CHAPTER 7

EXPANSION OF SMALL-SCALE CHANGES IN MACROBENTHIC COMMUNITY INSIDE AN OFFSHORE WIND FARM?

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ABSTRACT

The presence of offshore wind farms in the marine environment has some impacts on the macrobenthic community living in the natural sandy sediments. Changes in hydrodynamics, presence of epifaunal coverage along the turbine and fisheries exclusion are expected to be the main causes influencing the macrobenthos. In this study it was investigated whether changes in sediment characteristics and the macrobenthic community occurred inside a wind farm in the Belgian part of the North Sea. Both stations in the close vicinity of the turbines (50 m distance, close samples) and further away (350-500 m distance, far samples) were sampled with a Van Veen grab in autumn 2015.

No significant differences in abiotic factors were observed between the two distances. All samples were characterized by coarse sediments, with a low mud and total organic matter content. Macrobenthic densities on the other hand differed significantly between the two distances. Densities and number of species were higher for the far samples compared to the close samples. The latter were dominated by *Urothoe brevicornis* and *Gastrosaccus spinifer*, while *Bathyporeia elegans* and *Spiophanes bombyx* were more important in far samples. It is currently unclear what underlying ecological processes are responsible for the difference in community structure between both distances. Further, the current results are not consistent with results from previous studies, which might be related to the turbine type used. Therefore it is recommended to continue following the current sampling design for the coming years. In addition, it would be interesting to perform a targeted monitoring study to investigate potential changes in sedimentology and organic enrichment in the close vicinity of different turbine types.

7.1. INTRODUCTION

Since the early 2000s offshore wind farms are built all across the North Sea. As of June 2015 there were 3072 wind turbines present in European waters, in 82 wind farms across 11 countries (Ho and Mbistrova 2015). With the construction of these wind turbines, artificial hard substrates are introduced into the natural sandy environments (i.e. reef effect). This reef effect causes large impact on the marine environment at different scales (Petersen and Malm 2006). Biodiversity and ecosystem functioning are influenced and as a result these effects have environmental costs and benefits (Andersson et al. 2009, Langhamer 2012) including habitat alteration, changes in sediment characteristics, underwater noise and hydrodynamics. All these direct changes on the ecosystem influence community structure and trophic interactions in the marine environment, e.g. rapid colonization of hard substrates by an epifaunal community (De Mesel et al. 2013, De Mesel et al. 2015); changes in community composition of soft substrate macro- and epibenthos, demersal and benthic fish (Reubens et al. 2013, Reubens et al. 2014, Vandendriessche et al. 2015); changes in spatio-temporal distribution and migration routes of demersal fish, seabirds and marine mammals (Reubens et al. 2014, Haelters et al. 2015, Vanermen et al. 2015).

In this report we focus on the possible effects on the macrobenthic community in offshore wind farms. As stated by Kröncke (2011) and Kröncke et al. (2011) the main natural factors structuring macrobenthic species distribution and communities are temperature, the influence of different water masses, sediment type and food supply of the sediment. There is a natural temporal and spatial variability in presence of macrobenthic communities (Ysebaert and Herman 2002). Besides, anthropogenic stressors such as commercial fishing, dredging and eutrophication may play a role in structuring the macrofauna as well (Kröncke et al. 2011). Thus, one might expect that changes in sediment type, changes in food supply of the sediment and fisheries exclusion will have a major influence on the macrobenthic community present in offshore wind farms.

Macrobenthos is an important component of the marine environment to be monitored for potential reef effects. It provides us with direct information on how soft, sandy sediments and their inhabitants are changing (Coates 2014). The effects on macrobenthos can scale up to the food web, as many macrobenthic species are an important food source for demersal fish species (Vandendriessche et al. 2015). Changes in macrobenthic communities has the potential to alter food web energy flows (Dannheim et al. 2014).

For offshore wind farms a distinction can be made between construction and operation effects related to the macrobenthos (Coates 2014, Coates et al. 2015). During the construction, dredging activities have a direct effect on the macrobenthic assemblages by the removal of sediments. This leads to decreased abundance, diversity and biomass of the benthic organisms (Boyd et al. 2003, Coates et al. 2015). However, the effects on the macrobenthic community are rather small as they show a high recovery potential after disturbance and are restricted to the impacted sites (Coates et al. 2015). Effects related to the operational phase of the wind farms on the other hand, develop on a much slower pace, can be (long-)lasting and act over a larger spatial scale due to the lasting habitat alterations (Van den Eynde et al. 2013, Vanhellemont and Ruddick 2014, De Mesel et al. 2015, Coates et al. 2016).

