

CHAPTER 2

DESCRIBING THE EPIBENTHOS AND DEMERSAL FISH COMMUNITIES IN THE BELGIAN PART OF THE NORTH SEA IN VIEW OF FUTURE OFFSHORE WIND FARM MONITORING

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Abstract

Future epibenthos and demersal fish monitoring of potential ‘spillover’ effects of the fully operational 238 km² Belgian offshore wind farm (OWF) area together with future evaluation of the potential effects of the newly designated Princess Elisabeth area for renewable energy requires sound knowledge on the epibenthos and demersal fish communities of the BPNS. To this end, a community analysis on epibenthos and demersal fish abundance data (2008-2020), covering 540 beam trawl sampling events in autumn spread over 83 locations on the BPNS, was performed.

Both epibenthos and fish communities largely follow similar spatial distribution patterns with a clear distinction between the coastal and the offshore area. Within the coastal area, we distinguish a mud community occurring in the muddy sediments near the eastern part of the coast which is dominated by brown shrimp *Crangon crangon* and gobies *Pomatoschistus* spp., for resp. epibenthos and fish. The fine sand community is correlated

with the fine sandy sediments in the coastal area and is highly dominated by resp. the serpent star *Ophiura ophiura* and dab *Limanda limanda*. Distinction between the different offshore communities seems to be structured by sand bank topography. For both epibenthos and fish, a widespread offshore coarse sand community is observed with *Spisula solida*, *Spisula elliptica*, *Liocarcinus marmoreus* and squid species *Loligo vulgaris* and *Sepioloatlantica* as typical epibenthic species. For fish, this community is dominated by lesser weever *Echiichthys vipera*, with solenette *Buglossidium luteum*, scaldfish *Arnoglossus laterna*, red mullet *Mullus surmuletus* and reticulated dragonet *Callionymus reticulata* as additional characteristic fish species. For both epibenthos and fish, a species-poor version of this community occurs on top of the steep sand banks dominated by *Pagurus bernhardus* for epibenthos and dominated completely by lesser weever for fish. For fish, a clear third transitional community could be discerned around the 12 NM consisting of a mixture of coastal and offshore species making this the most diverse community.

The current operational Belgian OWF area largely overlaps with the spatial distribution of the offshore epibenthos and fish communities. Locations inside the OWF concessions cluster nicely together with all non-concession locations confirming the conclusion from previous studies that epibenthos and fish assemblages on the soft sediments in between the turbines underwent no drastic changes. For studying potential future spillover effects, the offshore coarse sand community locations are the best candidates to be included in a gradient design.

For the newly designated Princess Elisabeth area, data on soft sediment communities is scarce with regard to the current beam trawl sampling locations. The wider surroundings suggest that for the sandy areas the coarse sand community is to be expected within the south-western zone. However, the topography of this area is very heterogeneous with steep sandbanks, and gravel beds occurring in between these sand banks, so a thorough before-impact monitoring will be essential to enable assessing the future OWF effects on epibenthos and fish. Here as well, inclusion of a gradient design is preferred and the outcomes of the community analyses will help in defining the best possible reference locations.

1. Introduction

The Belgian OWF area in the eastern part of the Belgian Part of the North Sea (BPNS) is fully operational since the end of 2020, making this a contiguous zone of 238 km² with an installed capacity of 2.26 GW renewable energy (Rumes & Brabant 2021). All fishery activities are excluded in the OWFs. Up till now, effects on soft sediment epibenthos and demersal fish have been focused on the two oldest wind farms C-Power and Belwind (De Backer & Hostens 2018a; De Backer *et al.* 2020). The BACI design, with ‘impact’ and ‘near control’ beam trawl samples, was mainly focussed on potential changes in the OWF compared to the surrounding sandy environment outside the concession areas.

Now that all concessions are combined in one large contiguous OWF area, we expect that the fisheries exclusion or ‘refugium’ effect (Handley *et al.* 2014) might become more prominent and lead to ‘spillover’ or fringe effects (export of biomass to surrounding habitats by recruitment or migration out of the area). To capture these potential refugium and ‘spillover’ effects, the sampling design need to be changed towards a gradient design, including sample locations within and at different distances from the OWF area. In that respect, it is key to delineate distinct epibenthos and demersal fish communities within the BPNS, to ensure that gradient sampling locations are situated within similar communities, allowing for a proper comparison.

Macrobenthos communities are already well described for the BPNS (Van Hoey *et al.* 2004; Breine *et al.* 2018), but for epibenthos and demersal fish such well-defined communities based on high resolution sampling are still to be described. Moreover, the Belgian federal government has delineated a second area of 285 km² for renewable energy (i.e. the Princess Elisabeth area) located at 35-40 km offshore in the northwestern part of the BPNS (Rumes & Brabant 2021). This created a second reason for a thorough analysis and description of the epibenthos and demersal fish communities in the BPNS, allowing for a good monitoring design from the start.

As such, the main objective of this study was to perform a community analysis on mid-term epibenthos and demersal fish data of the BPNS, to be able to determine a proper gradient design to investigate ‘spillover’ effects in the first Belgian OWF area, and to propose a future environmental monitoring design for the Princess Elisabeth Zone (PEZ).

2. Material and methods

2.1. Study area

The BPNS is situated in the southern part of the North Sea and only covers 0.5 %

(3,454 km²) of the North Sea basin. It is a shallow sea with an average water depth of 20 m and a maximum depth of 46 m and it is characterized by numerous sand bank systems: (1) Coastal Banks, parallel to the coastline, (2) Flemish Banks, about 10-30 km offshore of the western Belgian coast, (3) Zeeland Banks, some 15-30 km offshore of the eastern Belgian coast, and (4) Hinderbanks, about 35-60 km offshore (Van Hoey *et al.* 2004). Due to the presence of these sandbanks, a highly variable and complex topography is observed and sedimentological diversity is high as well. Fine sand occurs along the coastline, high mud content near the mouth of the river Scheldt in the eastern part of the BPNS, while further offshore, grain size increases to medium and coarse sand (Verfaillie *et al.* 2006) (Figure 1). Moreover, subtidal natural hard substrates, i.e. gravel beds occur in the area as well in between the sandbanks (Van Lancker *et al.* 2007; Montereale-Gavazzi *et al.* 2021).

For the sandbank habitat, five distinct macrobenthic assemblages have been described that are strongly related to sediment type and bottom topography (Van Hoey *et al.* 2004; Degraer *et al.* 2008; Breine *et al.* 2018). Three are situated within the coastal area: the *Macoma balthica* community occurring in the muddy sediments at the east coast, the *Abra alba* community associated with fine coastal sediments and the *Magelona - Ensis leei* community in the shallow, nearshore area. Offshore, two communities are present: the *Nephtys cirrosa* community, occurring in medium sands, and the *Hesionura elongata* community typical for coarser sands.

The gravel beds are suitable for an array of species that cannot occur in soft-bottom habitats (Houziaux *et al.* 2008). They naturally host rich macro- and epibenthos communities that include sessile and/or long-lived species (i.e. >5 yrs) (e.g. *Pomatoceros triqeter*, *Sabellaria spinulosa*, *Haliclona oculata*, *Flustra foliacea*, *Alcyonium digitatum*, *Sertularia cupressina*, *Ostrea edulis*, *Buccinum undatum*) (Houziaux *et al.* 2008). Therefore, gravel beds are very

