CHAPTER 3

SOFT SEDIMENT EPIBENTHOS AND FISH MONITORING AT THE BELGIAN OFFSHORE WIND FARM AREA:
SITUATION 6 AND 7 YEARS AFTER CONSTRUCTION

DE BACKER Annelies & HOSTENS Kris

Flanders Research Institute for Agriculture, Fisheries and Food (ILVO), Aquatic Environment and Quality, Ankerstraat 1, 8400 Oostende, Belgium

Corresponding author: annelies.debacker@ilvo.vlaanderen.be

Abstract

Since 2005, ILVO performs beam trawl monitoring surveys to evaluate the potential effects of offshore wind farms (OWFs) on soft sediment epibenthos and demersal-benthopelagic fish. The study effort has been concentrated on the C-Power and Belwind OWFs. The time series has been investigated in detail in a previous report, therefore this chapter focuses on the results of 2017, which is resp. 6 (C-Power) and 7 (Belwind) years after construction.

No direct wind farm (‘reef’) effect, nor indirect fisheries exclusion effect, was yet observed for the soft-bottom epibenthos and demersal-benthopelagic fish assemblage in 2017. Species composition, species number, density and biomass (for epibenthos only) of the soft-bottom assemblage inside the OWFs were very similar compared to the assemblage in reference locations outside the OWFs. The species, originally inhabiting the soft sediments of both OWFs, remain to be dominant.

Remarkable was that two epifaunal animals, *i.e.*, *Mytilus edulis* and Anthozoa sp., known to be fouling on the foundations, were quite abundant in the C-Power OWF soft sediment samples, and totally absent or only present in much lower densities in the reference locations outside the OWF. This could indicate that the ‘reef’ effect is starting to expand beyond the direct vicinity of the turbines. However, detailed follow-up is needed to validate whether this is a one-off observation or a real wind farm effect reflected with time after construction possibly because of increasing epifaunal biomass on the foundations.

1. Introduction

Since 2005, ILVO performs beam trawl monitoring surveys to evaluate the potential effects of offshore wind farms (OWFs) on soft sediment epibenthos and demersal-benthopelagic fish. Construction of OWFs introduces artificial hard substrates into the typical soft bottom sandy environment in the Belgian part of the North Sea (BPNS). Introduction of these hard substrates may affect the original soft bottom epibenthos and fish assemblages between the wind turbines. This for two reasons: (1) attraction of hard substrate species (Lindeboom *et al.* 2011; Kerckhof *et al.* 2012; De Mesel *et al.* 2015;

Coolen 2017), and (2) creation of a reef effect for epibenthic fauna and demersal and benthopelagic fish (Reubens *et al.* 2011, 2013; Stenberg *et al.* 2015). Additionally, fisheries are excluded in the area, which is another potential effect at play to induce changes on the soft-bottom assemblages (Handley *et al.* 2014).

Our study effort has been concentrated on the C-Power (54 turbines, 325 MW) and Belwind (55 turbines, 165 MW) OWFs, the first OWFs in Belgian waters. In De Backer & Hostens (2017), an update on the time series up to 2016 (resp. 5 and 6 years after construction) was given. Results so far showed a post-construction 'overshoot' of epibenthos density and biomass caused by an increase in opportunistic, scavenging species (similar as was noted in Derweduwen *et al.* 2016a). This was, however, a temporary phenomenon lasting only two years post-construction. Overall, soft sediment epibenthos and demersal-benthopelagic fish assemblages in between the turbines (at distance > 200 m) had not really changed six years after the construction of the wind turbines, and no effect of fisheries exclusion is yet observed in soft sediment epibenthos and fish between the turbines. Nevertheless, the feeding behaviour 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. For the moment, time after construction is probably still too short, and the whole OWF operational area not yet large enough to signal effects of fisheries exclusion beyond the immediate vicinity of the turbine (De Backer & Hostens 2017).

In 2017, another survey was undertaken to extend the time series. Last year, the time series was investigated in detail (De Backer & Hostens 2017), hence this chapter focuses on the results of 2017, 6 (C-Power) and 7 (Belwind) years after construction. We compare the results observed in 2017, with the observations described in previous years (*i.e.*, no real 'reef' and fisheries exclusion effect yet on the soft sediment assemblage between the turbines) to see whether the previous conclusions remain valid or whether effects occurred in 2017 due to increased time after construction.

