CHAPTER 5

EFFECTS OF BELGIAN OFFSHORE WINDFARMS ON SOFT SEDIMENT EPIBENTHOS AND FISH: AN UPDATED TIME SERIES

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Abstract

Since 2005, ILVO has been performing beam trawl monitoring aimed at evaluating the potential effects of wind farms on the soft sediment epibenthos and fish in between turbines. The study effort is concentrated on the Thornton and Bligh Bank offshore wind farms (OWFs). In this chapter, an update on the time series collected between 2005 and 2016 is presented.

The main conclusions are: 1) soft sediment epibenthos and fish assemblages in between the turbines (at distance > 200 m) have not really changed 6 years after the construction of the wind turbines; 2) species assemblages within the OWFs seem to be mainly structured by temporal variability at larger spatial scales; 3) the post-construction "overshoot" of epibenthos density and biomass caused by an increase in opportunistic, scavenging species, was a temporary phenomenon lasting only 2 years post-construction; 4) no effect of fisheries exclusion is yet observed in soft sediment epibenthos and fish between the turbines; 5) monitoring effort should be increased with a higher number of replicate samples per survey to increase the statistical power of the analyses.

1. Introduction

Construction of offshore wind farms (OWFs) introduces artificial hard substrates into the typical soft bottom sandy environment in the Belgian part of the North Sea (BPNS). These hard substrates generate a new "rocky" habitat which attracts hard substrate species (Lindeboom *et al.* 2011; Kerkhof *et al.* 2012; De Mesel *et al.* 2015), and creates a reef effect for epibenthic fauna and demersal and benthopelagic fish (Reubens *et al.* 2011; 2013; Stenberg *et al.* 2015). This reef effect, in combination with fisheries exclusion in the wind farm area, may affect the original soft bottom epibenthos and fish assemblages between the wind turbines.

Currently, three OWFs are operational in the BPNS. In 2008, C-Power installed the first six gravity-based wind turbines (30 MW) at the Thornton Bank, followed by the construction of 48 more jacket foundation turbines (295 MW) in 2011, becoming operational in 2013. In 2009-2010, Belwind constructed 55 monopile turbines (165 MW) at the Bligh Bank, and additionally 50 monopile turbines (165 MW) in 2016-2017 in the adjacent Nobelwind concession zone. In between these two OWFs, Northwind NV built 72 more monopile turbines in 2013 at the Lodewijckbank.

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2. Material and methods

2.1. Sampling

Since the previous report of Derweduwen *et al.* (2016a), one extra sampling campaign was performed in autumn 2016. Due to recurring technical problems with RV Belgica (which gave us less ship time) in combination with construction works at Nobelwind, adjacent to the Belwind concession area, we could only focus on the wind farm effects and not on the fringe effects. In autumn 2016, trawl samples were taken in between the wind farms (4 within C-Power and 2 within Belwind) and at several reference locations away of the concessions (fig. 1). On these track locations, 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. The net was towed for 15 minutes at an average speed of 4 knots. Data on time, start and stop coordinates, trajectory and sampling depth were noted to enable a correct conversion towards sampled surface units. The fish tracks are more or less positioned following depth contours that run parallel to the coastline, thereby minimizing the depth variation within a single track, except for tracks 2 and 3 within the C-power concession which are perpendicular to the coastline due to the positioning of the in-field electricity cables. Epibenthos and fish were identified, counted, measured (all fish, crabs and shrimps) and wet weighted (all epibenthos) onboard. The samples that could not be fully processed onboard were frozen and further processed in the lab.

2.2. Data used and statistical analyses

The time series of trawl samples in both C-Power and Belwind dates back to respectively 2005 and 2008. However, within the sampling period 2005-2016, the sampling design had to be adapted based on previous monitoring results, wind farm accessibility, weather conditions, and research vessel availability. An overview on sampled stations in autumn during the entire time period is given in table 1 and 2. For an overview map of all track locations, the reader is referred to Vandendriessche *et al.* (2015).

For this chapter, we tested wind farm effects for two ecosystem components (epibenthos and demersal-benthopelagic fish) in a two-factorial PERMANOVA design with factors "year" and "impact" for univariate parameters (species number, density, biomass), and with factors "phase" and "impact" for community structure (with "phase" we mean the state of the concession, being either T0, construction, right after construction, and operational phase). This was done for both the C-Power and Belwind concession separately. The primary aim was to analyse interaction effects between "year" and "impact" or "phase" and "impact", since these would reveal whether the changes that occurred could be attributed to the construction of the OWF. When a significant effect for the "impact x year" or "impact x phase" interaction term was found, pairwise tests were conducted to test for differences between impact and reference samples within each year or each phase. P values for pairwise test were, due to the restricted number of possible permutations, drawn from Monte Carlo (MC) permutations (Anderson & Robinson 2003).

SIMPER analyses were done to find the species responsible for the observed changes. All samples used for the tests in this chapter are highlighted in table 1 and 2. Tests were done on density, biomass (the latter only for epibenthos), species richness and

