BrG	*Branchiostoma lanceolatum*	10.34	15.93	*Spiophanes bombyx*	5.03	12.31
	Aonides paucibranchiata	8.66	27.96	Echinoidea spp.	5.75	23.86
	Lanice conchilega	10.01	36.91	*Lanice conchilega*	4.71	33.56
	Glycera alba	5.01	44.35	*Bathyporeia guilliamsoniana*	3.53	41.57
	Phyllodoce lineata	6.61	50.99	*Aonides paucibranchiata*	4.36	48.14
Focus area	Community 1 - Average similarity: 71.71			Community 2 - Average similarity: 70.72		
	Species	**Av. Abund**	**Cum (%)**	**Species**	**Av. Abund**	**Cum (%)**
DgB	*Spiophanes bombyx*	5.15	9.94	*Spiophanes bombyx*	4.05	9.07
	Amphiura filiformis	4.5	17.81	*Bathyporeia elegans*	3.61	17.11
	Bathyporeia guilliamsoniana	4.12	25.10	*Bathyporeia guilliamsoniana*	3.54	24.99
	Bathyporeia elegans	3.48	30.99	*Owenia fusiformis*	3.26	31.83
	Owenia fusiformis	3.01	36.49	*Echinocyamus pusillus*	2.96	38.29
Focus area	Community 1 - Average similarity: 55.28			Community 2 - Average similarity: 58.86		
	Species	**Av. Abund**	**Cum (%)**	**Species**	**Av. Abund**	**Cum (%)**
SAR	*Nucula nitidosa*	3.35	9.56	*Varicorbula gibba*	2.8	8.66
	Thyasira flexuosa	3.22	18.29	*Turritellinella tricarinata*	2.11	16.02
	Phoronis spp.	3.07	26.25	*Nucula nitidosa*	1.77	22.42
	Abra alba	2.98	32.04	*Thyasira flexuosa*	1.71	28.56
	Nephtys hombergii	1.92	37.33	*Echinocardium cordatum*	1.51	34.45

nity 2 was dominated by the polychaete *Spiophanes bombyx* and juvenile echinoids. At station D4, high abundance of the bivalve *Spisula elliptica* occurred (Table 2). In DgB, community 1 was dominated by the ophiuroid *Amphiura filiformis*, the polychaete *Spiophanes bombyx* and the amphipods *Bathyporeia elegans* and *B. guilliamsoniana*. Community 2 revealed high mean abundances of the echinoid *Echinocyamus pusillus*. In SAR, community 1 (eastern stations of the transects) was characterized by high mean abundances of the bivalves *Nucula nitidosa* and *Thyasira flexuosa* (Table 2). Community 2 was dominated by the bivalve *Varicorbula gibba* and the gastropod *Turritellinella tricarinata* (Table 2).

Relationship between infauna community structure, natural environmental drivers, and MBF

The cumulative DistLM revealed that the sand, mud, gravel and shell contents significantly correlated with the infauna community variation in BrG, DgB and SAR. The marginal test showed that in BrG, the cumulative sediment fractions accounted for 88.1% of the variation in the infauna community structure, 34.68% in DgB and 20.38% in SAR (Table 3). The MBF intensity explained 9% in BrG, 16% in DgB and 12.7% in SAR (Table 3).

The dbRDA showed that the 1st axes explained 70% of variation in BrG and DgB, 51% in SAR (Fig. 5). In SAR and DgB, the vector length for MBF intensity indicated the importance of the variable and MBF intensity (subsur) (r = 0.77 or -0.7), which correlated significantly with the 1st axis, followed by mud contents (r = 0.54 or 0.57). Stations with higher MBF intensity were plotted close to the vector for MBF intensity (Fig. 5).

Table 3. Results of the DistLM analyses for the BrG, DgB, and SAR areas. The marginal tests depict how much of the variation in the infauna community structure is explained by the different variables, when all other variables are ignored (proportion in %). Significant results ($p < 0.05$) are marked in bold.

MARGINAL TESTS	BrG			DgB			SAR		
	Pseudo-F	P	Prop. %	Pseudo-F	P	Prop. %	Pseudo-F	P	Prop. %
sand (%)	4.164	**0.003**	25.70	2.288	**0.011**	11.30	3.042	**0.002**	8.21
mud (%)	3.523	**0.008**	22.70	2.701	**0.002**	13.00	3.503	**0.004**	9.34
shell (%)	5.029	**0.001**	29.50	2.084	**0.02**	10.38	0.991	0.4	2.83
gravel (%)	1.358	0.208	10.20						
MBF (subsur)	1.190	0.275	9.00	3.449	**0.001**	16.08	4.941	**0.001**	12.69
depth (m)	1.763	0.119	12.80	0.716	0.761	3.82	2.938	**0.005**	8.80

Discussion

Our study revealed pronounced spatial variability in the infauna communities - observable at both large and small-scales - within the NATURA 2000 in the focus areas of the German EEZ. Notably, our analyses showed that sediment characteristics and MBF intensity had significant impact on communities' structure in the Dogger Bank (DgB) and Sylter Outer Reef (SAR).