2. Material and methods

2.1. Sampling

Since the previous report of De Backer and Hostens (2017), one extra sampling campaign was performed in autumn 2017 with RV Belgica. Trawl samples were taken in between the wind farms (4 within C-Power and 3 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 during 15 minutes at an average speed of 4 knots over approximately 1 nautical mile. 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 infield electricity cables. Epibenthos and fish were identified, counted, measured (all fish, crabs and shrimps) and wet weighted (all epibenthos) on board. The samples that could not be fully processed on board, were frozen and further processed in the lab.

Figure 1. Overview map showing the 2017 trawl locations at the C-Power and Belwind concession area and the respective reference locations.

2.2. Data used and statistical analyses

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 this chapter, we tested wind farm effects for sampling year 2017 for two ecosystem components (epibenthos and demersal-benthopelagic fish) for the C-Power and Belwind concession separately.

For each trawl sample, univariate variables for each ecosystem component (species number, density and biomass for epibenthos only) were calculated using the DIVERSE application in Primer v6 with PERMANOVA add-on software (Clarke & Gorley 2006; Anderson *et al.* 2008). To test for significant differences in univariate variables for 2017, one-way Permanova with factor 'impact' was done on Euclidean distance resemblance matrices with unrestricted permutations of raw data. P values were, due to the restricted number of possible permutations, drawn from Monte Carlo (MC) permutations (Anderson & Robinson 2003). However, for visualization purposes and to show the extension of the time series, 2017 results were added to time series graphs, which were produced based on average values (± standard deviation) in R 3.3.3. (R Core Team 2017) using plyr (Wickham 2011) and ggplot2 (Wickham 2009) packages. For Belwind OWF, we excluded the gully samples, both in impact (ftWBB07) and reference (ftWOH01-03 and ftWBB01-03), from the univariate analyses and only included the top samples, since univariate variables are known to be higher in gully samples compared to top samples (Vandendriessche *et al.* 2009), and this could blur effect results, which we are interested in. For the multivariate analyses looking at species composition of Belwind OWF, both top and gully samples were included. For C-Power OWF, all samples were included in both the univariate and multivariate analyses.

Multivariate data analysis was done using a multivariate model-based approach available in the package 'mvabund' (Wang *et al.* 2012) in R 3.3.3. Square root transformed multivariate species abundance data were fitted against impact using the *manyglm* function with 'negative binomial' family. The mean-variance assumption was checked by plotting residuals versus fits. Afterwards, univariate tests for each species separately can be run as well which allows looking at individual species effects. This package allows for visualization of multivariate species data against impact by using *e.g.*, boxplots.

3. Results

3.1. Epibenthos

3.1.1. Species number, density and biomass

For 2017, no significant effects in any of the univariate variables were observed, not for C-Power, nor for Belwind. Values were very similar between impact and reference samples, and much higher for C-Power compared to Belwind (table 1).

The 2017 values were added in time series graphs (fig. 2) showing average values for species richness (S), density (N) and biomass for impact and reference samples at both C-Power and Belwind (only top samples) over time for epibenthos. The trend from 2016 to 2017 for impact and reference samples is very similar, and within the boundaries of what can be expected in natural variability (fig. 2). Overall, trends over time are very similar between impact and reference samples, with the exception of the post-construction overshoot in density and biomass in the two years following construction for both OWFs (see De Backer & Hostens 2017).

Table 1. Average epibenthos species richness (S), density (N) and biomass for 2017 of both impact and reference samples in C-Power and Belwind

OWF	Imp/Ref	Avg. S ± SD	Avg. N ± SD (Ind. 1000 m^{-2})	Avg Biomass ± SD (g WW 1000 m^{-2})
C-Power	Imp	23 ± 2	60 ± 46	285 ± 156
	Ref	20 ± 4	68 ± 48	192 ± 100
Belwind	Imp	15 ± 4	8 ± 4	60 ± 21
	Ref	12 ± 8	4 ± 3	35 ± 44