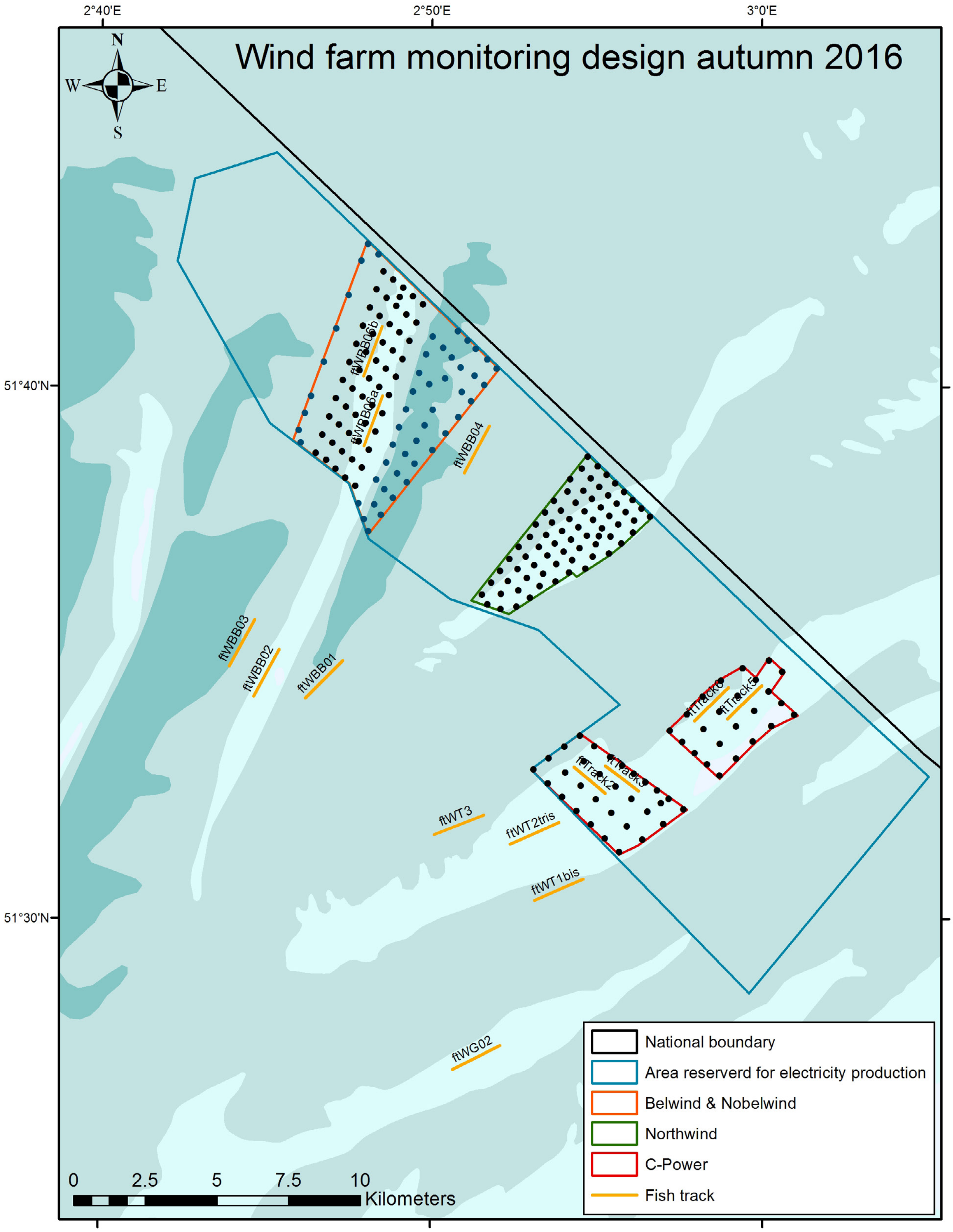

Figure 1. Overview map showing the 2016 trawl locations at the C-Power and Belwind concession area and the respective reference locations.

Table 1. Overview table of autumn sampled locations for effects of the C-Power wind farm within the time period 2005-2016 with indication of different phases within the wind farm's construction

Thornton Bank design			T0 Baseline			Construction phase 1		Operational phase 1	Construction phase 2 & 3	Right after construction	1 year after construction	Operational phase		
Location	imp/ref/fri	top/gully	2005	2006	2007	2008	2009*	2010	2011	2012	2013	2014	2015	2016
ft330	ref	gully	x		x	x	x (l)	x	x	x	x	x		
ftWG2	ref	top	x	x	x	x		x		x	x	x		x
ftWT1bis	ref	gully	x			x		x		x	x	x		x
ftWT2bis	ref	top	x			x	x (l & s)	x	x	x	x	x		x
ftWT3	ref	gully	x			x	x (l & s)	x		x	x	x		x
ftWT4	impact	top	x			x		x						
ftWT5	impact	top	x			x	x (l & s)	x						
ftWT6	impact	gully	x			x		x						
ftWT7	fringe	gully	x			x	x (l)	x		x	x	x		
ftWT8	impact	top	x	x	x	x	x (l)	x						
ftWT9	fringe	gully	x			x	x (l & s)	x		x	x	x		
ftWT10	fringe	gully								x	x	x		
ftWT11	fringe	gully								x	x	x		
ftTrack1	impact	top								x				
ftTrack 2	impact	top								x	x			x
ftTrack 3	impact	top								x	x			x
ftTrack4	impact	top								x				
ftTrack 5	impact	top								x	x	x		x
ftTrack 6	impact	top								x	x	x		x

* Before 2009 all fish tracks were 2 NM – 30' trawls. In 2009, there was a switch from long (l) (2 NM – 30' trawl) to short (s) (1 NM – 15' trawl) fish tracks and afterwards all tracks were short trawls (see Derweduwen et al. 2010). Highlighted samples were used for the current analyse.

Table 2. Overview table of autumn sampled locations for effects of the Belwind wind farm within the time period 2005-2016 with indication of different phases within the wind farm's construction

Bligh Bank design			T0 Baseline	Construction Belwind		Right after construction	1 year after construction	Operational phase			
Location	imp/ref/fri	top/gully	2008	2009	2010*	2011	2012	2013	2014	2015	2016
ftWBB01	ref	gully	x	x	x (l & s)	x	x	x	x		x
ftWBB02	ref	top	x	x	x	x	x	x			x
ftWBB03	ref	gully	x	x	x	x	x	x	x		x
ftWBB04	fringe	gully	x	x	x	x	x	x	x		x
ftWBB05	impact	gully	x	x		x	x	x	x		
ftWBB06a	impact	top	x	x		x	x	x			x
ftWBB06b	impact	top				x	x	x			x
ftWBB07	impact	gully	x	x		x	x	x	x		
ftWBB08	fringe	gully	x	x	x	x	x	x	x		
ftWOH01	ref	gully	x		x	x	x	x			
ftWOH02	ref	top	x	x	x	x	x	x			
ftWOH03	ref	gully	x	x	x	x	x	x			

* Before 2010 all fish tracks were long (l) 2 NM 30' trawls, from 2010 onwards all fish tracks became short (s) 1 NM – 15' trawls (see Derweduwen et al. 2010). Highlighted samples were used for the current analyses.

community structure per ecosystem component and per OWF.