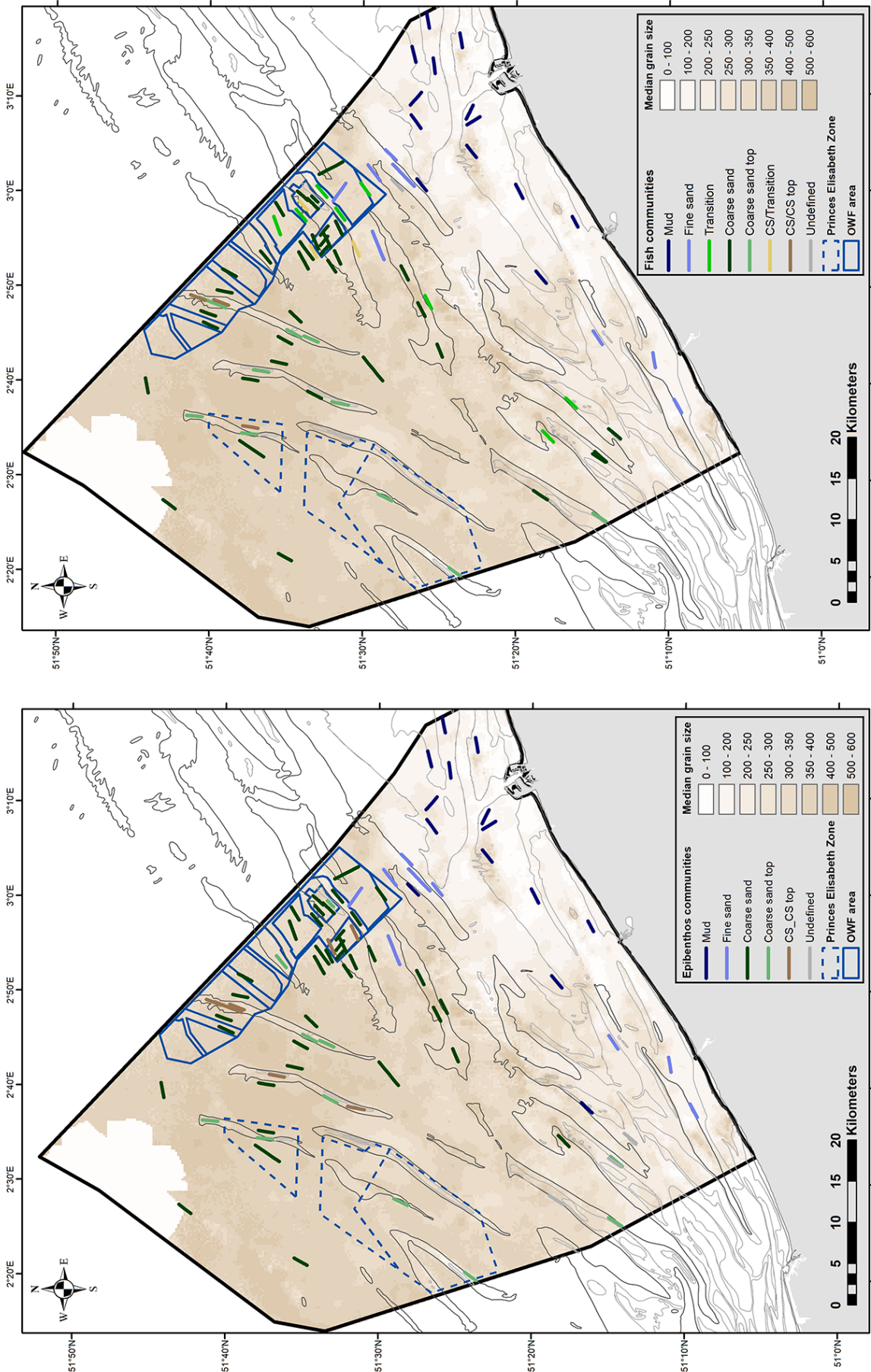
valuable habitats and hotspots of biodiversity, but they are highly pressurized and mostly in a deteriorated state putting them high on the agenda for conservation and restoration measures.

2.2. Sampling and biological data

A dataset was compiled with beam trawl samples (540 in total) that were collected in the BPNS in autumn over the period 2008-2020. Samples were collected in the framework of the ILVO long-term environmental impact monitoring programs in relation to different human activities. Samples with a direct impact of dredge disposal and sand extraction were excluded, while samples taken in the framework of the offshore wind farm (WinMon.BE) monitoring program (both impact and control) have been included, since the aim of the analyses was to find suitable reference locations at a gradient from the wind farms. In total, 540 sampling events at 83 locations (Figure 1) have been included in the dataset.

On these locations, demersal fish fauna and epibenthos were sampled with an 8-meter shrimp beam trawl (22 mm mesh in the cod end) equipped with a bolder-chain. Till 2009, the net was towed for a total of 30 minutes at an average speed of 4 knots over the bottom along with the current (approx. 2 NM). From 2010 onwards, tow duration was reduced to 15 minutes (approx. 1 NM). A comparative field study revealed no difference in catch composition for the different tow durations (Derweduwen *et al.* 2010). Data on time, start and stop coordinates, trajectory and sampling depth were recorded to enable a correct conversion towards sampled surface units. Epibenthos and fish were identified to the lowest possible taxonomic level, mostly species level, counted, measured (all fish, crabs and shrimps) and wet weighted (all epibenthos) onboard. Some epibenthos samples that could not be fully processed onboard, were frozen and further processed in the lab.

Figure 1. Overview map with beam trawl sampling locations on top of the median grain size map with indication of the epibenthic (left) and fish (right) community to which they belong (see further). Grey lines are locations which could not be properly assigned to one of the communities. Depth contours provided are 10 m (light grey) and 20 m (dark grey).



Count and wet weight data were converted to densities/wet weight based on the trawled surface area for standardization to individuals per 1000m² or gWW per 1000 m². Pelagic species (based on www.fishbase.org) such as *Sprattus sprattus*, *Trachurus trachurus*, *Scomber scombrus*, along with jellyfish, certain benthic bivalves (such as *Abra alba*) and polychaetes were excluded from the analyses, since these are not quantitatively sampled with a beam trawl. Given that data was gathered over different monitoring programs, and by different persons over different years, species difficult to identify (e.g. *Pomatoschistus* spp., *Macropodia* spp.) were lumped at a higher taxonomic level to exclude taxonomic errors. Because of much higher abundances of epibenthos compared to fish (sometimes up to 100 × higher densities), the dataset was split in two, i.e. epibenthos and demersal and benthic-pelagic fish, further referred to as fish. In this way, fish patterns are not blurred by the dominance of certain epibenthos species.

2.3. Data analysis

All data analyses were performed in Primer version 7 with PERMANOVA add-on software (Clarke & Gorley 2015; Anderson *et al.* 2008). The analyses were done for each ecosystem component (i.e. epibenthos and fish) separately.

For each ecosystem component, two different datasets were used for two types of analyses, i.e. (1) identification of the different communities, and (2) structural characterization of the communities. To identify the different epibenthos and fish communities in the BPNS, a dataset containing resp. 35 and 37 taxa was used, excluding taxa occurring in less than 3% of the sampling events to rule out the influence of different sampling effort in a specific community (a higher sampling effort enhances the chance of finding rare species). Cluster analyses was performed to identify the epibenthos and fish communities, based on a Bray Curtis resemblance matrix after resp. fourth-root

and square-root transformation of species densities. The choice of transformation was aided by visualising the data matrix through shade plots (Clarke & Gorley 2015). Since certain epibenthos taxa (e.g. *Ophiura* spp.) tend to dominate in huge numbers, we opted for fourth-root, while for fish this is less the case and a square root transformation was sufficient. Cluster groups were visualised using non-parametric Multidimensional Scaling Ordination (nMDS). A similarity Percentages (SIMPER) routine with a cut-off level of 90% was applied to identify the species that contributed most to the within-group similarity of the cluster groups (i.e. the communities). Furthermore, shade plots have been used to visualise species occurrence in the different cluster groups by ordering samples per cluster group and by clustering species which tend to have similar patterns of abundance across the samples (Clarke & Gorley 2015).

Distribution of the cluster groups over the BPNS was visualised using ArcMAP 10.4. Each sampling location was attributed to a cluster group if it clustered for the majority of the sampling events in the same group. Otherwise, a sampling location was attributed to a transition group if it switched between two cluster groups, or it remained undefined if it switched between more than 2 groups.

In the second analysis, the identified communities were characterised by means of structural variables using the DIVERSE module (density, biomass for epibenthos, number of taxa (S), Margalef's diversity (d), Shannon index ($H'(\log_e)$) and Simpson index ($1-\lambda$)). For these analyses, the entire datasets, containing resp. 50 and 51 taxa, were used, with density and biomass standardised to 1000 m². To test for significant differences in these variables between cluster groups, a univariate one-way Permanova based on the Euclidean distance resemblance matrix (with unrestricted permutation of raw data) was performed (Anderson & Robinson 2003), followed by pairwise tests to situate the differences between cluster groups.