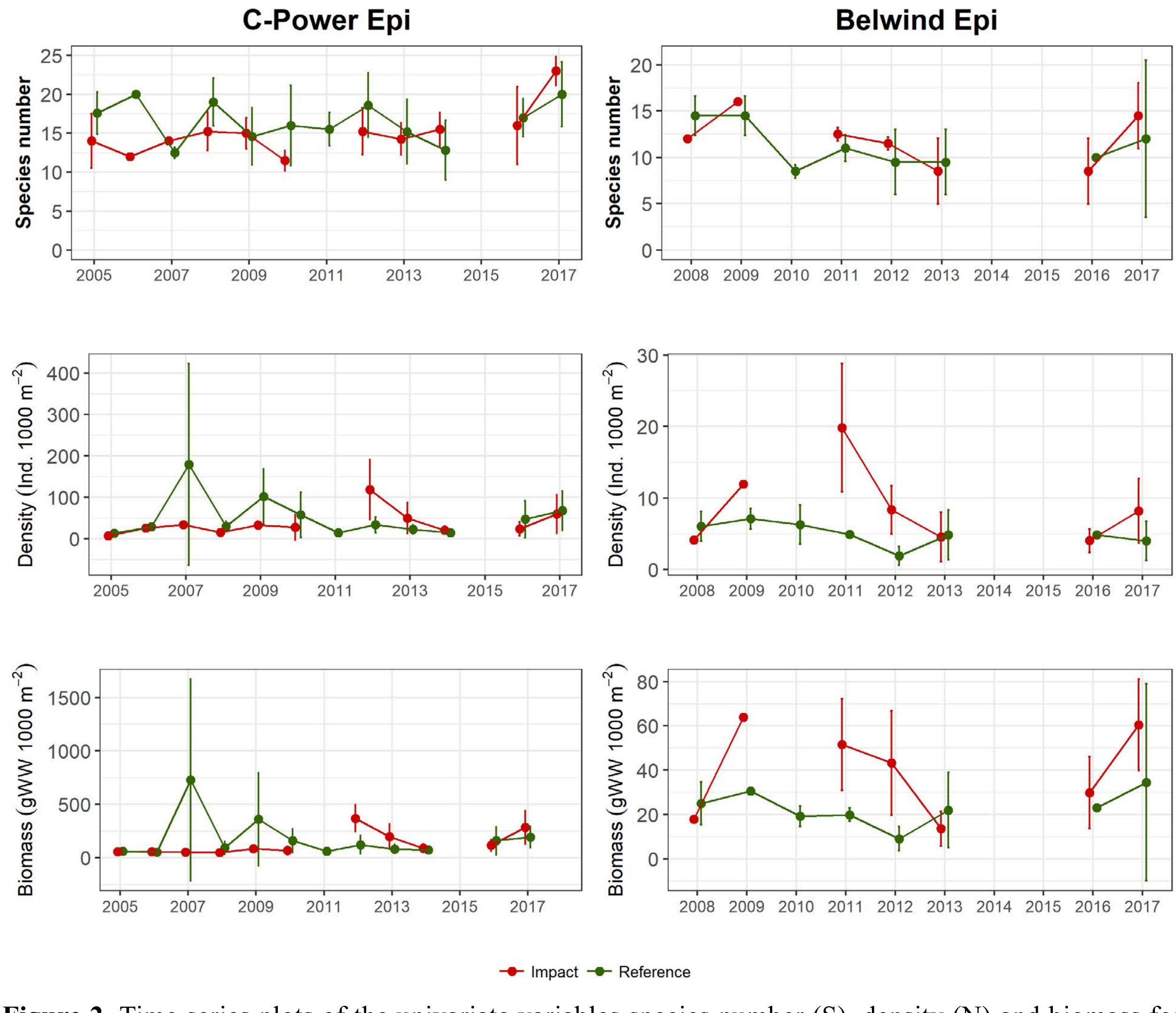

Figure 2. Time series plots of the univariate variables species number (S), density (N) and biomass for epibenthos for both impact and reference samples at C-Power and Belwind wind farm. Average values ± SD are shown. Construction second phase C-Power in 2011, construction of Belwind in 2009-2010.

