

CHAPTER 5

CONTINUED EXPANSION OF THE ARTIFICIAL REEF EFFECT IN SOFT-SEDIMENT EPIBENTHOS AND DEMERSAL FISH ASSEMBLAGES IN TWO ESTABLISHED (10 YEARS) BELGIAN OFFSHORE WIND FARMS

DE BACKER Annelies*, WYNS Liam & HOSTENS Kris

Flanders Research Institute for Agriculture, Fisheries and Food (ILVO), Marine Research, Ankerstraat 1, 8400 Oostende, Belgium.

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

Since 2005, the effect of offshore windfarms (OWFs) on the soft sediment epibenthos and demersal fish assemblages is being monitored in the Belgian part of the North Sea. Long-term yearly monitoring campaigns in C-Power (54 turbines) and Belwind (56 turbines) allow us to evaluate how the soft sediment ecosystem in between the turbines responds to the introduction of hard substrates. Two major changes are expected: an ‘artificial reef effect’ (e.g. Coolen *et al.* 2020) and a fisheries exclusion or local ‘refugium effect’ (Handley *et al.* 2014). Changes related to the artificial reef effect are most obvious at turbine scale and their near surroundings (Dannheim *et al.* 2019, 2020). Although an expansion of the reef effect beyond the immediate vicinity of the turbines is possible (Degraer *et al.* 2020). De Backer *et al.* (2020) observed such a reef effect expansion seven years after the construction of OWFs C-Power and Belwind, as suggested by significantly increased densities of epifouling species (blue mussel *Mytilus edulis* and anemones *Anthozoa* spp.) and an increased occurrence of other hard substrate-associated species on the soft sediments in between the turbines (> 200 m).

Additionally, slightly increased densities were recorded within C-Power OWF for some common soft sediment-associated fish species in between the turbines, hinting towards the first signs of a refugium effect, probably resulting from a combination of fisheries exclusion and increased food availability, partly related to the artificial reef effect.

This short communication describes whether these observations (*i.e.* expansion of the reef effect and first signs of a refugium effect on the soft sediments in between the turbines) remain valid, using the results of our 2020 sampling campaign, respectively nine (C-Power) and ten (Belwind) years after construction. Epibenthos and bottom-dwelling fish were sampled at 19 locations (four within C-Power, four within Belwind and eleven reference locations) with an 8-meter shrimp beam trawl (22 mm mesh in the cod end) equipped with a bolder chain (Fig. 1). The net was towed for 15 minutes at an average speed of 4 knots over approximately 1 nautical mile. Several metadata were recorded (time, coordinates, trajectory, sampling depth, etc.) to allow for a correct conversion towards a standardized sampling area (1000 m²). All fish