Coates et al. (2014) revealed changes in sedimentology up to 50 m distance from wind turbines. Grain size significantly reduced and organic matter content increased close to the turbines. The changes in grain size were the result of changing hydrodynamics. In the wake of the turbines, there is a decreased current flow, which prevents the re-suspension of finer sands. The increase in organic matter results from the epifouling organisms. Epifauna present on foundations contribute to the organic matter input on the seabed by sedimentation of faeces and detritus, and filtering suspended particulate matter out of the water (Maar et al. 2009). In addition, the refinement of the sediment reduces the pore-water flow within the sediments (Janssen et al. 2005), which results in less organic matter being flushed (Coates 2014). The changes in these environmental characteristics triggered changes in the macrobenthic community. Density and diversity increase and a shift in species dominance was observed (Coates et al. 2014).

The small-scale enrichment and fining of the sediment around wind turbines is the result of the prevailing hydrodynamics and epifaunal coverage. However, it is hypothesized, that in the longer term an expansion of these changing environmental characteristics could be facilitated due to the prohibition of beam trawling inside the wind farms (Coates 2014).

Now, three years later, it is investigated whether: 1) the small scale changes observed by Coates et al. (2014) are still present and 2) changes in the environmental characteristics and macrobenthic community expanded to larger distance from the turbines.

7.2. MATERIAL & METHODS

STUDY AREA

Within the Belgian part of the North Sea (BPNS) an area of 238 km² is reserved for the production of renewable energy. This area is subdivided in several concession areas (Brabant et al. 2013). The current study was conducted in the concession area of the offshore wind farm 'C-Power', which is located on the Thorntonbank sandbank (fig. 1). The wind farm consists of 54 turbines. The first six (constructed in 2008) were built on gravity-based foundations. The other 48 turbines have a jacket foundation and were constructed between 2011 and 2013 (Brabant et al. 2013).

SAMPLE DESIGN, COLLECTION AND TREATMENT

Effect of distance from turbine

A systematic stratified sampling design was adopted (fig. 1). Samples were collected in autumn 2015 at two distances (close and far) from the wind turbines. The close samples (n = 16) were taken at a distance of approximately 50 m from the turbines on the South-West side. If sampling at South-West direction was not possible (to comply with a minimum distance of 50 m from infield electricity cables) samples were taken at the North-East site of the turbines. The far samples (n = 32) were gathered in the middle between the four surrounding wind turbines. Here, distances ranged between 350 and 500 m from the turbines (fig. 1). The close samples were gathered on October 23th and November 3th, 2015, while the far samples were collected on October 6th and 7th, 2015.

Initially, a two-way spatial (close vs far) and temporal (present vs 2011 and 2012 (Coates et al. 2014)) comparison of samples was planned. Too many differences in sampling strategy (Table 1) however, resulted in a one-way spatial comparison only.

Table 1. Overview of differences in sampling design between 2011-2012 and 2015.

	2011-2012	2015
Season	Spring	Autumn
Replication	3 replicates at one location	Samples as replicates
# samples	1	16 close 32 far
Gradient	Taken into account	Not taken into account

Samples were collected by means of a Van Veen grab (0.1m²), sieved alive onboard over a 1 mm sieve table and subsequently preserved in an 8 % formaldehyde-seawater solution. In the laboratory, samples were stained with Rose Bengal and rinsed over a 1 mm sieve. All macrobenthic animals were identified to species level, whenever possible. Individuals were counted and biomass (blotted wet weight, mg) was determined for every species per sample.

From the grab sample, a subsample was taken with a core (Ø 3.6cm) to obtain information on grain size distribution, total organic matter (TOM) content and mud content. Median grain size was determined on dried samples (dried at 60°c) using a laser diffraction method with a measuring range of 0.02 - 2000 µm (Malvern Mastersizer 2000G, hydro version 5.40). Sediment fractions larger than 2000 µm were quantified using a 2 mm sieve. TOM was determined per sample by weighing the difference between the dry weight (48 h at 60°C) and the ash weight (2h at 500°C).