3.1.2. Species composition

The overall epibenthos species assemblage was not significantly different between impact and reference samples in 2017, not for C-Power (LRT = 39; p = 0.1), nor for Belwind (LRT = 3; p = 0.75). Looking at individual species abundances (fig. 3), occurrence and abundance was very similar between reference and impact samples. Top 3 species for C-Power were the brittle stars *Ophiura ophiura* (resp. avg. 15 and 24 Ind. 1000 m^{-2}) and *Ophiura albida* (resp. avg. 13 and 22 Ind. 1000 m^{-2}) and the hermit crab *Pagurus bernhardus* (resp. avg. 6 and 8 Ind. 1000 m^{-2}) both in impact and reference. For Belwind, top 3 species in both impact and reference, were *Pagurus bernhardus* (resp. avg. 6 and 4 Ind. 1000 m^{-2}), *Ophiura albida* (resp. avg. 2 and 1 Ind. 1000 m^{-2}) and the star fish *Asterias rubens* (resp. avg. 1 and 1 Ind. 1000 m^{-2}) (fig. 3).

Anemones Anthozoa and blue mussel *Mytilus edulis* were in C-Power, however, much more abundant in impact (resp. avg. 3.4 and 5 Ind. 1000 m^{-2}) compared to reference samples (resp. avg. 0.3 and 0.04 Ind. 1000 m^{-2}) (fig. 3). For Anthozoa, this was even significantly higher (LRT = 9; p = 0.03). For Belwind, the squid *Loligo vulgaris* was observed in higher abundances in impact (avg. 1 Ind. 1000 m^{-2}) than in reference samples (avg. 0.5 Ind. 1000 m^{-2}), however, this was not at all significant.

3.2. Demersal and bentho-pelagic fish

3.2.1. Species number and density

In 2017, no significant effects for S or N were observed in neither of the two OWFs. Average values for species richness and density were very similar for both impact and reference samples (table 2).

The 2017 results were added to the time series graphs (fig. 4) for demersal and bentho-pelagic fish showing average values for species richness (S) and density (N) for impact and reference samples at both C-Power and Belwind (only top samples) over time. Both impact and reference samples show exactly the same evolution between 2016 and 2017, indicating that no wind farm effect is at play when looking at univariate variables (fig. 4). Overall, trends over the entire time series are very similar between impact and reference samples, and this for both OWFs.

3.2.2. Species composition

The overall demersal and bentho-pelagic fish species assemblage was not significantly different between impact and reference samples in 2017, not for C-Power (LRT = 3.5, p = 0.8), nor for Belwind (LRT = 9, p = 0.07).

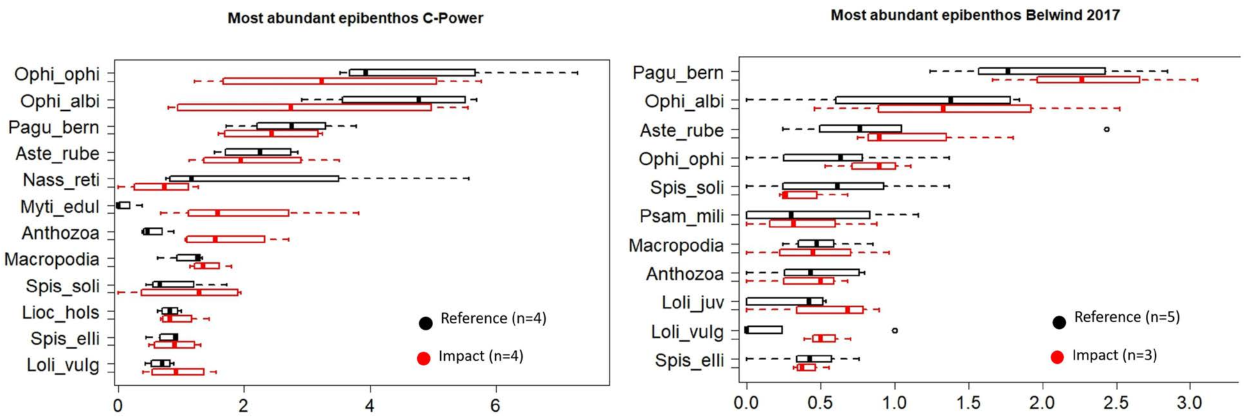

Figure 3. Box-and-whisker-plots showing minimum, maximum, 0.25 percentile, 0.75 percentile and median sqrt densities for most abundant epibenthos species in reference (black) and impact (red) samples for C-Power and Belwind (Autumn 2017). Outliers are represented as circles. List for full species names in annex 1.