Pelagic species (based on www.fishbase.org) such as *Sprattus sprattus*, *Trachurus trachurus*, *Scomber scombrus*, next to jellyfish, bivalves (such as *Abra alba)* and polychaetes were excluded from the analyses, since these are not quantitatively sampled with a beam trawl. For analyses on community structure, rare species (frequency $< 6\%$ in the dataset) were excluded, data were square root transformed and similarity among samples was quantified using Bray-Curtis similarity index. PERMANOVA analyses on univariate data (species richness, density and biomass) were performed on Euclidean distance resemblance matrices with unrestricted permutation of raw data.

All analyses were executed using Primer v6 with PERMANOVA add-on software (Clarke & Gorley 2006; Anderson *et al.* 2008).

3. Results

3.1. Epibenthos

3.1.1. Species number, density and biomass

For both wind farms, the number of epibenthic species (S) remained similar over the years between impact and reference samples, and was not affected by the construction of the wind farm (interaction year x impact, Permanova $p > 0.05$) (fig. 2). In the Belwind area, we did observe a decrease in number of species both in impact and reference samples, which may be linked to the switch from long to short fish tracks. Density and biomass showed a similar trend in both wind farms, with an increase in the first two years after construction (*i.e.*, 2011 for C-Power phase 2 and 2010 for Belwind), and levelling off after three years post-construction (fig. 2). This trend was only significant in C-Power (interaction term “year x impact”, Permanova $p = 0.04$ for both density and biomass), not in Belwind.

Variances between samples were higher in the first post-construction years (presented by the wider/longer bars in fig. 2), indicating a higher degree of heterogeneity within the wind farms immediately after the construction phase. Increases in density and biomass in C-Power in the two years post-construction were mainly due to the common star fish *Asterias rubens* and the flying crab *Liocarcinus holsatus* (the latter only in 2013). In Belwind, increases in both biomass and density two years post-construction were owing to *A. rubens* and serpents’ table brittle star *Ophiura albida*.

3.1.2. Species composition

For C-Power, a significant wind farm effect (impact x phase, $p = 0.007$) was found. Pairwise tests showed that impact and reference samples differed significantly in community structure in the phase “right after construction” ($p = 0.04$) and “one year after construction” ($p[mc] = 0.03$). SIMPER analysis showed that this was not due to the occurrence of other species, but related to differences in species’ densities. Much higher average densities of *A. rubens* (80 in impact vs 14 ind./1000 m^2 in reference), and higher densities of the hermit crab *Pagurus bernhardus* (12 vs 5 ind./1000 m^2) occurred in impact samples “right after construction” (*i.e.*, 2012) compared to reference samples in the same phase (fig. 3). One year after construction, differences were again related to higher densities of *A. rubens* (avg. 21 in impact vs 7 ind./1000 m^2 in reference), and this time also higher densities of *L. holsatus* (avg. 18 in impact vs 4 ind./1000 m^2 in reference). During the first three phases (baseline, construction phase 1 and operational phase 1), the dominant species were the brown shrimp *Crangon crangon* and *O. albida* both in impact and reference samples, but after construction phase 2 & 3, densities of both species dropped (fig. 3). This is not a wind farm effect, but rather natural variation since this trend was observed in both impact and reference locations.