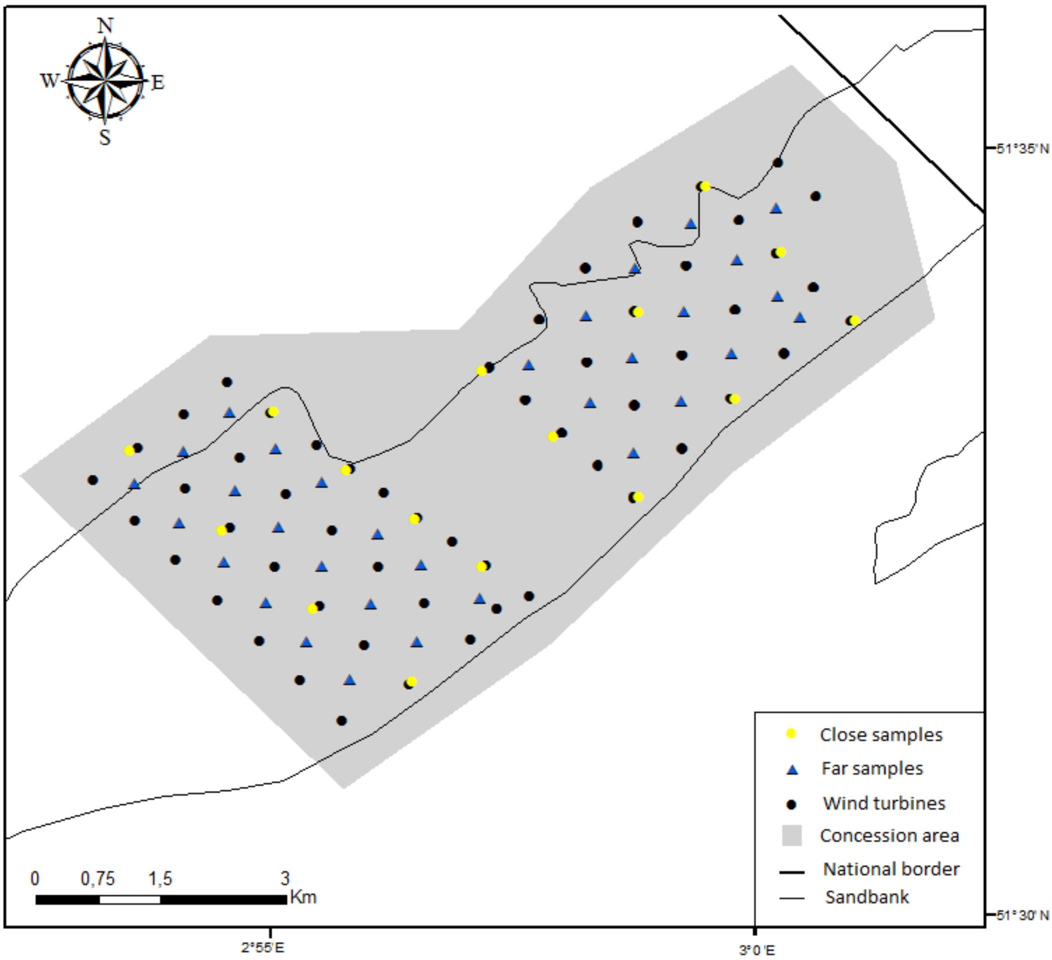

Figure 1. Overview of the C-Power concession area with indication of the close (yellow dots) and far (blue triangles) sampling locations.

Differences in median grain size over time

Although no direct comparison of biotic samples on temporal scale was possible, we investigated potential differences in median grain size over time at the C-Power concession area. Within the wind farm monitoring programme, samples on median grain from the Thorntonbank are available since 2005. However, due to construction works and safety issues, no samples could be collected within the concession area between 2011 and 2014. Data is available for 2008-2010.

DATA ANALYSIS

Effect of distance from turbine

Rare species were not removed from the dataset, as the presence of these species might be a first indication that something is changing in the macrobenthic community (not evaluated in this report). The abundance (ind m^{-2}), number of species (S) and Pielou's evenness were calculated. One-way Anovas were performed to detect any significant differences between the distances. Levene's test was used to control for homogeneity of variance, while the shapiro test was used for normality. If needed data were log-transformed.

Permutational Anova (Permanova) with a fixed one-factor (distance) design was used to investigate the effect of distance on the macrobenthic community composition. Permanova makes no explicit assumptions regarding the distribution of original variables (Anderson et al. 2008). It was decided to use Type III sums of squares as the design was unbalanced. Number of permutations was set to 9999 and unrestricted permutation of raw data was performed as there was only one factor. The multivariate analysis of abundance data was based on a Bray-Curtis resemblance matrix and performed on fourth root transformed data. The resemblance matric Euclidean distance was applied for the multivariate analysis of the environmental variables (Grain size, TOM and sediment fraction > 2mm) after normalization. Homogeneity of multivariate dispersions was tested using the PERMDISP routine, using distances among centroids. Principal Coordinates Analysis (PCO) was run to visualize the data. Furthermore, a distance-based linear model (DistLM) based on Adjusted R^2 and Stepwise criterion was carried out to investigate the relationship between the macrobenthic community and the environmental variables. Variables were tested for multi-collinearity (Anderson et al. 2008). Mud was excluded from the analysis, as data remained skewed (even after transformation). In addition a similarity percentage (SIMPER) routine was done to specify the role of individual species in separation between groups of samples and the closeness of samples within a group (Clarke and Gorley 2006).