Spatial variability of macrofauna communities and effects of natural environmental drivers and MBF

Our results confirm that the infauna communities within the three focus areas support a species inventory consistent with previous studies conducted in these regions as also found by Gutow et al. (2026). The infauna communities in SAR belong to the *Nucula nitidosa* community found by Salzwedel et al. (1985), Rachor and Nehmer (2003) and Kröncke et al. (2004), which was called Coast and River Elbe community by Meyer et al. (2018).

The BrG community belongs to the *Fabulina fabula* community (Salzwedel et al. 1985; Rachor and Nehmer 2003), which was called coastal community by Meyer et al. (2018). At the stations with gravel content the infauna community revealed high abundances of polychaetes such as *Lanice conchilega*, *Aonides paucibranchiata*, *Glycera alba*, and of the acrania *Branchiostoma lanceolatum* as also found by Dörjes (1977) and Meyer et al. (2018). Among the key novel results is the observation that the non-native polychaete *Loimia ramzega* (Lavesque et al. 2017) occurred in high abundance in this area. The DgB *Bathyporeia* community was found to be similar to earlier studies by Kröncke (2011) and Meyer et al. (2018).

In addition to the natural environmental drivers and MBF considered in this study, the spatial extent of the DgB, SAR and BrG communities is determined by other variables such as TOC, chlorophyll content in sediments, stratification, currents and tidal stress according to earlier studies by Heip et al. (1992), Reiss et al. (2009), and Meyer et al. (2018).

In our study, a clear spatial gradient emerged: infauna abundance peaked in the nearshore BrG and decreased with distance offshore towards SAR and DgB. Yet, species richness showed the reverse relationship. Such inverse patterns between abundance and species numbers were documented for North Sea for infauna communities by Heip and Craeymeersch (1995), Meyer et al. (2018).