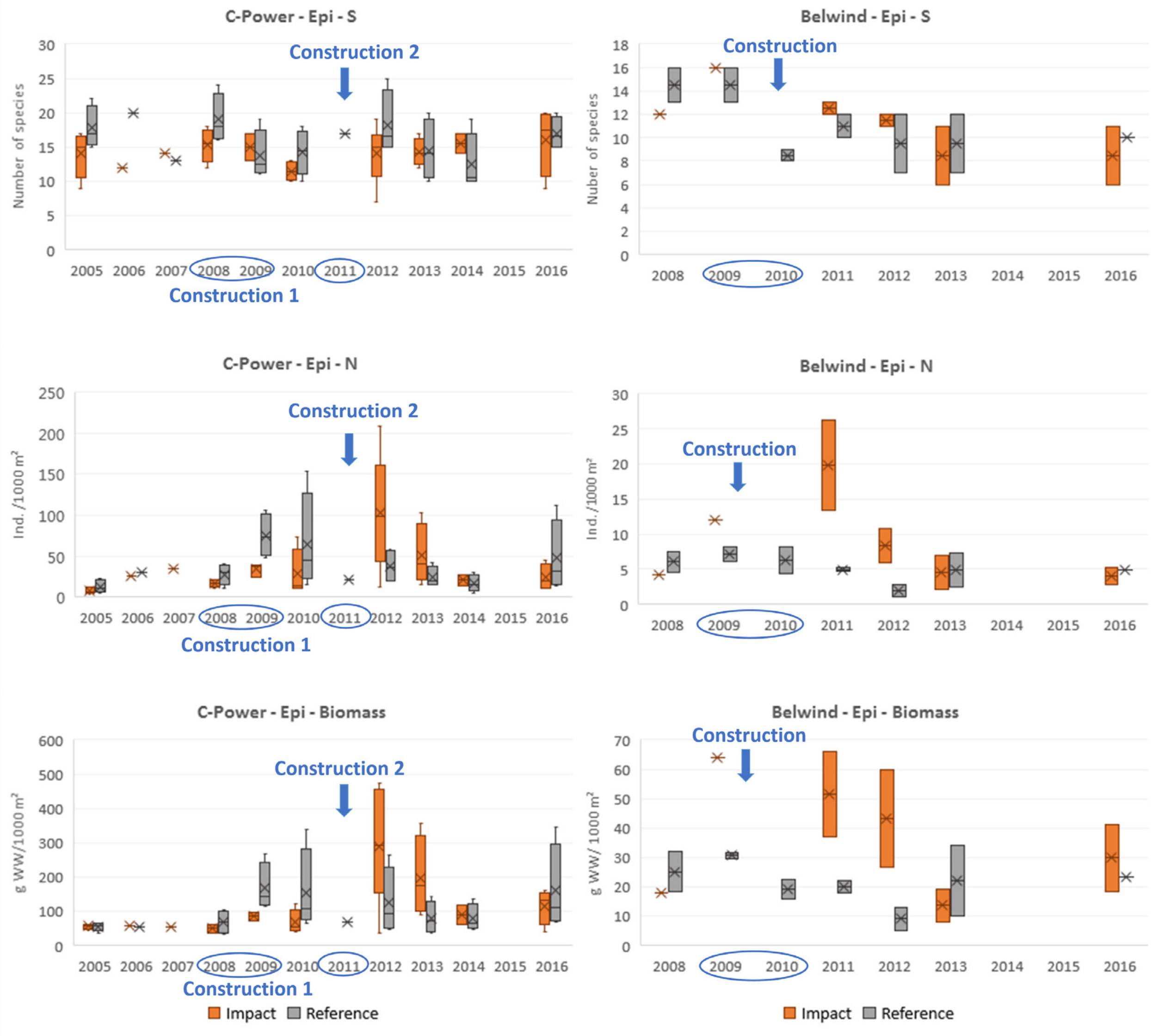

Figure 2. Boxplots showing species richness (S), density (N) and biomass for the ecosystem component epibenthos in both impact and reference samples at C-Power and Belwind wind farm. Median is shown as a horizontal line, average is indicated by x, the bars represent the 0.25 and 0.75 percentiles and the vertical lines are the minima and maximal values recorded.

For Belwind, no significant wind farm effect was observed (impact x phase, p = 0.2) for community structure. The lack of significance can be attributed to the limited number of samples, since differences in species densities were seen in the phase “right after” and “one year after” construction, although again no differences in species composition were found. Higher densities in impact samples were mainly observed for *O. albida* (3 in impact vs 0.2 ind./1000 m² in reference right after construction; 2 vs 0.1 one year after construction) and *P. bernhardus* (8 vs 3 ind./1000 m² shortly after; 3 vs 1 one year after). This is also shown by the vector overlay based on multiple species correlation (r > 0.4) (fig. 4). *Asterias rubens* also showed much higher densities in impact samples (4 vs 0.3 ind./1000 m² “shortly after”; 2 vs 0.3 ind./1000 m² “one year after”), but since this species is highly correlated to *O. albida* (r = 0.8), it is not shown in the multiple vector overlay.

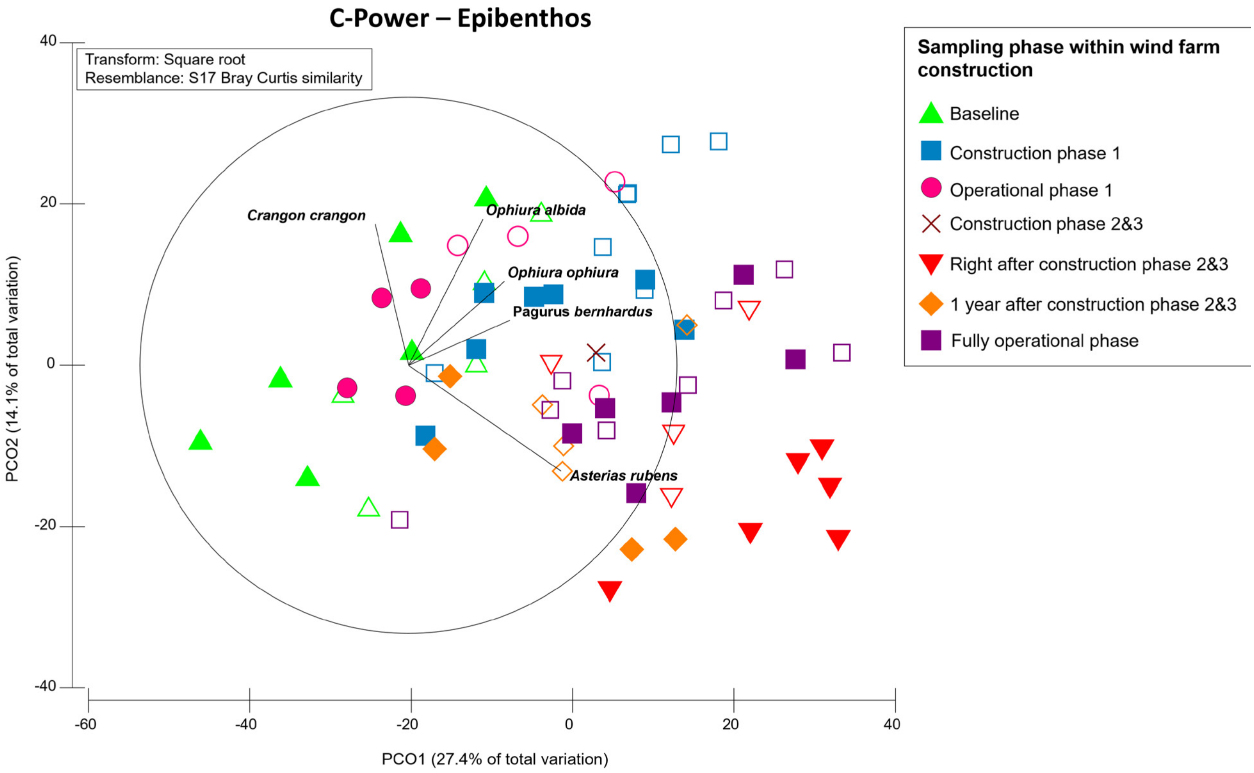

Figure 3. PCO plot of the epibenthos community at C-Power wind farm with indication of the situation phase of the wind farm. Open symbols refer to reference samples, filled symbols are impact samples. Vector overlay shows the species that are best correlated (multiple correlation r > 0.4) with the observed multivariate pattern.