All analyses were performed in the Plymouth Routines in Multivariate Ecological Research (PRIMER) programme (version 6.1.11) with the PERMANOVA add-on software (Clarke and Gorley 2006, Anderson et al. 2008) and in R (version 3.2.2) (Team 2015). A significance level of $p = 0.05$ was used in all tests. Results are expressed as mean ± standard deviation (SD).

Differences in median grain size over time

Since the assumptions of parametrical statistical approaches were not fulfilled, not even after log-transformation of the data, the non-parametric Kruskal-Wallis test was used to compare median grain size between years. Analyses were performed in R (version 3.2.2) (Team 2015). A significance level of $p = 0.05$ was used in all tests. Results are expressed as mean ± standard deviation (SD).

7.3. RESULTS

EFFECT OF DISTANCE FROM TURBINE

All samples consisted of coarse sediments (median grain size > 300 µm). At the close samples median grain size ranged from 301 to 515 µm, while at the far samples it ranged from 306 to 518 µm. The mud content was zero in most samples. Only two far samples had a mud content of 0.5 and 0.9 % respectively. TOM content remained low in all samples with a mean percentage of 0.59 ±0.16 at close and 0.76 ± 0.37 at the far distance. The sediment fraction over 2 mm ranged from 0.2 to 5.8 % at the close samples, while at the far samples it ranged from 0.1 to 9.2 % (Table 2 and Fig. 2). A multivariate analysis on the normalized abiotic data (Grain size, MUD, TOM and >2mm) revealed that there were no significant differences between the two distances (1-factor Permanova: $p = 0.34$; Permdisp: $p = 0.28$).

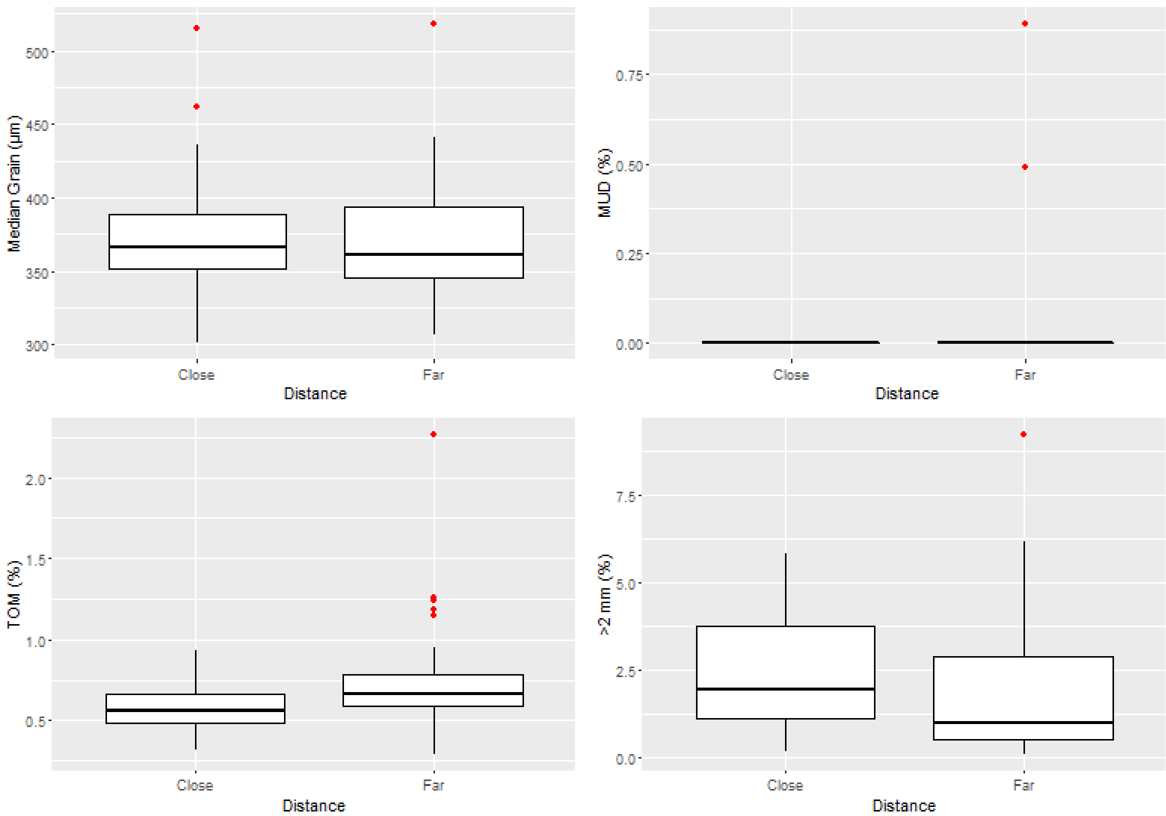

Figure 2. Box plots of the median grain size (Median_Grain), mud content (MUD, volume %), total organic matter (TOM) and sediment fraction above 2mm (>2mm, mass %) per sampling sites. Red dots represent the outliers.