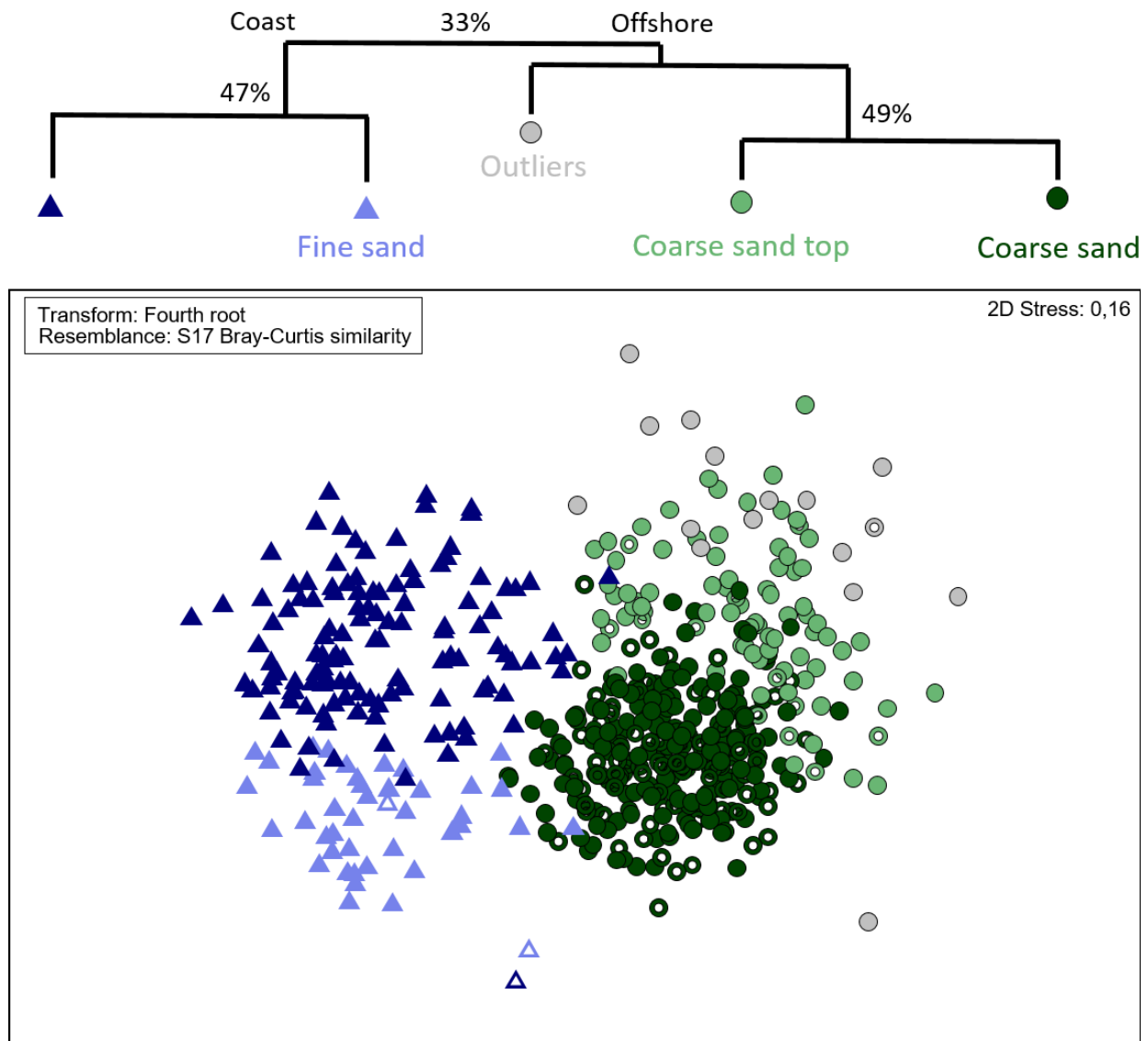


Figure 2. Top: simplified representation of cluster analysis on fourth root transformed species abundance data for epibenthos, only representing the position of the main groups and with indication of split-off similarity level. Below: nMDS ordination. Every point represents a sampling event assigned to a certain community based on the cluster analysis, open symbols represent sampling events within OWFs.

3. Results

3.1. Epibenthos

3.1.1. Communities and spatial distribution

The cluster analyses showed a first separation in two broad clusters at the 33% similarity level, i.e. a coastal and an offshore cluster (Figure 2). Further split off at the 49% similarity level identified four main groups, i.e. two within the coastal cluster and two within the offshore cluster, which have been included in further analyses (Figure 2). In total,

16 samples (all situated offshore) could not be assigned to one of the four main clusters, as they split off at a lower similarity level. The four main cluster groups were defined as the Mud (57% avg. within-group similarity), Fine sand (60% avg. w/i-group sim.), Coarse sand (61% avg. w/i-group sim.) and Coarse sand-top (54% avg. w/i-group sim.) communities, based on the habitat/sediment type of the area where they are located, sometimes in combination with the position on the sand bank.

Table 1. Characterization of the epibenthic communities by indication of the average ‘within-group’ similarity (SIMPER); species listed account for 90% of cumulative contribution of the ‘within group’ similarity (in % and average abundance (N, ind 1000 m⁻²)), the average (\pm SD) for a number of univariate parameters is provided per community.

Assemblage	Mud	Fine sand				Coarse sand				Coarse sand top			
W/i group similarity	57%	60%				61%				54%			
	Species	%	N	Species	%	N	Species	%	N	Species	%	N	
	<i>Crangon crangon</i>	33.1	488	<i>Ophiura ophiura</i>	24.1	1402	<i>Pagurus bernhardus</i>	15.2	5.8	<i>Pagurus bernhardus</i>	25.2	2.07	
	<i>Ophiura ophiura</i>	22.8	200	<i>Crangon crangon</i>	10.8	109	<i>Ophiura albida</i>	12.5	4.4	<i>Asterias rubens</i>	13.9	0.47	
	<i>Liocarcinus holtsatus</i>	17.1	39	<i>Asterias rubens</i>	10.3	93	<i>Asterias rubens</i>	11.4	2.8	<i>Loliginidae juv</i>	13.8	0.50	
	<i>Pagurus bernhardus</i>	7.4	2.3	<i>Liocarcinus holtsatus</i>	9.9	52	<i>Ophiura ophiura</i>	10.3	2.4	<i>Ophiura ophiura</i>	13.2	0.32	
	<i>Asterias rubens</i>	5.9	2.1	<i>Ophiura albida</i>	7.8	40	<i>Liocarcinus holtsatus</i>	7	0.6	<i>Liocarcinus holtsatus</i>	8.1	0.10	
	<i>Anthozoa</i> spp.	2.5	0.3	<i>Pagurus bernhardus</i>	7.7	15	<i>Spisula solida</i>	5.8	0.4	<i>Sepioida atlantica</i>	4.9	0.02	
	<i>Tritia reticulata</i>	2.3	0.4	<i>Tritia reticulata</i>	5.6	12	<i>Spisula elliptica</i>	4.3	0.2	<i>Macropodia</i> spp.	3.5	0.01	
				<i>Crepidula fornicata</i>	4.1	10	<i>Macropodia</i> spp.	4.3	0.1	<i>Ophiura albida</i>	3.1	0.03	
				<i>Liocarcinus navigator</i>	3.8	3	<i>Loliginidae juv</i>	4	0.2	<i>Loligo vulgaris</i>	2.4	0.01	
				<i>Liocarcinus depurator</i>	3	1.2	<i>Liocarcinus marmoreus</i>	3.6	0.1	<i>Crangon crangon</i>	2.1	0.03	
				<i>Macropodia</i> spp.	2.9	1.3	<i>Sepioida atlantica</i>	3.4	0.1				
							<i>Loligo vulgaris</i>	3.4	0.1				
							<i>Psammechinus miliaris</i>	3.1	0.1				
							<i>Anthozoa</i> spp.	2.8	0.1				
# samples	44		121		272		87						
N (ind/1000 m²)	1776.3 ± 2533.3		3732 ± 3007		47.2 ± 76.8		11.5 ± 14.6						
Biomass (g/1000m²)	2652.2 ± 2933.9		6860.6 ± 5244.9		156.8 ± 172.7		43.6 ± 60.6						
S	10.1 ± 3.3		14.4 ± 2.8		15.3 ± 2.9		9.8 ± 2.1						
Margalev's diversity	1.4 ± 0.7		1.8 ± 0.5		4.4 ± 1.1		5.2 ± 2.9						
Shannon diversity	0.9 ± 0.4		1.1 ± 0.4		1.8 ±0.3		1.5 ± 0.3						
Simpson diversity	0.4 ± 0.2		0.5 ± 0.2		0.8 ± 0.1		0.9 ± 0.4						

Regarding the coastal communities, the Mud community is mainly restricted to the nearshore eastern part of the coast, while the Fine sand community has a broader onshore distribution, close to the shoreline in the west and a bit further away in the east (Figure 1). Most offshore samples ($\pm 75\%$) were assigned to the Coarse sand community and are widely distributed offshore. Most locations within the OWF area do belong to this community. The offshore Coarse sand top community is mainly restricted to the top of the offshore steeper sand banks (Figure 1). The outliers are also most related to this group (Figure 2).