Table 2. Average fish species richness (S) and density (N) for 2017 of both impact and reference samples in C-Power and Belwind

OWF	Imp/Ref	Avg. S ± SD	Avg. N ± SD (Ind. 1000 m^{-2})
C-Power	Imp	15 ± 2	24 ± 13
	Ref	15 ± 2	19 ± 11
Belwind	Imp	11 ± 1	10 ± 2
	Ref	13 ± 0	15 ± 5

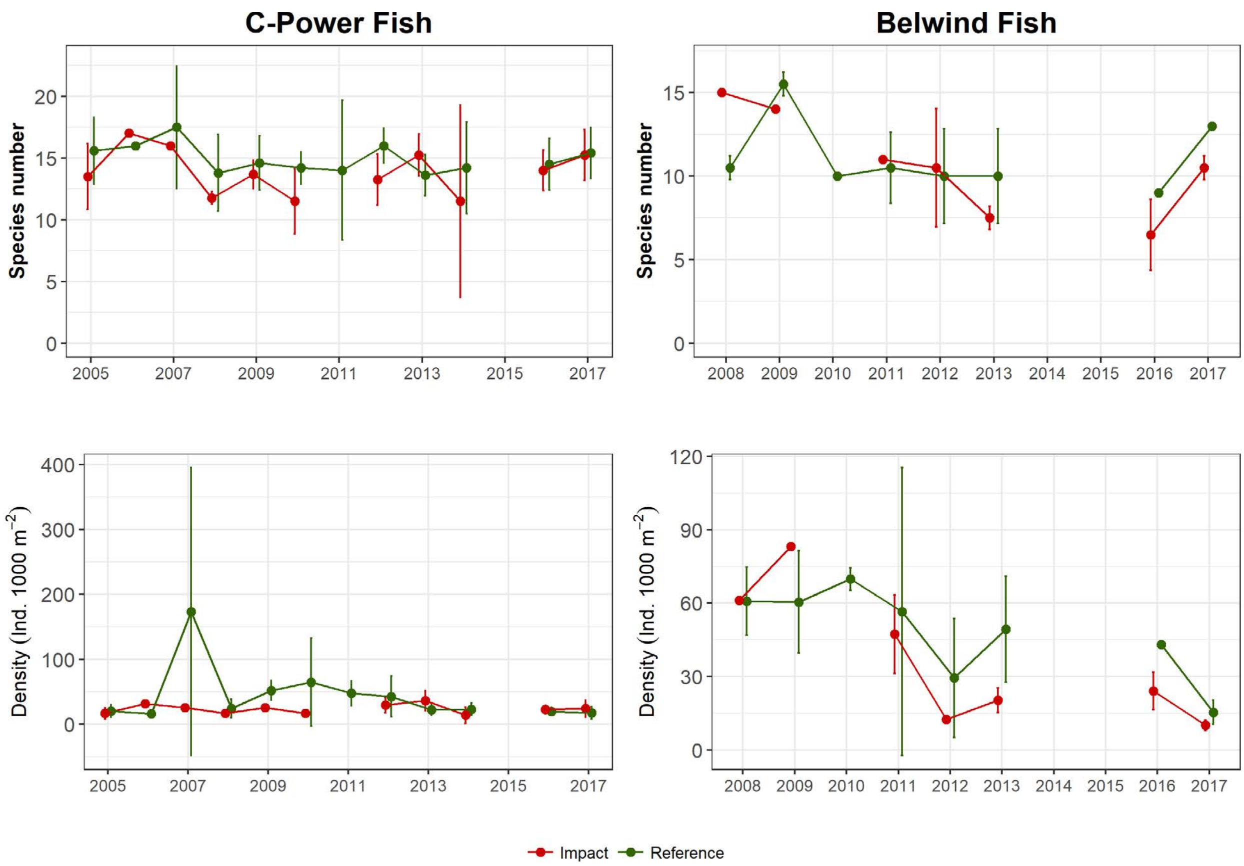

Figure 4. Time series plots of the univariate variables species number (S) and density (N) for bentho-pelagic fish for both impact and reference samples at C-Power and Belwind wind farm. Average values ± SD are shown. Construction second phase C-Power in 2011, construction of Belwind in 2009-2010.