Abundance and number of species present were low in all samples of both sites (Table 2). However, average abundance was higher at the far samples (492 ± 263 ind m^{-2}) than at the close samples (319 ± 195 ind m^{-2}). The same trend was observed for the number of species in the samples (far: 13 ± 4; close: 9 ± 4). A significant difference between the sites was found both for abundance (one-way Anova, p = 0.01) and number of species (one-way Anova, p = 0.0008). Mean eveness was slightly higher in the far samples (0.84 ± 0.08) compared to the close ones (0.81 ± 0.09) (Table 2, Fig. 3), but this yielded no significant differences (one-way Anova, P = 0.23). The multivariate analysis on the macrobenthic community structure revealed a significant effect of distance (Permanova, p=0.001), as visualized by the PCO analysis (Fig. 4). Permdisp was not significant (p= 0.945), thus the significant differences between the two sites are not the result of a dispersion effect.

Table 2. Overview of number of stations and calculated community descriptors (mean ± SD) of the two distances (close-far) sampled at the C-Power wind farm in 2015. * indicates whether significant differences were observed

	Close	**Far**
# Samples	16	32
Species abundance N (ind m-^{2}) *	319.38 ± 195.01	492.81 ± 263.01
Number of species S *	8.56 ± 3.53	12.88 ± 4.10
Evenness	0.81 ± 0.09	0.84 ± 0.08
Median grain size (µm)	378.39 ± 53.39	373.14 ± 43.01
Mud content (%)	0	0.04 ± 0.18
Total organic matter (%)	0.59 ± 0.16	0.76 ± 0.37
Sediment fraction > 2mm (%)	2.50 ± 1.78	1.99 ± 2.22

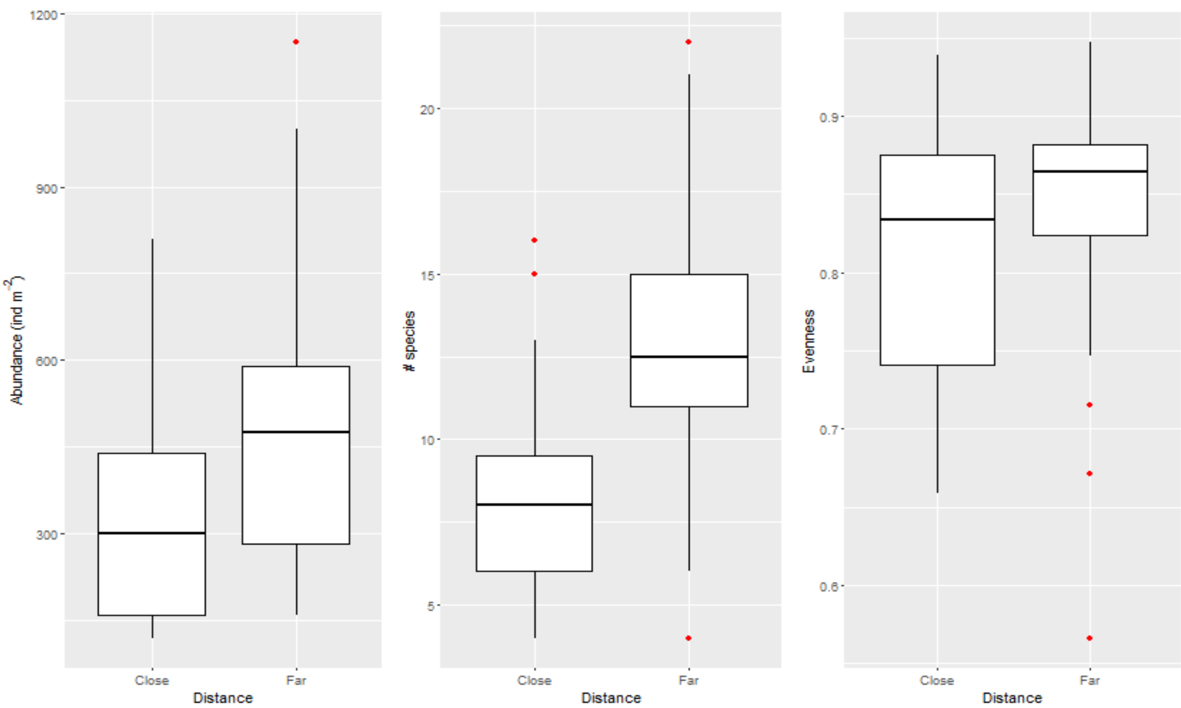

Figure 3. Box plots of the abundance, number of species and evenness per sampling site. Red dots represent the outliers.