Overall, structural characteristics differed significantly among the four communities (one-way Permanova, for all main tests $p=0.0001$). Although, number of species did

not differ between Mud and Coarse sand top and not between Fine sand and Coarse sand (resp. $p=0.47$ and $p=0.09$). Simpson index was not different (both low values) between the coastal communities Mud and Fine sand ($p=0.18$), indicating high dominance of a few species. Density and biomass were at least an order of magnitude higher in the coastal communities compared to the offshore communities, whereas diversity measures (Margalev's, Shannon and Simpson) were higher in the offshore communities. (Table 1).

3.1.2. Community characteristics

Based on the shade plot (Figure 3), it is clear that six species (*Asterias rubens*, *Pagurus bernhardus*, *Ophiura albida*, *Liocarcinus*

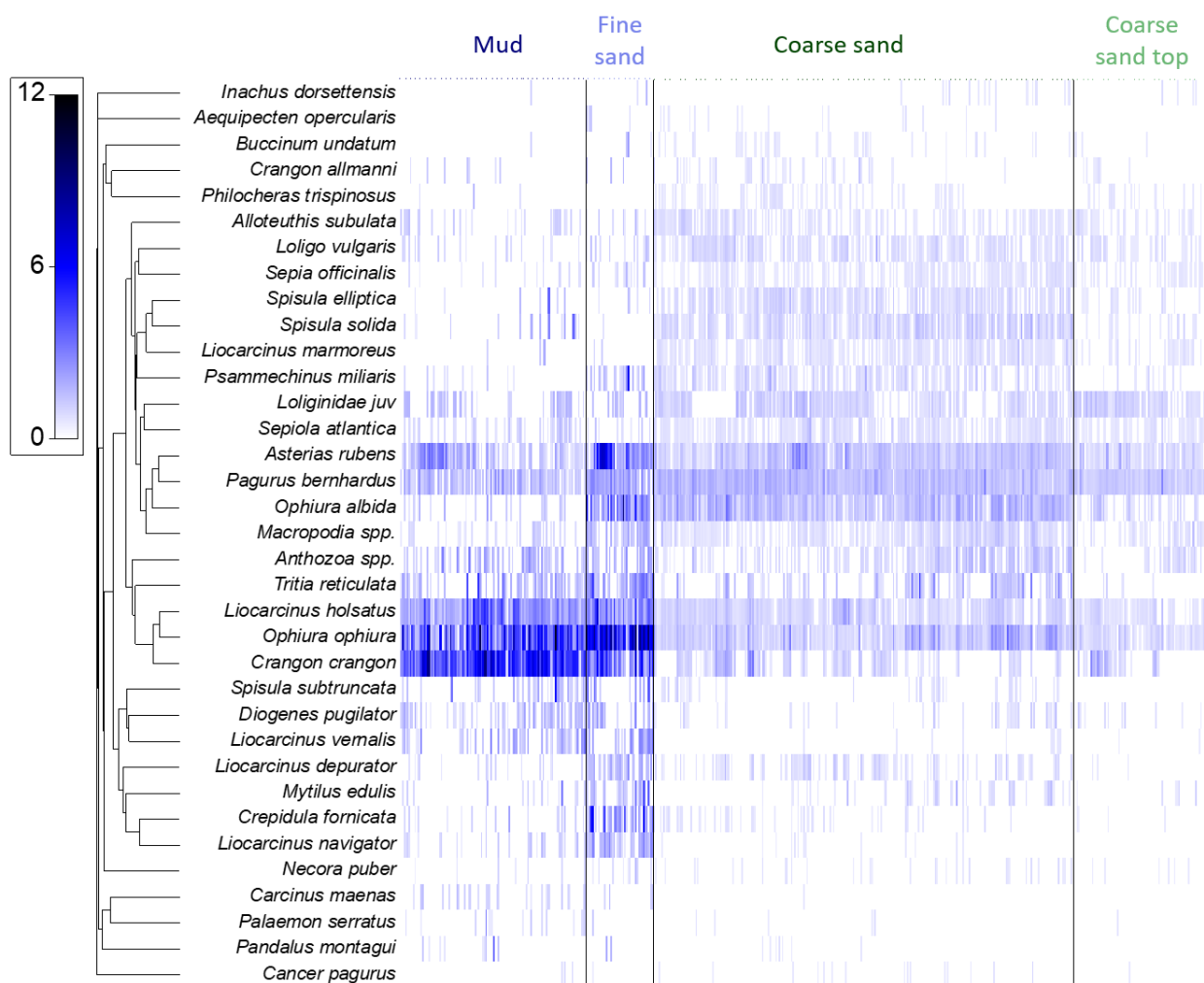


Figure 3. Shade plot showing averaged, fourth-root transformed abundance (ind. 1000 m⁻²) of the main epibenthos species in the delineated epibenthic communities.

holsatus, *Ophiura ophiura* and *Crangon crangon*) occur commonly on the BPNS across all communities, but at much lower abundances offshore compared to coastal. Seven other species are more common in the coastal communities (*Spisula subtruncata*, *Diogenes pugilator*, *Liocarcinus vernalis*, *Liocarcinus navigator*, *Liocarcinus depurator*, *Mytilus edulis* and *Crepidula fornicata*) albeit with different abundances in both coastal communities. Another nine species (*Alloteuthis subulata*, *Loligo vulgaris*, *Sepia officinalis*, *Spisula elliptica*, *Spisula solida*, *Liocarcinus marmoreus*, *Psammechinus miliaris*, *Loliginidae* juv. and *Sepiola atlantica*) are generally more common and abundant in the offshore communities (Figure 3).

3.1.2.1. Coastal communities

Mud

This community is mainly dominated by the brown shrimp *C. crangon* (33% contribution to within-group similarity), followed by *O. ophiura* (23%) and *L. holsatus* (17%) (Table 1 and Figure 3). It is characterized by high densities ($N=1776\pm2533$ ind. 1000 m⁻²) and biomass (2652 ± 2934 g 1000 m⁻²) and a low number of species (10 ± 3 , $d=1.4\pm0.7$). Diversity measures Simpson (0.4 ± 0.2) and Shannon (0.9 ± 0.4) are very low compared to the other communities.

Fine sand

This community is dominated by the serpent star *O. ophiura* (24% contribution to within-group similarity), followed by *C. crangon*, *Asterias rubens* and *L. holsatus* (each 10 %). Other characteristic species are *Tritia reticulata* (6 %) and *Crepidula fornicata* (4 %) (Table 1; Figure 3). Density ($N=3732\pm3007$ ind. 1000 m⁻²) and biomass (6861 ± 5245) are very high, while species richness is average ($S=14\pm3$, $d=1.8\pm0.5$). Shannon (1.1 ± 0.4) and Simpson (0.5 ± 0.2) diversity are again low compared to both offshore communities.

3.1.2.2. Offshore communities

Coarse sand

This community is not dominated by a single species, but characterized by a more or less equal contribution to within-group similarity of *P. bernhardus* (15%), *O. albida* (13%), *A. rubens* (11%) and *O. ophiura* (10%). Other typical species/taxa are *S. solida* (6%) and *S. elliptica* (4%), *Macropodia* spp. (4%) and representatives of the squid family i.e. *Sepiola atlantica* (3%), *Loligo vulgaris* (3%) and juvenile squids *Loliginidae* juv. (4%) (Table 1; Figure 3). Density (47 ± 77 ind. 1000 m⁻²) and biomass (157 ± 173 g 1000 m⁻²) are very low compared to the coastal communities but still three times higher compared to the offshore Coarse sand top community (Table 1). Species richness on the other hand is higher compared to the coastal communities ($S=15\pm3$, $d=4\pm1$) as are the diversity measures Shannon (1.8 ± 0.3) and Simpson (0.8 ± 0.1).

Coarse sand top

The common hermit crab *P. bernhardus* (25% contribution to within-group similarity) dominates this community, followed by *A. rubens* (14%), *Loliginidae* juv. (14%) and *O. ophiura* (13%). It has the lowest density (11 ± 15 ind. 1000 m⁻²) and biomass (44 ± 61 g 1000 m⁻²) amongst all communities. Number of species is low (10 ± 2), while Margalef's diversity, which takes into account the number of individuals, is highest across communities (5 ± 3). Diversity measures Shannon (1.5 ± 0.3) and Simpson (0.9 ± 0.4) are higher than for both coastal communities, while comparable with the offshore Coarse sand community.