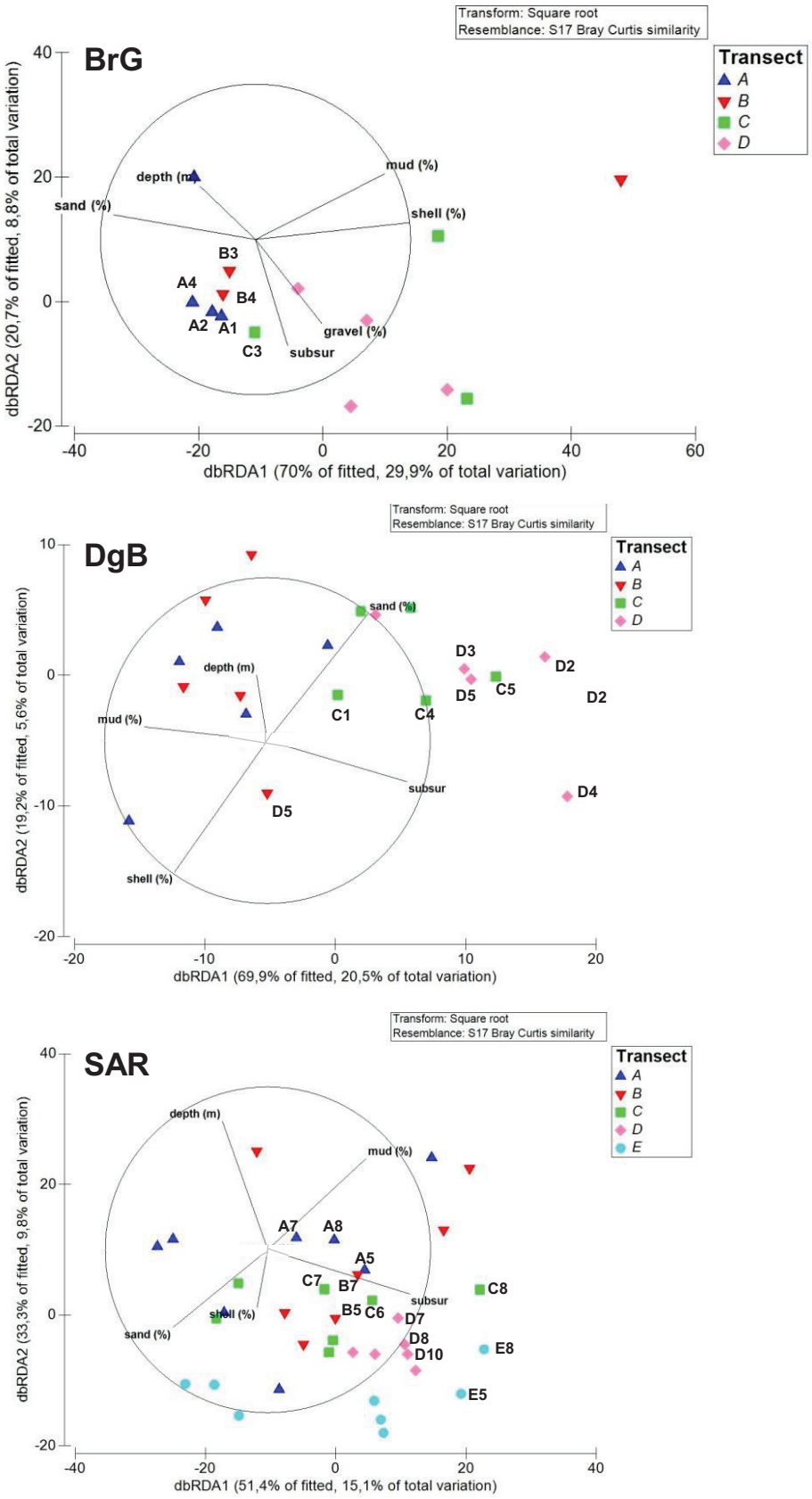

Figure 5. Mean infauna abundance based dbRDA-analyses results for Borkum Reef Ground (BrG) (**A**), Dogger Bank (DgB) (**B**) and Sylter Outer Reef (SAR) (**C**). The ordination of the stations along the sediment composition (sand fraction < 2 mm > 0.063 mm, mud fraction < 0.063 mm), depth (m) and the mobile bottom-contact fishery intensity MBF (subsur) depend on significance marginal tests (p-value < 0.05). Stations with high MBF intensity (Fig. 1) are indicated.

On smaller spatial scale, the distribution of infauna species and communities is often significantly correlated to the sediment characteristics, similar to what was found in previous studies (Wieking and Kröncke 2003; Reiss et al. 2010).

In addition to natural environmental drivers (Kröncke et al. 2011) infauna communities of the North Sea have been disturbed by MBF for decades (Hiddink et al. 2017; Mazor et al. 2021), suggesting that many infauna communities have already adapted to a certain degree of MBF disturbance (Hiddink et al. 2018; Kraan et al. 2024). The response of a benthic community to MBF will also depend on the degree of natural disturbance of the habitat (van Denderen et al. 2015; van der Reijden et al. 2018). Is the natural disturbance high due to currents, waves or storms, the infauna species are adapted to this natural variability. Therefore, changes in response to trawling seem to be smaller or undetectable in communities exposed to high natural disturbance (van Denderen et al. 2015) as observed in our study. This makes it difficult to disentangle natural environmental drivers and MBF effects on infauna communities. In a recent model approach Kraan et al. (2024) showed that the impact of MGF was of limited importance in driving epifauna and demersal fish community patterns. They discussed the dependency of scale, data resolution and number of environmental drivers included in the analyses to be responsible for under- or overestimation of MGF assessments as also stated by Amoroso et al. (2018).

Regarding scale, our DistLM and dbRDA analyses on small spatial scale revealed a key result regarding the significant correlation of MBF intensity with the DgB and SAR infauna communities along gradients of decreasing MBF intensity. In these areas, significant differences in MBF intensity occurred, which caused significant effects on the variation of the infauna abundance and community structure. An additional hint for continuous MBF disturbance of the infauna communities was the high abundance of opportunistic, small bodied, r-strategic species in the respective infauna communities (Queirós et al. 2006; Kröncke 2011).

How will the BrG, DgB and SAR infauna communities change after MBF exclusion?

In general, all North Sea infauna communities will benefit from the decreasing MBF intensity since the 1990s (Couce et al. 2020; STECF 2020). MBF cessation will also support the infauna communities in the NATURA 2000 sites to recover from this disturbance as found already for infauna communities in a protected area in the Kattegat (Sköld et al. 2025) and for epifauna communities at SAR (Hahn et al. 2025). Parts of the SAR and the BrG have been closed since March 2023 for commercial and scientific MBF and parts of DgB since November 2025 (EC 2022). It is important to note that other human activities such as shipping, pelagic fishing and pollution will continue within the MPAs and may hinder conservation measures. With the MBF ban having been in effect in parts of these areas since 2023, this baseline study now provides an essential reference against which future recovery of infauna communities can be evaluated. Long-term studies or monitoring over several years to decades will be carried out in the MPAs by the German Federal Agency for Nature Conservation. They are indispensable for tracking patterns of change and assessing responses

across human activities such as MBF and to create a continuous database as available for the protected area in the Kattegat (Sköld et al. 2025). Long-term studies are the basis to understand ecosystem changes, to develop appropriate protection measures for benthic communities and their habitats (Birchenough et al. 2026). They will also enable us to potentially adjust management plans in well-managed MPAs, which could be the key for ecosystem recovery from damages that occurred in the past.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Artificial Intelligence (AI) use

The authors accept full responsibility for the content of the manuscript, including the disclosure of any use of AI.
No AI tools were used in the preparation of this manuscript.

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Author contributions

Ramona Ohde: Sampling, Sample treatment, Data analysis, Writing - Original draft. Ingrid Kröncke: Conceptualization, Methodology, Data analysis, Data curation, Writing - Original draft and Review, Supervision, Project administration, Funding acquisition.

Author ORCIDs

I. Kröncke https://orcid.org/0000-0002-9839-0056

Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

Supplementary material 1

Infauna taxa found during the present study in North Sea NATURA 2000 sites Borkum Reef Ground (BrG), Dogger Bank (DgB) and Sylt Outer Reef (SAR)

Authors: Ramona Ohde, Ingrid Kröncke

Data type: docx

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