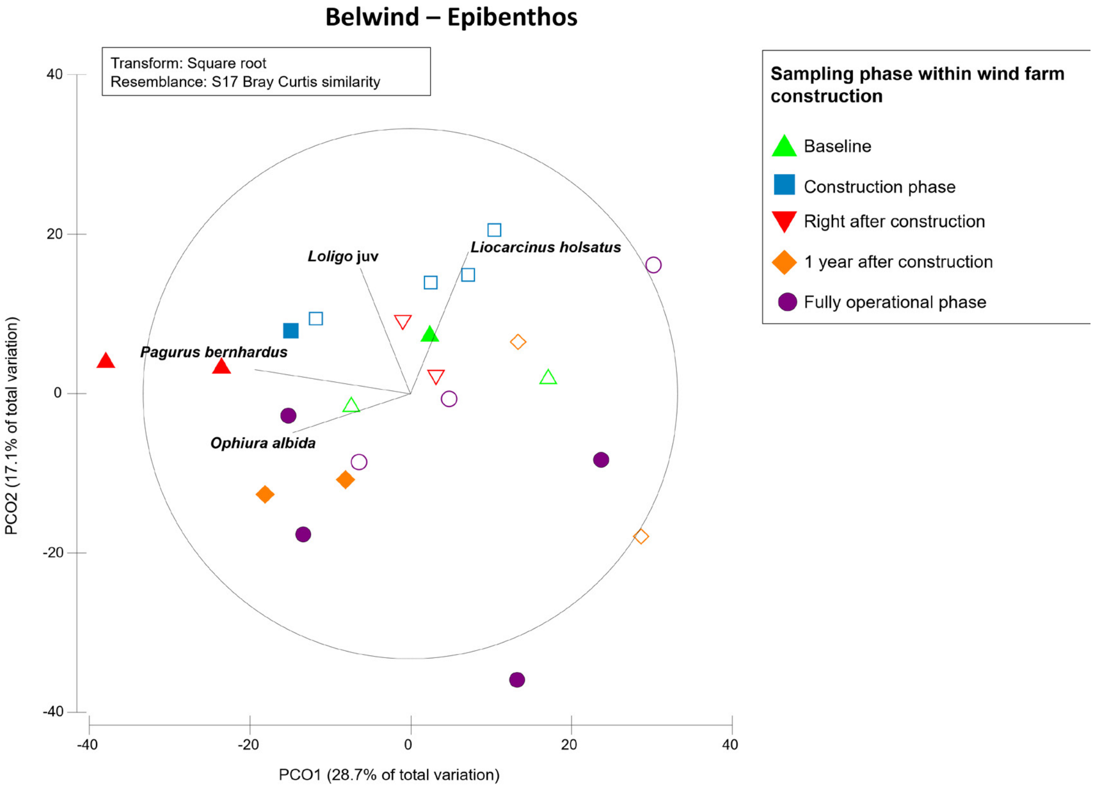

Figure 4. PCO plot of the epibenthos community at Belwind wind farm with indication of the situation phase of the wind farm. Open symbols refer to reference samples, filled symbols are impact samples. Vector overlay shows the species that are best correlated (multiple correlation r > 0.4) with the observed multivariate pattern.

3.2. Demersal and bentho-pelagic fish

3.2.1. *Species number and density*

For the number of species (S), no wind farm effect (interaction year x impact) was observed for the ecosystem component fish, not for C-Power (p = 0.5), nor for Belwind (p = 0.4). In Belwind, a significant year effect (p = 0.03) was observed, with a higher number of species in 2009 compared to the years 2011, 2013 and 2016, but this was the case for both impact and reference samples (fig. 5).

Fish density (N) did not show a significant wind farm effect for both C-Power (p = 0.1) and Belwind (p = 0.8). A decrease in density was observed in Belwind after 2011 in the impact samples, but this was also the case (to a lesser extent) in the reference samples, so this is probably related to natural variation (fig. 5). Especially lower densities of the dominant species lesser weever *Echiichthys vipera* were noted from 2012 onwards, but also decreases in other species like solenette *Buglossidium luteum,* gobies *Pomatoschistus* sp. and reticulated dragonet *Callionymus reticulatus* were observed, again both in reference and impact samples. As for epibenthos, there seemed to be some more variance in fish densities directly after construction.

3.2.2. *Community structure*

For both wind farms, fish community structure was not affected by the construction of the OWF (impact x phase, p > 0.05). The sampling period or phase, on the other hand, was significant for both C-Power (p = 0.0001) and Belwind (p = 0.006), indicating that similar changes occurred over time both in reference and impact samples. These changes were not on the level of