3.2. Fish

3.2.1. Fish communities and spatial distribution

At the 27% similarity level, hierarchical cluster analysis on fish abundance data identified a coastal and an offshore group (Figure 4). Within the coastal cluster, a further subdivision at the 42% similarity level discerned a 'mud' (60% avg. w/i-group

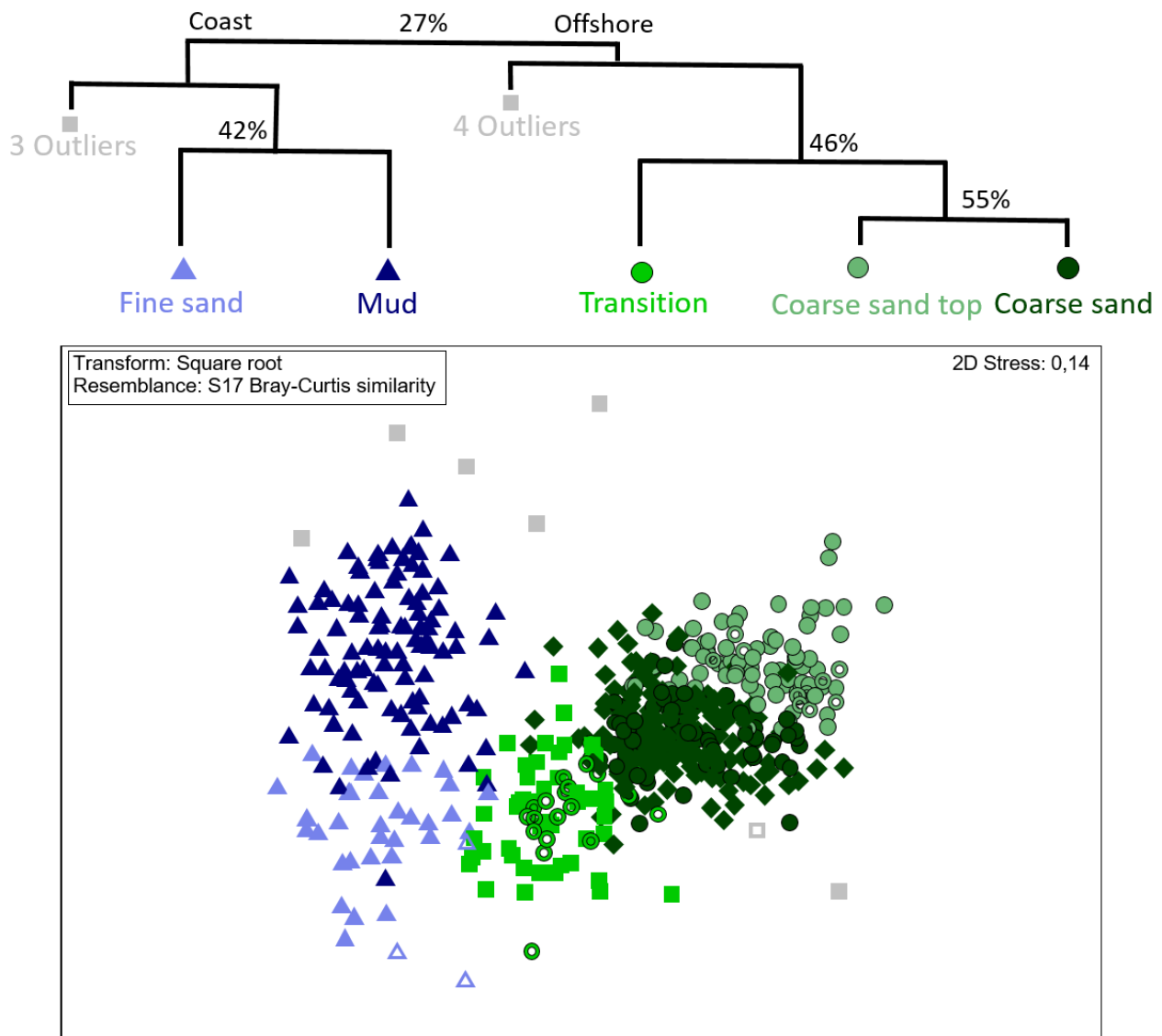


Figure 4. Top: simplified representation of cluster analysis on square root transformed species abundance data for fish, only representing the position of the main groups and with indication of split-off similarity level. Below: nMDS ordination. Every point represents a sampling event assigned to a certain community based on the cluster analysis, open symbols represent sampling events within OWFs.

sim.) and a ‘fine sand’ (61% avg. w/i-group sim.) community. Within the offshore cluster, three cluster groups could be distinguished: a ‘coarse sand’ (64% avg. w/i-group sim.) and ‘coarse sand top’ (67% avg. w/i-group sim.) community at the 55% similarity level, and a ‘transition’ community (63% avg. w/i-group sim.) splitting off at the 46% similarity level (Figure 4). Only 7 samples could not be assigned to one of the five clusters and were omitted from all further analyses.

The mud community is mainly restricted to locations near the eastern part of the coast, while the fine sand community has a wider onshore distribution (Figure 1). Within the offshore cluster, most locations (around 37) belong to the coarse sand community, which has a very broad offshore distribution. The ten locations of the ‘coarse sand top’ community are situated on top of the steep offshore sandbanks. A fifth cluster is distinguished as a separate fish community, the transition

community, which is mainly restricted to the slope/gully locations in the transitional area around the 12 NM border) between the coastal fine sand community and the offshore locations (Figure 1).

Overall, structural characteristics differed significantly among the five communities (one way Permanova, all main tests $p=0.0001$), although the fine sand and coarse sand community did not differ for number of species ($p=0.1$). Also, for Margalef's species diversity, no significant difference was observed between both coastal communities (mud and fine sand, $p=0.5$) nor between the coarse sand and transition community ($p=0.15$). Density was not significantly different between coarse sand

top and transition communities ($p=0.1$). In general, density was at least twice as high in the coastal communities compared to the offshore communities.

3.2.2. Community characteristics

The shade plot shows a transition in species composition from coastal to offshore. Three species occur commonly across all communities in the entire BPNS, i.e. gobies *Pomatoschistus* spp., plaice *Pleuronectes platessa* and dab *Limanda limanda* (Figure 5). Pouting *Trisopterus luscus*, hooknose *Agonus cataphractus*, sole *Solea solea* and whiting *Merlangius merlangus* are more characteristic of the coastal area, while the offshore communities are dominated by