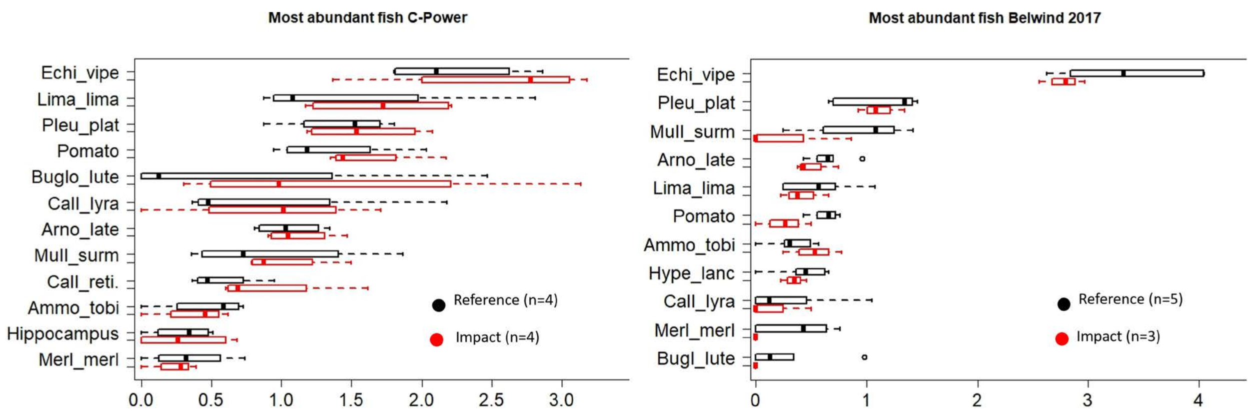

Figure 5. Box-and-whisker-plots showing minimum, maximum, 0.25 percentile, 0.75 percentile and median sqrt densities for most abundant bentho-pelagic fish species in reference (black) and impact (red) samples for C-Power and Belwind (Autumn 2017). Outliers are represented as circles. List for full species names in annex 1.

However, for Belwind, some differences in abundance could be observed, but these could mainly be attributed to the higher number of gully samples in the reference zone (3 versus 1 in impact).

For C-Power, lesser weever *Echiichtys vipera* (resp. avg. 7 and 5 Ind. 1000 m^{-2}), dab *Limanda limanda* (resp. avg. 3 and 3 Ind. 1000 m^{-2}) and plaice *Pleuronectes platessa* (resp. avg. 3 and 2 Ind. 1000 m^{-2}) were the most dominant species in both impact and reference samples (fig. 5). Lesser weever and plaice were dominant as well in both reference (resp. avg. 12 and 1 Ind. 1000 m^{-2}) and impact samples (resp. 8 and 1 Ind. 1000 m^{-2}) of Belwind, followed by mullet *Mullus surmuletus* in reference samples (1 Ind. 1000 m^{-2}) and scaldfish *Arnoglossus laterna* in impact samples (0.5 Ind. 1000 m^{-2}) (fig. 5). Other abundant species had similar density ranges for impact and reference samples in both OWFs. No significant wind farm effect was found for any of the individual species.

4. Discussion and conclusions

No direct wind farm ('reef') effect, nor indirect fisheries exclusion effect, was (yet) observed for the soft-bottom epibenthos and demersal-benthopelagic fish assemblage in 2017. Species composition, species number, density and biomass (for epibenthos only) of the soft-bottom assemblage inside the OWFs was very similar compared to the assemblage in reference locations outside the OWFs. This is completely in line with our previous monitoring results (Derweduwen *et al.* 2016a; De Backer & Hostens 2017) and other studies *e.g.*, Stenberg *et al.* (2015), showing as well that during the operational phase of the OWF, the species originally inhabiting the soft sediments remain to be dominant.