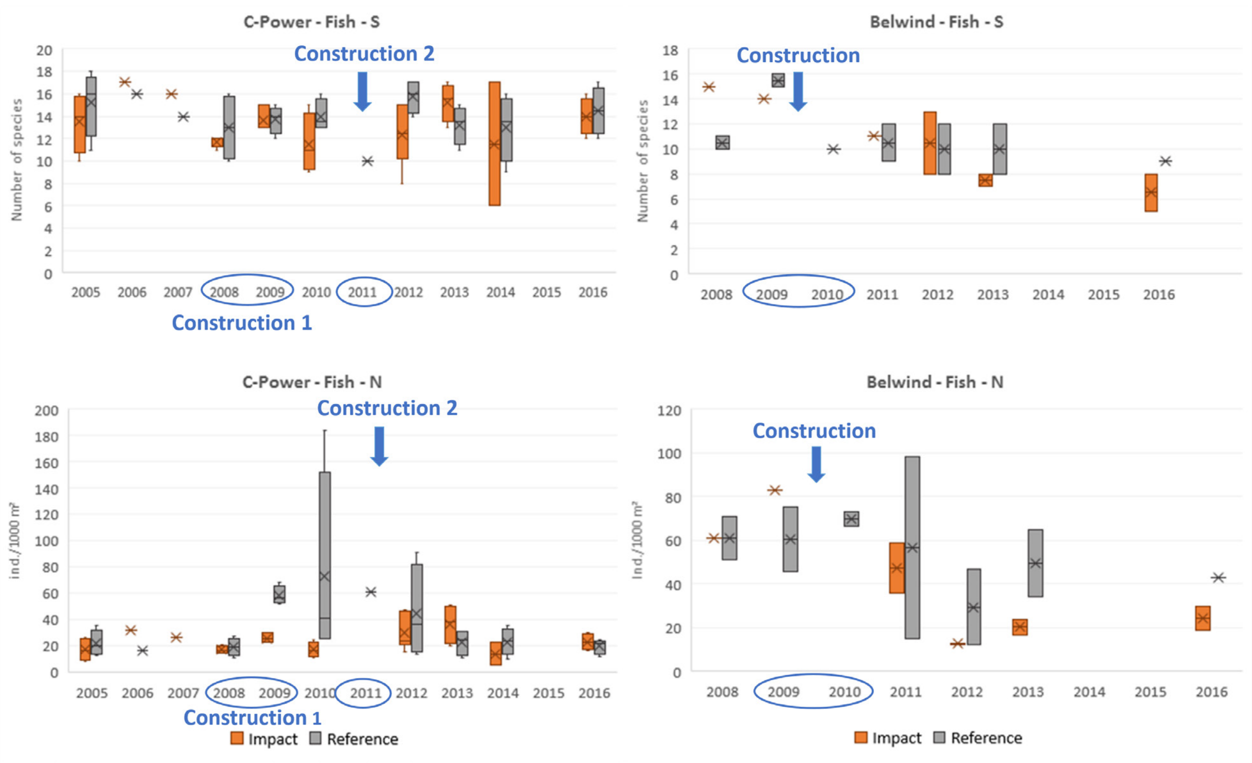

Figure 5. Boxplots showing species richness (S) and density (N) for the ecosystem component fish in both impact and reference samples at C-Power and Belwind wind farms. Median is shown with a line, average is indicated by x, the bars represent the 0.25 and 0.75 percentiles and the vertical lines are the minima and maximal values recorded.

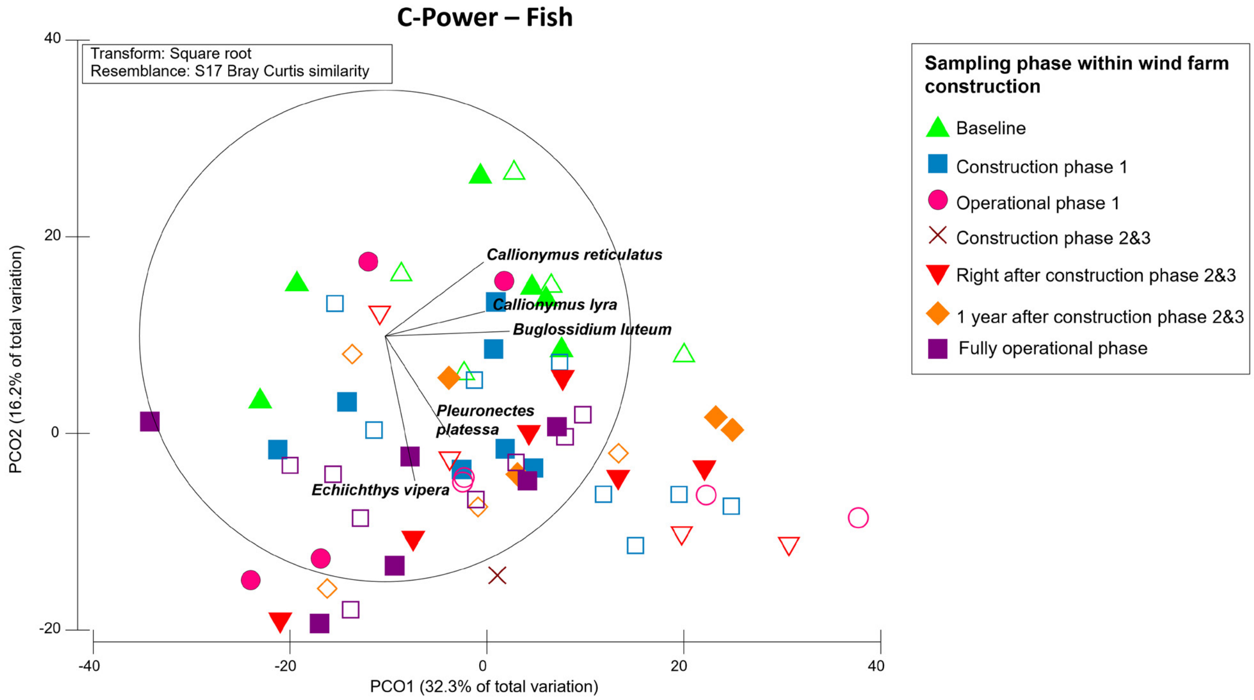

Figure 6. PCO plot of the fish community at C-Power wind farm with indication of the situation phase of the wind farm. Open symbols refer to reference samples, filled symbols are impact samples. Vector overlay shows the species that are best correlated (multiple correlation r > 0.4) with the observed multivariate pattern.

species composition, but were due to density changes at the species level for certain fish species.