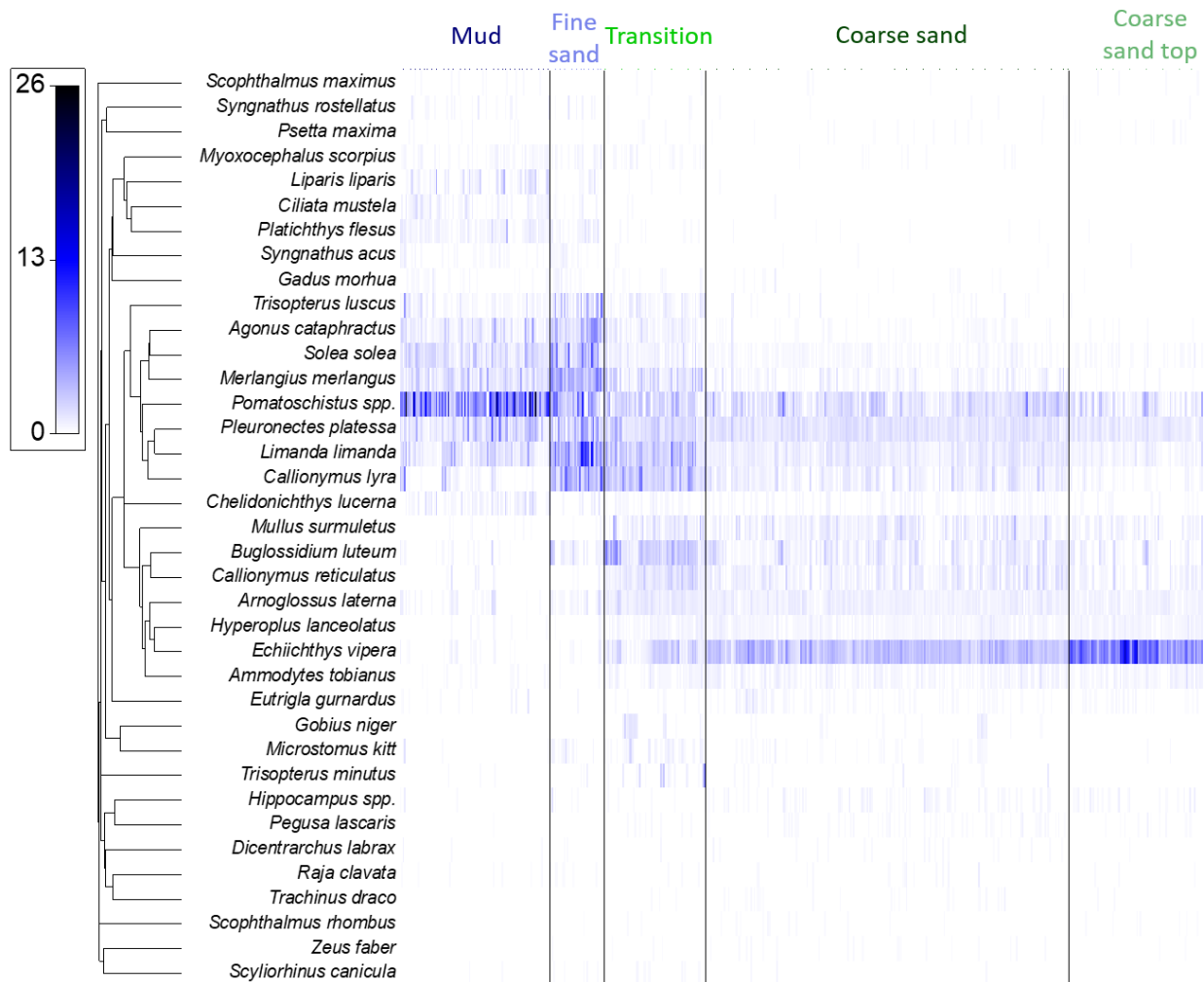


Figure 5. Shade plot showing averaged, square-root transformed abundance (ind. 1000 m⁻²) of the main fish species in the delineated fish communities.

Table 2. Characterization of the fish communities by indication of the average ‘within-group’ similarity (SIMPER); species listed account for 90% of cumulative contribution of the ‘within group’ similarity (in % and average abundance (N, ind 1000 m⁻²), the average (± SD) for a number of univariate parameters is provided per community.

Assemblage	Mud	Fine sand		Transition		Coarse sand		Coarse sand top							
W/I group similarity	60	61		63		64		67							
Species		%	N	Species	%	N	Species	%	N						
<i>Pomatoschistus</i> spp.		54.3	68.6	<i>Limanda limanda</i>	19.1	28.3	<i>Callionymus lyra</i>	14.3	6.8	<i>Echiichthys vipera</i>	32.7	9.1	<i>Echiichthys vipera</i>	64.6	47.3
<i>Pleuronectes platessa</i>		8.9	3.3	<i>Merlangius merlangus</i>	17.1	16.6	<i>Limanda limanda</i>	14.0	7.2	<i>Pleuronectes platessa</i>	13.9	1.7	<i>Pleuronectes platessa</i>	9.7	1.0
<i>Solea solea</i>		7.8	1.8	<i>Callionymus lyra</i>	15.2	15.1	<i>Buglossidium luteum</i>	12.7	6.4	<i>Pomatoschistus</i> spp.	12.2	2.4	<i>Pomatoschistus</i> spp.	5.3	1.1
<i>Limanda limanda</i>		7.3	1.6	<i>Pomatoschistus</i> spp.	11.4	11.9	<i>Pomatoschistus</i> spp.	10.8	4.3	<i>Limanda limanda</i>	7.9	0.8	<i>Arnoglossus laterna</i>	5.0	0.3
<i>Merlangius merlangus</i>		7.3	1.7	<i>Agonus cataphractus</i>	9.3	7.7	<i>Pleuronectes platessa</i>	10.3	3.5	<i>Arnoglossus laterna</i>	6.7	0.5	<i>Hyperoplus lanceolatus</i>	4.0	0.2
<i>Agonus cataphractus</i>		4.4	1.2	<i>Solea solea</i>	9.2	9.4	<i>Callionymus reticulatus</i>	6.8	1.7	<i>Mullus surmuletus</i>	4.5	0.5	<i>Limanda limanda</i>	2.9	0.2
<i>Platichthys flesus</i>		2.3	0.3	<i>Pleuronectes platessa</i>	9.1	7.8	<i>Echiichthys vipera</i>	6.6	2.4	<i>Callionymus lyra</i>	4.4	0.5			
							<i>Arnoglossus laterna</i>	5.8	0.9	<i>Buglossidium luteum</i>	4.4	0.6			
							<i>Merlangius merlangus</i>	5.4	1.8	<i>Callionymus reticulatus</i>	4.2	0.5			
							<i>Mullus surmuletus</i>	2.9	0.6						
							<i>Agonus cataphractus</i>	2.6	0.4						
# samples	100	36		67		241		89							
N (ind/1000 m²)	85.9 ± 109.2	142.5 ± 87.4		50.1 ± 32.4		21.8 ± 10.6		60.4 ± 47.7							
S	12 ± 2.5	13.9 ± 2.5		16.3 ± 2.3		13.1 ± 2.8		10.2 ± 2.7							
Margalefs diversity	2.8 ± 0.7	2.8 ± 0.6		4.2 ± 0.9		4.1 ± 0.9		2.4 ± 0.7							
Shannon diversity	1.1 ± 0.5	1.7 ± 0.2		2 ± 0.2		1.6 ± 0.4		0.5 ± 0.3							
Simpson diversity	0.5 ± 0.2	0.8 ± 0.1		0.8 ± 0.1		0.7 ± 0.2		0.2 ± 0.1							

lesser weever *Echiichthys vipera*. Four other species are more typical for the offshore area namely red mullet *Mullus surmuletus*, solenette *Buglossidium luteum*, reticulated dragonet *Callionymus reticulatus* and scaldfish *Arnoglossus laterna*. Also, greater and smaller sandeel (*Hyperoplus lanceolatus* and *Ammodytes tobianus*) are characteristic of the offshore clusters, although in lower densities (Figure 5).

3.2.2.1. Coastal communities

Mud

The mud community is dominated by *Pomatoschistus* spp. (54% contribution to w/i group similarity), followed by *P. platessa* (9%) and *S. solea* (8%). Density (86 ± 109 ind. 1000 m⁻²) is lower compared to the fine sand community but quite higher than the offshore/coarse sand communities. This is one of the least diverse fish communities in the BPNS: Number of species (12 ± 2), Margalefs diversity (3 ± 0.7), Shannon (1 ± 0.5) and Simpson (0.5 ± 0.2) are all low (Table 2).

Fine sand

Four species contribute for around 60% to within-group similarity i.e. *L. limanda* (19%), *M. merlangus* (17%), *Callionymus lyra* (15%) and *Pomatoschistus* spp. (11%). This community has the highest densities (142 ± 87 ind. 1000 m⁻²) and on average 14 (± 2.5) fish species are present per sample (Table 2). Shannon (1.7 ± 0.2) and Simpson (0.8 ± 0.1) are among the highest compared to the other communities.

3.2.2.2. Offshore communities

Coarse sand

This community is dominated by *E. vipera* (33% contribution to w/i group similarity) with an average density of 9 ind. 1000 m⁻². Other species contributing to within-group similarity are *P. platessa* (14%), *Pomatoschistus* spp. (12%), *L. limanda* (8%) and *Arnoglossus laterna* (7%) (Table 2). Density (22 ± 11 ind.

1000 m⁻²) is very low compared to the other communities. Number of species (13 ± 3) and diversity measures Shannon (1.6 ± 0.4) and Simpson (0.7 ± 0.2) have average values in comparison to the other communities, while Margalefs diversity (4.1 ± 0.9) is among the highest.

Coarse sand top

The coarse sand top community is spatially restricted to the tops of the steep offshore sandbanks (Figure 1) and completely dominated by *E. vipera* (65% contribution to w/i group similarity), with average density of 47 ind. 1000 m⁻². Few other species are occurring and only in very low densities, of which *P. platessa* (10%) contributes most to within-group similarity. Average density (60 ± 48 ind. 1000 m⁻²) is relatively high for this offshore community due to the high abundance of lesser weever, but in terms of biodiversity this is a very poor community, with a very low number of species (10 ± 3) and very low values for Margalefs diversity (2.4 ± 0.7), Shannon (0.5 ± 0.3) and Simpson (0.2 ± 0.1) (Table 2).

Transition

Callionymus lyra (14%), *L. limanda* (14%), *B. luteum* (13%), *Pomatoschistus* spp. (11%) and *P. platessa* (10%) contribute more or less evenly to the first 60% of within-group similarity in this transitional fish community. Species composition is a mixture between species more characteristic for coastal and species more typical for offshore locations (Table 2; Figure 5), making it the most diverse fish community. Density (50 ± 32 ind. 1000 m⁻²) is average, while number of species (16 ± 2) and Margalefs diversity (4 ± 1) are highest compared to the other communities. Also, Shannon (2 ± 0.2) and Simpson (0.8 ± 0.1) are highest among all fish communities.