One remarkable result in 2017 is that epifaunal animals *i.e.*, *Mytilus edulis* and Anthozoa sp. known to be fouling on the turbine foundations (Krone *et al.* 2013; De Mesel *et al.* 2015) are quite abundant in the C-Power OWF samples, and totally absent or present in much lower densities in the reference locations outside the OWF. This could be a first indication that the 'reef' effect is starting to expand beyond the direct vicinity of the turbines into the soft sediment zones between the wind turbines. Anthozoa were not identified to species level, so verification that the increase is due to the species dominant on the C-Power foundations *Metridium senile* (De Mesel *et al.* 2015) is premature but plausible. In the follow-up survey, identification to species level of Anthozoa can provide a validated answer. For *Mytilus edulis*, life mussel clumps were observed in all samples within C-Power, most probably originating from the turbines. Survival chances of *Mytilus edulis* on mobile soft-bottoms at depths of 20 m, with high risk of burial, are probably low (Hutchison *et al.* 2016). Nevertheless, this observation is in line with the Mytilusation hypothesis (Krone *et al.* 2013), which predicted that increased mussel biomass at wind farm foundations, can produce secondary hard substrate, which may alter the soft-bottom ecosystem. Follow-up is needed to validate whether this is a one-off observation or a real wind farm effect which can increase heterogeneity in the soft-bottom sediments in between foundations. When the increased mussel occurrence between the turbines would persist, more targeted research is needed to further investigate the processes at play. This could include *e.g.*, the survival potential of these mussel clumps on the sandy bottom or the fauna which is associated with this secondary produced hard substrate.

Acknowledgements

The authors would like to thank RBINS OD Nature/Belspo for granting shiptime on RV Belgica and its crew for help during sampling in autumn 2017. Robin Brabant (OD Nature) is acknowledged for help with permits and contacting WVC. Also thanks to several ILVO colleagues for their help during sampling and in the lab.

References

Anderson, M.J. & Robinson, J. 2003. Generalized discriminant analysis based on distances. *Australian & New Zealand Journal of Statistics* 45 (3): 301-318. DOI: 10.1111/1467-842X.00285

Anderson, M.J., Gorley, R.N. & Clarke, K.R. 2008. PERMANOVA+ for PRIMER: guide to software and statistical methods. Plymouth: PRIMER-E, 214 p.

Clarke, K.R. & Gorley, R.N. 2006. PRIMER v6: User Manual/Tutorial. Plymouth Marine Laboratory, 190 p.

Coolen, J. 2017. North Sea reefs. Benthic biodiversity of artificial and rocky reefs in the southern North Sea. PhD thesis, 203 p.

De Backer, A. & Hostens, K. 2017. Effects of Belgian offshore wind farms on soft sediment epibenthos and fish: an updated time series. In S. Degraer *et al.* (eds), *Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: A Continued Move Towards Integration and Quantification*. Brussels: Royal Belgian Institute of Natural Sciences, OD Natural Environment, Marine Ecology and Management Section, pp. 59-71.

De Mesel, I., Kerckhof, F., Norro, A., Rumes, B. & Degraer, S. 2015. Succession and seasonal dynamics of the epifauna community on offshore wind farm foundations and their role as stepping stones for non-indigenous species. *Hydrobiologia* 756 (1): 37-50.

Derweduwen, J., Vandendriessche, S. & Hostens, K. 2016a. Effects of Belgian wind farms on the epibenthos and fish of the soft sediment. In S. Degraer *et al.* (eds), *Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: Environmental Impact Monitoring Reloaded*. Brussels: Royal Belgian Institute of Natural Sciences, OD Natural Environment, Marine Ecology and Management Section, pp. 95-115.

Derweduwen, J., Ranson, J., Wittoeck, J. & Hostens, K. 2016b. Feeding behaviour of lesser weever (*Echiichthys vipera*) and dab (*Limanda limanda*) in the C-Power wind farm. In S. Degraer *et al.* (eds), *Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North*

Sea: Environmental Impact Monitoring Reloaded. Brussels: Royal Belgian Institute of Natural Sciences, OD Natural Environment, Marine Ecology and Management Section, pp. 143-166.

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.

Hutchison, Z., Hendrick, V., Burrows, M., Wilson, B. & Las, K. 2016. Buried alive: the behavioural response of the mussels, modiolus modiolus and mytilus edulis to sudden burial by sediment. *PloS ONE* 11 (3): e0151471. DOI: 10.1371/journal.pone.0151471

Kerckhof, F., Rumes, B., Norro, A., Houziaux, J.-S. & Degraer, S. 2012. A comparison of the first stages of biofouling in two offshore wind farms in the Belgian part of the North Sea. In S. Degraer *et al.* (eds), *Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: Heading for an Understanding of Environmental Impacts.* Brussels: Royal Belgian Institute of Natural Sciences, OD Natural Environment, Marine Ecology and Management Section, pp. 17-39.