A DistLM was carried out to investigate the relationship between the macrobenthic community and the environmental variables. The DistLM revealed that only grain size has a significant relationship with the multivariate data and explained 5.7 % of the variation in the community structure. All three environmental variables together explained only 10.5 % of the variation. Thus some other variables, which are key to explaining the community differences, are missing.

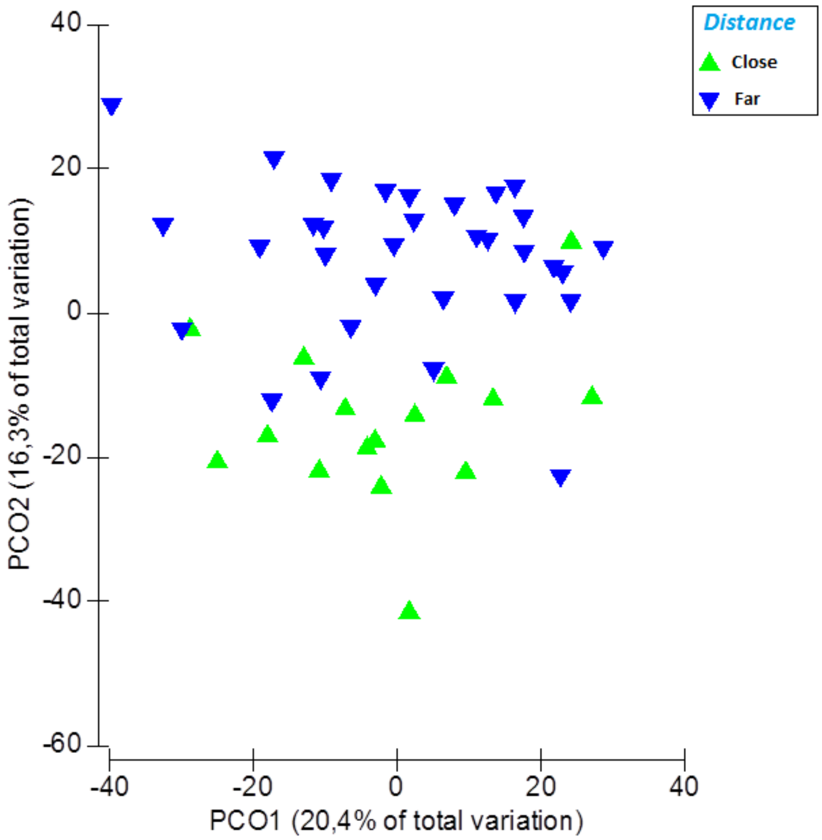

Figure 4. PCO (Principal Coordinates analysis) plot based on Bray-Curtis resemblance matrix of the fourth root transformed macrobenthic densities at two distances from the wind turbines.

In addition SIMPER analysis was run to specify the dominant species in the community of both groups of samples (Clarke and Gorley 2006). Average similarity between the close samples was 49%. Main contributing species to this similarity were: *Urothoe brevicornis* (28 %), *Nephtys spec. (36 %)* and *Gastrosaccus spinifer* (17%). Average similarity between the far samples was 51 % and this was made up of 35% from *Nephtys spec.*, 13 % from *Bathyporeia elegans*, 11 % from *Spiophanes bombyx*, 9 % from *U. brevicornis* and 8 % from *G. spinifer*. Average dissimilarity between the two groups was 55 %. *U. brevicornis* (7 %)*, B. elegans* (6 %) and *S. bombyx* (6 %) were the three most contributing species to this dissimilarity. Many other species contributed to a lesser extent.

DIFFERENCES IN MEDIAN GRAIN SIZE OVER TIME

Data on median grain size was available for the years 2008, 2009, 2010 and 2015 (Table 3 and Fig. 5). This data relates to far samples only.

Mean medain grain size did not differ much between the years. 2015 has the highest medain grain size (373.14 ± 43 µm), while in 2010 it was lowest (347.91 ± 45 µm). The non-parametric Kruskal-Wallis chi-squared test revealed that there are no significant differences in medain grain size among the different years (p= 0.43).