4. Discussion

4.1. Epibenthos and fish communities in the BPNS

Both fish and epibenthos communities largely follow similar spatial distribution patterns in the BPNS. For both ecosystem components, there is a clear distinction in communities between the coastal and the more offshore area, situated more or less around 3 NM off the south-western part of the coast and 12 NM off the north-eastern part of the coast. Densities and biomass (the latter only available for epibenthos) are very high within the coastal communities compared to the offshore clusters. For epibenthos, the main species are ubiquitous present in the entire BPNS, i.e. *P. bernhardus*, *C. crangon*, *O. albida*, *O. ophiura*, *A. rubens* and *L. holsatus* occur in all communities. These are indeed the species known to be common in the southern North Sea (Callaway *et al.* 2002). The division between epibenthic communities is mainly due to differences in abundance and/or dominance of one or more of these common species, next to the occurrence of some less abundant but characteristic species, like *Spisula* spp. and squids, that are more common offshore. For fish, there is more a gradient in species from coast to offshore with sole *S. solea*, hooknose *A. cataphractus* and pouting *T. luscus* more characteristic in the coastal communities and lesser weever *E. vipera* dominating the offshore clusters, while dab *L. limanda* and plaice *P. platessa* occur all over the BPNS with varying abundances.

The coastal community of both ecosystem components is further subdivided in a community occurring in more muddy sediments located at the north-eastern part of the coast. These communities largely coincide with the macrobenthic *Limecola balthica* community as described in Breine *et al.* (2018). Number of species and diversity is low within these communities and they are dominated by the brown shrimp, *C. crangon* and gobies, *Pomatoschistus* spp., for resp. epibenthos and fish. These Mud communities are most probably under influence of the

outflow of the Scheldt estuary as well. The other community distinguished within the coastal area for both epibenthos and fish seems to be correlated with fine sandy sediments, and largely overlaps with the macrobenthic *A. alba* community (Breine *et al.* 2018). The fine sand communities are the most species rich and diverse communities both for epibenthos and fish in the coastal zone, but highly dominated by resp. the serpent star *O. ophiura* and dab *L. limanda*. Other characteristic species for epibenthos are the netted dog whelk *Tritia reticulata*, the slipper limpet *Crepidula fornicata* and the crab species *L. navigator* and *L. depurator*. For fish, whiting *M. merlangus*, hooknose *A. cataphractus* and common dragonet *C. lyra* are seen as characteristic species in this fine sand community.

The offshore area is characterised by coarser, permeable sediments, harbouring two macrobenthic communities *Nephtys cirrosa* in medium sands and *Hesionura elongata* in coarse sand (Breine *et al.* 2018). Fish and epibenthic communities do not really follow this delineation in spatial distribution. A distinction between the different offshore communities seems to be structured by sand bank topography, and as such probably associated with current patterns. For epibenthos, two offshore communities are observed: a widespread ‘offshore coarse sand’ community occurring on the northern sandbank systems of the Zeeland banks and Hinderbanks, and a ‘coarse sand top’ community that only occurs on top of the steeper offshore sandbanks (i.e. Hinderbanks and offshore Flemish banks). The offshore coarse sand community has the highest number of species and is the most diverse epibenthic community with *S. solida*, *S. elliptica*, *L. marmoreus* and squid species *Loligo vulgaris* and *Sepiolo atlantica* as typical species. The coarse sand top epibenthos community can be seen as a species-poor version of the offshore coarse sand community, characterised by very low density and biomass and dominated by the hermit crab *P. bernhardus*.

For fish, the most widespread offshore coarse sand fish communities is characterized by intermediate diversity and number of species, and dominated by lesser weever *E. vipera*, with solenette *B. luteum*, scaldfish *A. laterna*, red mullet *M. surmuletus* and reticulated dragonet *C. reticulata* as additional characteristic species. In analogy with epibenthos, a species-poor version of this community, i.e. the coarse sand top community, occurs on top of the steeper offshore sand banks. This is the least diverse community, which is entirely dominated by lesser weever. In contrast to the epibenthos, we observed a slightly different subdivision in communities within the offshore area, with a clear third transitional community. It occurs around the 12 NM area in between the coastal fine sand and the offshore coarse sand fish communities, mainly on the slopes of the northern Zeeland banks and the more coastal southwest Flemish banks. This Transition community is the most diverse fish community with the highest number of species, consisting of a mixture of coastal (e.g. *C. lyra*) and offshore species (e.g. *Buglossidium luteum*).

The importance of sandbank topography in structuring communities on smaller-scale has been shown by previous studies (Ellis *et al.* 2010; Mestdagh *et al.* 2020). In a previous analysis of fish abundances, Buyse *et al.* (2022) also observed the two coastal communities (mud and fine sand), but only one offshore community, namely the coarse sand community. The fact that in our study, different offshore communities were discerned associated with sandbank topography, is most probably related to the higher number of sampling locations, which enabled us to distinguish communities at a higher spatial resolution.

4.2. Implications for future OWF monitoring of epibenthos and fish

The current OWF area in the eastern part of the BPNS largely overlaps with the spatial distribution of the offshore epibenthos

and fish communities, except for the most southern concession of Northier, where the coastal fine sand communities occur. In a previous study, we already concluded that Northier exhibited a different epibenthos and fish assemblage than the other concession areas (De Backer & Hostens 2018b). Within the actual concession areas, the majority of the current sampling locations belong to the coarse sand community for both epibenthos and fish. Few locations tend towards the species-poor coarse sand top community, especially on top of the Bligh Bank in the Belwind concession zone. The more diverse transitional fish community occurs at the slope and gully locations neighbouring C-Power, thus in the southern part of the OWF area.

From our analysis, it is clear that the locations inside the OWF concessions cluster nicely together with all non-concession locations in the same respective epibenthos and fish communities. They do not form a separate community or assemblage. This corroborates the conclusion of De Backer *et al.* (2020) that epibenthos and fish assemblages on the soft sediments in between the turbines underwent no drastic changes. Secondary effects suggesting an expansion of the artificial reef effect and some refugium effects due to fisheries exclusion have been picked up already at the species level (De Backer *et al.* 2020; Buyse *et al.* accepted). However, these are not yet at a magnitude to be picked up as such in the overall community analysis.

Nevertheless, the larger contiguous OWF area where fisheries are excluded, is expected to act as a refugium after a certain time and potentially enhance biomass or length of certain species or even change assemblage composition (Handley *et al.* 2008). This refugium effect might potentially lead to ‘spillover’ (export of biomass to surrounding habitats by recruitment or migration out of the area). The current BACI design used for monitoring the potential impacts of OWFs on epibenthos and fish – with impact and near control locations – is, however, not optimal

to detect such spillover effects. A gradient design would be more suited. This type of design has been used to evaluate the patterns of fish distributions and to elucidate spillover effects in and around marine protected areas (Methratta 2020). One of the advantages of BAG (Before-After Gradient) designs is that there is no need to identify suitable control areas, but instead focus the effort on sampling multiple locations along a distance gradient (Methratta 2020). Nevertheless, it is important that these sampling locations are characterized by similar epibenthos and fish communities, to avoid that differences in abundance or species diversity only reflect differences in communities due to environmental differences rather than real effects of the OWFs.

For sure, it will be important that the difference in community is accounted for in statistical models. In that respect, the analyses conducted in this study are important to select suitable sampling locations. Based on our results, the coarse sand community locations are the best candidates to be included in a gradient design, e.g. locations on the Gootebank, the Hinderbanks, but also the most offshore locations that are currently monitored already by ILVO. Even some of the coarse sand top community locations, the species-poor version of the offshore coarse sand community, may be included since some of the OWF locations (within Belwind) tend towards this community. Of course, then it will be important to account for this in the statistical models, e.g. by introducing a ‘community’ factor. Another important aspect when studying spillover/refuge effects is to not only focus on fish abundances, but also to look at fish life history and population characteristics, such as age, length, weight and sex ratio to enhance the detection of potential refuge effects (Florin *et al.* 2013). Including this in future gradient monitoring for a selection of commercially important species, such as plaice and dab, will help to further elucidate OWF effects.