Krone, R., Gutow, L., Joschko, T. & Schröder, A. 2013. Epifauna dynamics at an offshore foundation – Implications of future wind power farming in the North Sea. *Marine Environmental Research* 85: 1-12.

Lindeboom, H.J. *et al.* 2011. Short-term ecological effects of an offshore wind farm in the Dutch coastal zone; a compilation. *Environmental Research Letters* 6: 035101.

R Core Team 2017. A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available online at: http://CRAN.R-projects.org/

Reubens, J.T., Degraer, S. & Vincx, M. 2011. Aggregation and feeding behaviour of pouting (Trisopterus luscus) at wind turbines in the Belgian part of the North Sea. *Fisheries Research* 108 (1): 223-227.

Reubens, J.T., Vandendriessche, S., Zenner, A.N., Degraer, S. & Vincx, M. 2013. Offshore wind farms as productive sites or ecological traps for gadoid fishes? Impact on growth, condition index and diet composition. *Marine environmental research* 90: 66-74.

Stenberg, C., Støttrup, J., Deurs, M.V., Berg, C.W., Dinesen, G.E., Mosegaard, H., Grome, T. & Leonhard, S.B. 2015. Long-term effects of an offshore wind farm in the North Sea on fish communities. *Marine Ecology Progress Series* 528: 257-265. DOI: 10.3354/meps11261

Vandendriessche, S., Hostens, K. & Wittoeck, J. 2009. Monitoring of the effects of the Thorntonbank and Bligh Bank windmill parks on the epifauna and demersal fish fauna of soft-bottom sediments: Thorntonbank, status during construction (T1) and Bligh Bank, reference condition (T0). In S. Degraer *et al.* (eds), *Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: State of the Art After Two Years of Environmental Monitoring.* Brussels: Royal Belgian Institute of Natural Sciences, OD Natural Environment, Marine Ecology and Management Section, pp. 93-150.

Vandendriessche, S., Derweduwen, J. & Hostens, K. 2015. Equivocal effects of offshore wind farms in Belgium on soft substrate epibenthos and fish assemblages. *Hydrobiologia 756* (1): 19-35.

Wang, Y., Naumann, U., Wright, S. & Warton, D. 2012. Mvabund – an R package for model-based analysis of multivariate abundance data. *Methods in Ecology and Evolution* 3: 471-474.

Wickham, H. 2009. *Elegant Graphics for Data Analysis.* New York: Springer.

Wickham, H. 2011. The split-apply-combine strategy for data analysis. *Journal of Statistical Software* 40 (1): 1-29.

Annex 1

Species names with according abbreviations used in the figures in this chapter

	Species name	Abbreviation
Epibenthos	*Anthozoa* sp.	Anthozoa
	Asterias rubens	Aste_rube
	Liocarcinus holsatus	Liohol
	Loligo juv	Loli_juv
	Loligo vulgaris	Loli_vulg
	Macropodia sp.	Macropodia
	Mytilus edulis	Myti_edul
	Nassarius reticulatus	Nass_reti
	Ophiura albida	Ophi_albi
	Ophiura ophiura	Ophi_ophi
	Pagurus bernhardus	Pagu_bern
	Psammechinus miliaris	Psam_mili
	Spisula elliptica	Spis_elli
	Spisula solida	Spis_soli
Fish	*Ammodytes tobianus*	Ammo_tobi
	Arnoglossus laterna	Arno_late
	Buglossidium luteum	Buglut
	Callionymus lyra	Call_lyra
	Callionymus reticulatus	Call_reti
	Echiichthys vipera	Echi_vipe
	Hippocampus sp.	Hippocampus
	Hyperoplus lanceolatus	Hype_lanc
	Limanda limanda	Lima_lima
	Merlangius merlangus	Merl_merl
	Mullus surmuletus	Mull_surm
	Pleuronectes platessa	Pleu_plat
	Pomatoschistus sp.	Pomato