Table 3. Overview of number of stations and Median grain size (mean ± SD) sampled over the years.

Year	# Samples	Median grain size (µm)
2008	26	360.23 ± 33.60
2009	30	371.02 ± 70.78
2010	4	347.91 ± 45.44
2015	32	373.14 ± 43.01

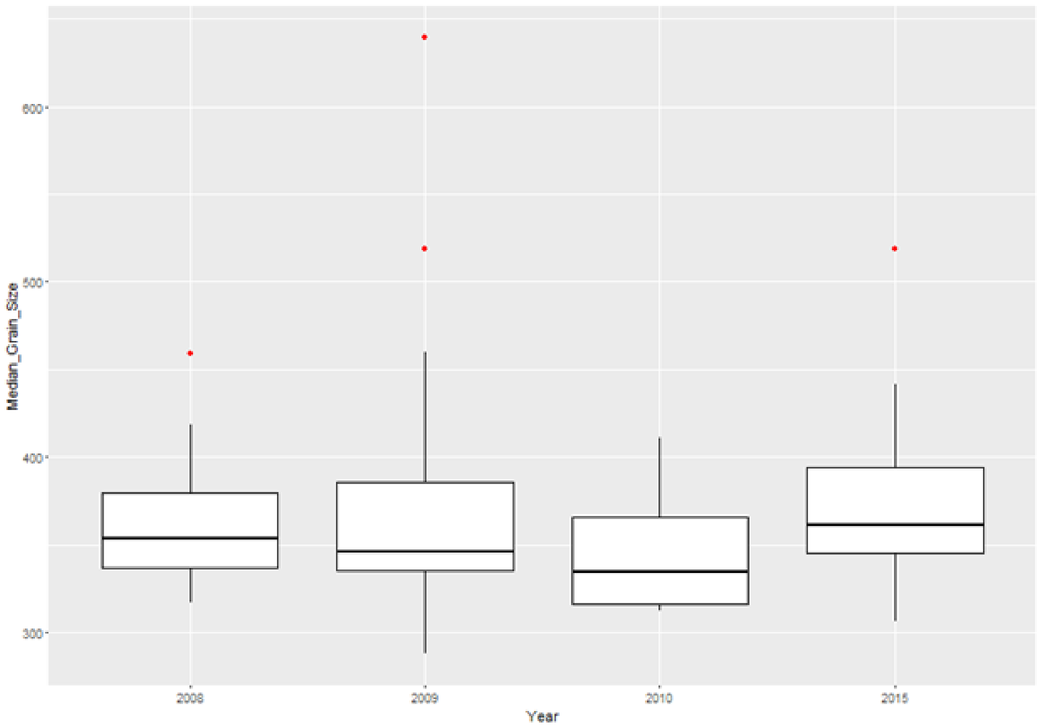

Figure 5. Boxplots of median grain size for the factor 'Year'. Red dots represent the outliers.

7.4. DISCUSSION

Close to gravity-based turbines, small-scale enrichment and fining of the sediment occurs (Coates et al. 2014), which are the result of playing hydrodynamics and epifaunal coverage. These changes result in changes of the macrobenthic community and were observed up to 50 m distance from the turbines. In the current study however, no changes in sediment characteristics were observed close to the turbines. The currently measured values are in line with preconstruction values (Reubens et al. 2009, Coates and Vincx 2010). In addition, the comparison of median grain size over the years (2008-2015) did not yield any significant differences. The discrepancy between the current work and the one of Coates et al. (2014) might be due to the turbine type involved. The latter was performed around one gravity-based foundation. These foundation types have a large concrete base that largely effect local current flow. Decreased current flows in the wake of the turbine will prevent the re-suspension of finer sands and enriched TOM close to the turbines. In the current study we took close samples near 16 turbines. However, 13 out of the 16 turbines are jacket foundations, having an open structure allowing the main current flow to pass through the construction (Lancelot et al. 1987). In addition, the work of Coates (2014) was performed in late spring, shortly after the Phaeocystis bloom. When the bloom dies of there is an increase in deposition of organic material to the bottom (Lancelot et al. 1987). At locations with reduced currents (such as in the wake of gravity-based turbines) the organic material can accumulate. The possible influence of turbine type will be investigated in more detail in future work.

Another variable that cannot be ruled out to explain differences between the close and far samples is the time lag in sampling. The far samples were gathered in the beginning of October, while the close ones were collected the end of October/beginning of November. 6 and 7 October, surface seawater temperature was 16.15 °C on average, while on November 3th, temperature dropped to 13.8 °C. Temperature is known to structure macrobenthic communities (Kröncke 2011, Kröncke et al. 2011).