Regarding the newly designated Princess Elisabeth area, few sampling locations have been investigated by means of an 8 m beam

trawl in the past. Especially the largest south western zone is data poor. The locations that are currently sampled within the ILVO environmental monitoring programs are mainly located on top of steeper sandbanks, which harbour the species-poor coarse sand top epibenthos and fish communities. Based on the known locations from the wider surroundings (e.g. in the north-eastern offshore zone), the coarse sand community is certainly to be expected within the south-western zone of the Princess Elisabeth area. For sure, the topography of this area is very heterogeneous with steep sandbanks, so it will be important to take this into account in future monitoring and modeling. Additionally, relict gravel beds with high biological value are to be expected in the area, as suggested by the potential gravel distribution map of the BPNS (Van Lancker *et al.* 2007; Pecceu *et al.* 2021). Due to the high heterogeneity and poor data availability, a thorough before-impact monitoring will be essential to enable assessing the future effects. Follow-up of these gravel beds may require a different approach, but to properly evaluate the potential effects of OWFs on the soft sediment epibenthos and fish communities, a gradient design from the start will be the most suitable solution, since this will improve our understanding of how OWFs influence species distribution patterns (Methratta 2020).

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References

- Anderson, M.J. & Robinson, J. 2003. Generalized discriminant analysis based on distances. *Australian & New Zealand Journal of Statistics* 45 (3): 301-318.
<https://doi.org/10.1111/1467-842X.00285>
- Anderson, M.J., Gorley, R.N. & Clarke, K.R. 2008. PERMANOVA+ for PRIMER: guide to software and statistical methods. PRIMER-E, Plymouth, 214 pp.
- Breine, N.T., De Backer, A., Van Colen, C., Moens, T., Hostens, K. & Van Hoey G. 2018. Structural and functional diversity of soft-bottom macrobenthic communities in the Southern North Sea. *Estuarine, Coastal and Shelf Science* 214: 173–184.
<https://doi.org/10.1016/J.ECSS.2018.09.012>
- Buyse, J., Hostens, K., Degraer, S. & De Backer, A. 2022. Long-term series demonstrate small-scale differences in trends within fish assemblages explained by climate variability. *Estuarine, Coastal and Shelf Science* 264: 107663. <https://doi.org/10.1016/j.ecss.2021.107663>
- Buyse, J., Hostens, K., Degraer, S. & De Backer, A. Accepted. Offshore wind farms affect the spatial distribution pattern of plaice *Pleuronectes platessa* at both the turbine and wind farm scale. *ICES Journal of Marine Science*.
- Callaway, R., Alsvag, J., de Boois, I., Cotter, J., Ford, A., Hinz, H., Jennings, S., Kroncke, I., Lancaster, J., Piet, G., Prince, P., Ehrich, S. 2002. Diversity and community structure of epibenthic invertebrates and fish in the North Sea. *ICES Journal of Marine Science* 59 (6): 1199-1214.
- Clarke, K.R. & Gorley, R.N. 2015. PRIMER v7: User Manual/Tutorial.
- De Backer, A. & Hostens, K. 2018a. Soft sediment epibenthos and fish monitoring at the Belgian offshore wind farm area: situation 6 and 7 years after construction. In: Degraer, S *et al.* (eds) *Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: Assessing and Managing Effect Spheres of Influence. Memoirs on the Marine Environment*: 27-37.
- De Backer, A. & Hostens, K. 2018b. Defining reference condition (T_0) for the soft sediment epibenthos and demersal-benthopelagic fish in the Norther and Rentel concession zones. In: Degraer, S. *et al.* (eds) *Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: Assessing and Managing Effect Spheres of Influence. Memoirs on the Marine Environment*: 39-55.
- De Backer, A., Buyse, J. & Hostens, K. 2020. A decade of soft sediment epibenthos and fish monitoring at the Belgian offshore wind farm area. In: Degraer, S. *et al.* (eds) *Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: Empirical Evidence Inspiring Priority Monitoring, Research and Management. Memoirs on the Marine Environment*: 79-113.
- Degraer, S., Verfaillie, E., Willems, W., Adriaens, E., Vincx, M. & Van Lancker, V. 2008. Habitat suitability modelling as a mapping tool for macrobenthic communities: an example from the Belgian part of the North Sea. *Continental Shelf Research* 28: 369–379.
<https://doi.org/10.1016/j.csr.2007.09.001>
- Derweduwen, J., Vandendriessche, S. & Hostens, K. 2010. Monitoring the effects of the Thorntonbank and Bligh Bank wind farms on the fpifauna and demersal fish fauna of soft bottom sediments. Thorntonbank: Status during construction (T2). Bligh Bank: Status during construction (T1). In: Degraer, S. *et al.* (eds) *Offshore Wind Farms in the Belgian Part of the North Sea: Early Environmental Impact Assessment and Spatio-Temporal Variability*: 105-132.

- Ellis, J.R., Maxwell, T., Schratzberger, M. & Rogers, S.I. 2010. The benthos and fish of offshore sandbank habitats in the southern North Sea. *Journal of the Marine Biological Association of the UK* 91(6): 1319-1335. <https://doi.org/10.1017/S0025315410001062>
- Florin, A.-B., Bergström, U., Ustups, D., Lundström, K., Lundström, L. & Jonsson, P.R. 2013. Effects of a large northern European no-take zone on flatfish populations. *Journal of Fish Biology* 83: 939–962. <https://doi.org/10.1111/jfb.12097>
- Handley, S.J., Willis, T.J., Cole, R.G., Bradley, A., Cairney, D.J., Brown, S.N. & Carter, M.E. 2014. The importance of benchmarking habitat structure and composition for understanding the extent of fishing impacts in soft sediment ecosystems. *Journal of Sea Research* 86: 58-68.
- Houziaux, J.-S., Kerckhof, F., Degrendele, K., Roche, M. & Nooro, A. 2008. *The Hinder Banks: Yet an Important Area for the Belgian Marine Biodiversity?* Belgian Science Policy, Brussels, 259p.
- Houziaux, J.-S., Fettweis, M., Francken, F. & Van Lancker, V. 2011. Historic (1900) seafloor composition in the Belgian-Dutch part of the North Sea: A reconstruction based on calibrated visual sediment descriptions. *Continental Shelf Research* 31: 1043–1056.
- Mestdagh, S., Amiri-Simkooei, A., van der Reijden, K.J., Koop, L., O'Flynn, S., Snellen, M., Van Sluis, C., Govers, L.L., Simons, D.G. & Herman, P.M. 2020. Linking the morphology and ecology of subtidal soft-bottom marine benthic habitats: A novel multiscale approach. *Estuarine, Coastal and Shelf Science* 238: 106687. <https://doi.org/10.1016/j.ecss.2020.106687>
- Methratta, E.T. 2020. Monitoring fisheries resources at offshore wind farms: BACI vs. BAG designs. *ICES Journal of Marine Science* 77: 890–900. <https://doi.org/10.1093/icesjms/fsaa026>
- Montereale-Gavazzi, G.O.A., Kapasakali, D., Kerckhof, F., Deleu, S., Degraer, S. & Van Lancker, V. 2021. Subtidal natural hard substrate quantitative habitat mapping: interlinking underwater acoustics and optical imagery with machine learning. *Remote Sensing* 13: 4608. <https://doi.org/10.3390/rs13224608>
- Pecceu, E., Paoletti, S., Van Hoey, G., Vanelslander, B., Verlé, K., Degraer, S., Van Lancker, V., Hostens, K. & Polet, H. 2021. Scientific background report in preparation of fisheries measures to protect the bottom integrity and the different habitats within the Belgian part of the North Sea. *ILVO-Mededinging* 277.
- Rumes B. & Brabant R. 2021. Offshore renewable energy development in the Belgian part of the North Sea. In: Degraer, S. et al. (eds) *Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: Attraction, Avoidance and Habitat Use at Various Spatial Scales. Memoirs on the Marine Environment*: 11-17.
- Van Hoey, G., Degraer, S. & Vincx, M. 2004. Macrobenthic communities of soft-bottom sediments at the Belgian continental shelf. *Estuarine Coastal and Shelf Science* 59: 601–615.
- Van Lancker, V., Du Four, I., Verfaillie, E., Deleu, S., Schelfaut, K., Fettweis, M., Van den Eynde, D., Francken, F., Monbaliu, J., Giardino, A., Portilla, J., Lanckneus, J., Moerkerke, G. & Degraer, S. 2007. Management, research and budgeting of aggregates in shelf seas related to end-users (Marebasse). Brussel (B), Belgian Science Policy (D/2007/1191/49). 139 pp. + DVD GIS@SEA + Habitat Signature Catalogue.
- Verfaillie, E., Van Lancker, V. & Van Meirvenne, M., 2006. Multivariate geostatistics for the predictive modelling of the surficial sand distribution in shelf seas. *Continental Shelf Research* 26 (19): 2454–2468. <https://doi.org/10.1016/j.csr.2006.07.02>