Within the Thornton Bank area (C-Power), the multivariate pattern was best explained by the species *Pleuronectes platessa* (plaice), *E. vipera*, *B. luteum*, *Callionymus lyra* (common dragonet) and *C. reticulatus* (fig. 6). An overall increase over time was observed for *E. vipera*, while *C. reticulatus* showed a decreasing trend, but this was noted in both impact and reference samples. Only for *P. platessa*, a wind farm effect was observed (interaction p = 0.04), a continuously increasing trend over time was seen mainly in impact samples,

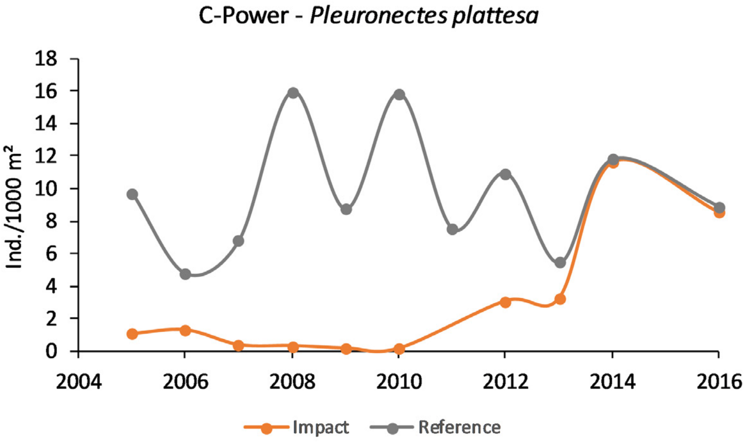

Figure 7. Timeline of average plaice densities in impact and reference samples at C-Power.

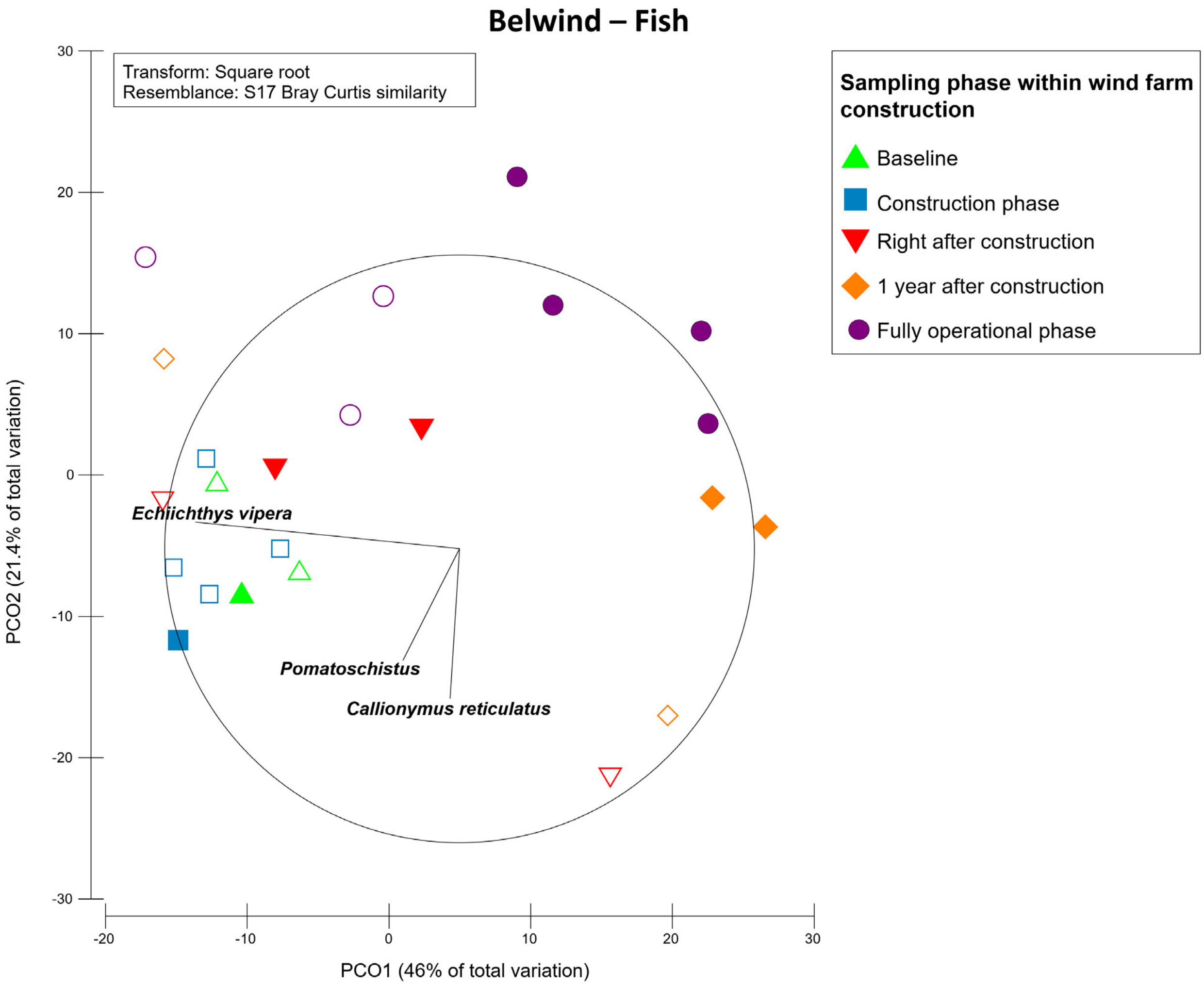

Figure 8. PCO plot of the fish community at Belwind wind farm with indication of the situation phase of the wind farm. Open symbols refer to reference samples, filled symbols are impact samples. Vector overlay shows the species that are best correlated (multiple correlation r > 0.4) with the observed multivariate pattern.

reaching similar densities as reference samples in 2013 (start of the fully operational phase) (fig. 7).