Changes in the environmental characteristics and the macrobenthos not only occur in close vicinity of offshore wind turbines, but might also occur at a larger distance due to the fisheries exclusion (Hiscock et al. 2002). Trawl fisheries cause physical disruption of the seabed through contact of the gear components with the sediment. As a result sediment resuspension into the water column occurs in the wake of the gear (Depestele et al. 2015). Mainly the smaller particle sizes are resuspended. These types of fisheries thus prevent smaller sediment fractions to settle down on the seabed. In addition, intensive trawling activities can significantly affect mortality, diversity and species composition of macrobenthic communities (Piet et al. 2000, Jennings et al. 2001). Due to the prohibition of trawling inside offshore wind farms, species sensitive to physical disturbance might get the chance to recover (e.g. bivalve species, tube building terebellids, echinoderms) (Rijnsdorp et al. 1998). Next to macrobenthic species, also epibenthic species and fish benefit from the fisheries closure as higher numbers and larger individuals can be observed in these zones (Vandendriessche et al. 2015).

In contrast to the findings on the abiotic factors, a clear difference in macrobenthic community was found between the close and the far samples. Currently it is unclear what causes these differences. SIMPER analyses revealed that *U. brevicornis* and *G. spinifer* thrive better closer to the turbines while *B. elegans* and *S. bombyx* were more abundant in far samples. All four species are known to be widely distributed along the BPNS. *Urothoe brevicornis* and *B. elegans* prefer medium to coarse-grained sediments with a low mud content, while *G. spinifer* and *S. bombyx* can cope with a wider range of sediment types (Degraer et al. 2006). Thus, the relative abundance of these species is no direct indication for specific habitat changes.

In addition, samples at the far distance yielded more species and higher densities on average than the close samples, once again contrasting the results of Coates et al. (2014). The lower abundances and number of species near the turbines might again be related to the turbine type. Personal observations, while performing scientific dives, at the jacket foundations revealed that this turbine type is heavily fouled by blue mussels (*Mytilus edulis*), which is in accordance to different other studies in the North Sea and Baltic Sea that investigated fouling assemblages at offshore structures (Zettler and Pollehne 2006, Joschko et al. 2008, Wilhelmsson and Malm 2008). The observed *M. edulis* densities have been confirmed by F. Kerckhof (pers. comm.) and it seems to be a stable community as high densities were observed in 2012, 2013 and 2014.

Commonly, beneath suspended mussel cultures, there is an increased sedimentation rate, TOM and total organic carbon (TOC) while oxygen levels reduce. These effects result in reduced infaunal diversity and abundance (Chamberlain et al. 2001), which is in line with the current findings. However, the BPNS is characterized by a well-mixed water column, thus reduced oxygen levels are not expected in these waters. In the long run, it might be that long lasting shell debris (originating from ceased individuals) may lead to coarser sediments. These shells can potentially serve as attachment sites for sessile reef forming organisms (Krone et al. 2013).

7.5. CONCLUSIONS AND RECOMMENDATIONS

It can be concluded that the installation of offshore wind turbines induces changes in the macrobenthos. Results from the current study revealed that differences in macrobenthic community were observed between the close and far samples. As no differences in sedimentology were present, it is unclear what underlying ecological processes are responsible for these community changes. It might be related to changing hydrodynamics, presence of an epifaunal community on the turbines, fisheries exclusion inside the wind farm or a combination of these factors.

The current results are not consistent with results from previous studies, which might be related to the turbine type used. This study was performed in a wind farm dominated by jacket foundations, while the previous study focused on effects near one gravity-based foundation. Jackets have an open structure, allowing the main current flow to pass through. Gravity-based foundations on the other hand obstruct currents and areas with a lower current flow are generated in the wake of the turbine. These differences in flow velocity influence colonization potential of epifaunal species and sediment and TOM resuspension. In addition, the fisheries exclusion inside the wind farm might give macrobenthic species that are sensitive to disturbance a chance to recover. Although no clear trend was observed yet, this reason cannot be ruled out.

As the current study revealed that some differences in the macrobenthic community are present between the close and far samples, but cannot be explained by specific ecological processes, it is recommended to continue to current sampling design and take samples close to the turbines. In addition it would be interesting to perform a targeted monitoring study on the sedimentology and enrichment potential in the close vicinity of the turbines. In addition to Coates et al. (2014) this should include different foundation types as the current results suggest that the turbine type might play an important role in the habitat structuring. We suggest using the sampling design of Coates et al. (2014) and sample at a gravity-based foundation, a monopile and a jacket foundation.

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