The Bligh Bank (Belwind) multivariate pattern was best explained by trends in densities of *E. vipera*, *Pomatoschistus* sp. and *C. reticulatus* (fig. 8). A decrease in *E. vipera* was observed over time, and is best related with the first PCO axis (fig. 8). This decreasing trend was most obvious in impact samples, but also in reference samples a slight decrease was also seen. *Pomatoschistus* sp. and *C. reticulatus* showed a decreasing trend over time in both impact and reference samples. This trend is best related to the second PCO axis (fig. 8).

4. Discussion and conclusions

This chapter presents an update of the monitoring time series for epibenthos and fish sampled between 2005 and 2016 in the C-Power and Belwind concession area. Since the previous report (Derweduwen *et al.* 2016a), the time series was expanded with one sampling survey in autumn 2016. Hence, the analyses focused on the effect of a wind farm (combined influence of introduction of hard substrate and fisheries exclusion) on the soft sediment epibenthos and fish communities. No fringe effects were investigated. Seasonality was excluded by only including autumn samples.

The main conclusions are:

• The OWFs did not directly affect the number of species or the species composition of the soft sediment epibenthos and fish assemblages. This indicates that the soft sediment ecosystem in between the turbines (at distance > 200 m) has not really changed (yet), some 5 to 6 years post-construction. The species originally inhabiting the sandy bottom are still in place and remain dominant in the species assemblages. This is in line with other studies, *e.g.*, Bergström *et al.* (2013) and Stenberg *et al.* (2015). However, there is one species, *Pleuronectes platessa* (plaice) that seems to be positively affected by the OWF, since densities increased after construction, indicating an attraction effect due to increased food availability and/or fisheries exclusion. Furthermore, although overall fish assemblages did not change, the feeding behavior of some fish species within the assemblage has changed (Derweduwen *et al.* 2016b): instead of limiting their diet to characteristic sandy bottom prey species, the investigated fish species (*i.e.*, lesser weever and dab) started preying upon species typically associated with hard substrates, so in that respect the presence of OWFs surely has an impact on the soft bottom ecosystem.

• The species assemblages within the OWFs seem to be mainly structured by temporal variability at larger spatial scales such as yearly temperature fluctuations, hydrodynamic changes, or plankton blooms. These processes influence species populations in a wider area, and that signal is picked up in our samples both in the OWFs and reference areas. For instance, the brown shrimp *Crangon crangon* was a dominant species in autumn samples at C-Power before 2012 in both impact and reference locations, but it almost disappeared afterwards. This can be linked to a change in the migration pattern or reproduction cycle in relation to temperature differences (Boddeke 1975; Beukema 1992). For future analyses, it would be worthwhile to include environmental variables to gain a better insight in the observed patterns.

• For epibenthos, a post-construction "overshoot" of density and biomass was discerned directly after the construction phase of the windfarms. The pattern was identical for both OWFs; a density and biomass peak up to two years post-construction, but decreasing towards comparable levels as reference samples after three years post-construction. This shows that the previously observed wind farm effect (Vandendriessche *et al.* 2013; Derweduwen *et al.* 2016) was probably only a temporary phenomenon. Density and biomass peaks could be attributed to four species: *Asterias rubens* and *Pagurus bernhardus* (in both OWFs), *Liocarcinus holsatus* (C-Power) and *Ophiura albida* (Belwind). Increased densities in the common starfish (*A. rubens*) were also noted in macrobenthos samples from the area (Coates *et al.* 2014) and on the turbine foundations (Kerkhof *et al.* 2012). These four species are all typical opportunistic, scavenging species, that were probably attracted to the increased food availability due to fouling communities on the turbines. It also seems that these species had a patchy distribution, since variability between replicate samples was large in the two post-construction years compared to other years. High variability is characteristic for disturbances in biological communities, which can explain why several common species did aggregate, instead of being equally distributed. This density pattern was also noted in the multivariate analyses, especially in C-Power since *A. rubens* and *L. holsatus* were highly dominant in the assemblage during the two years post-construction.

• An effect of fisheries exclusion is not observed yet in the area in between the turbines. Near the turbines, "refugium" effects have been observed for fish (Reubens *et al.* 2013; Stenberg *et al.* 2015), but in the current phase of the wind farms, such a refugium effect could not be observed at further distances from the turbines, except maybe for plaice that showed a clear increased density after construction. Besides the direct positive effects of fisheries exclusion on fish populations and bycatch species, that could be expected in OWFs serving as marine protected areas, a change in benthic community is also expected as an indirect effect due to the absence of trawling (Duineveld *et al.* 2007). Handley *et al.* (2014) showed that when fisheries are excluded, a change in the macrobenthic assemblages is expected with a bigger share of large long-lived species, sessile epifaunal species and species sensitive to trawling. Functionally, this can mean a shift from mobile scavengers, motile burrowing deposit feeders and predators to more suspension feeders and grazers, as observed in a soft bottom area closed to fisheries for 28 years in New Zealand (Handley *et al.* 2014). This change in benthic community triggered a functional change in the fish assemblage as well. Up till now, no changes in macrobenthos related to fisheries exclusion have been observed in the investigated wind farms in the Belgian part of the North Sea (Reubens *et al.* 2016). As such, a related change in epibenthos and fish assemblage is also not to be expected yet. At this moment, time after construction is probably still too short, and the whole wind farm concession area is not yet large enough to signal effects of fisheries exclusion beyond the immediate vicinity of the turbine.

- Due to several reasons, such as wind farm accessibility, weather conditions and research vessel availability, the number of samples remains limited, which hampers the statistical power for thorough analyses on soft sediment epibenthos and demersal fish assemblages. Striking changes will surely be detected with this design, but more subtle changes may be difficult to be picked up. For the following years we will try to increase the number of replicate samples per survey to increase the power of the analyses.

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