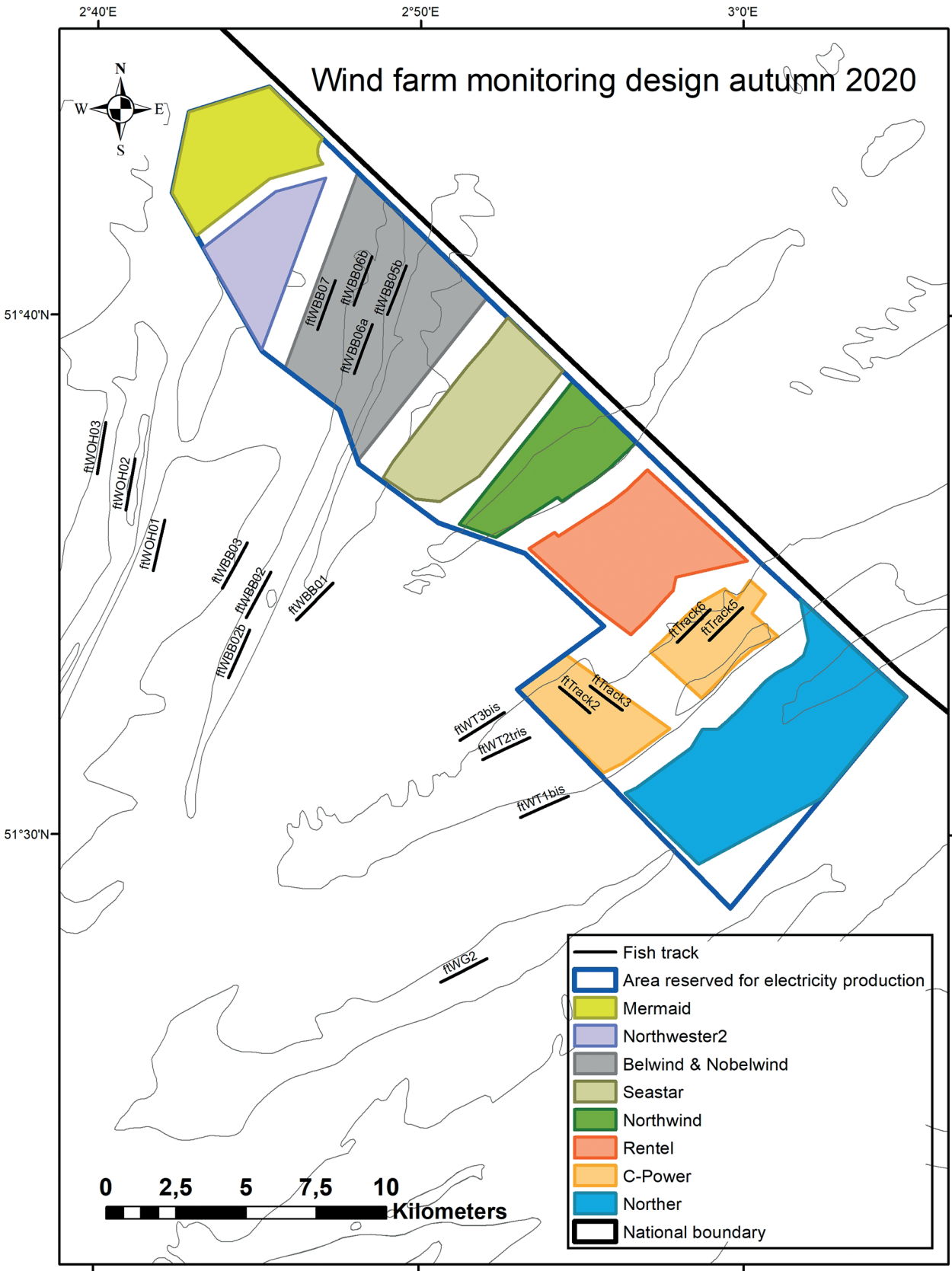


Figure 1. Overview map showing the 2020 trawl locations at the C-Power and Belwind concession area and the respective reference locations.

and epibenthos species were identified and counted, bulk wet weights were registered for all epibenthos species, and all fish, shrimps and crabs were measured. As pelagic fish (e.g. mackerel, horse mackerel, herring, sprat, anchovy) and jellyfish are not quantitatively sampled with a beam trawl, these were further excluded from all analyses. As such, throughout this chapter the term fish refers to both demersal and benthic-pelagic fish species.

Several univariate variables (species number, total density and total biomass; the latter only for epibenthos) were calculated per ecosystem component and for the combined hard substrate-associated species (see further). Type III Analyses of Variance (ANOVA) using the Wald F test and Kenward-Roger degrees of freedom (R package ‘Car’) were ran on linear mixed-effect models (lmer), with wind farm (Belwind and C-Power), impact factor (reference vs impact) and their interaction as fixed effects, and position on the sandbank (top or gully) as random effect. The univariate response variables were log-transformed where necessary to meet model requirements. The interaction (OWF*Impact) was omitted

when not significant, prior to running the ANOVA, whereas in case the interaction was significant, a pairwise test using the lsmeans function with Kenward-Roger degrees of freedom was performed. Furthermore, multivariate model-based approaches were performed with the package ‘mvabund’ (Wang *et al.* 2012), to explore differences in species composition. Square root transformed multivariate species abundance data were fitted against the impact factor for each OWF separately using the *manyglm* function with ‘negative binomial’ family. The mean-variance assumption was checked by plotting residuals versus fits. Subsequently, univariate tests were run per species to investigate individual species effects. All analyses were done using R version 4.0.3 (2020-10-10).

Based on the 2020 dataset, no significant differences could be noted between impact and reference samples for both epibenthos and fish assemblages, not for C-Power (*manyglm*, $p=0.11$ and $p=0.39$, respectively) nor for Belwind (*manyglm*, $p=0.14$ and $p=0.07$, respectively) (Fig. 2). Comparably, no significant effects were observed in number of species (S) for both ecosystem components

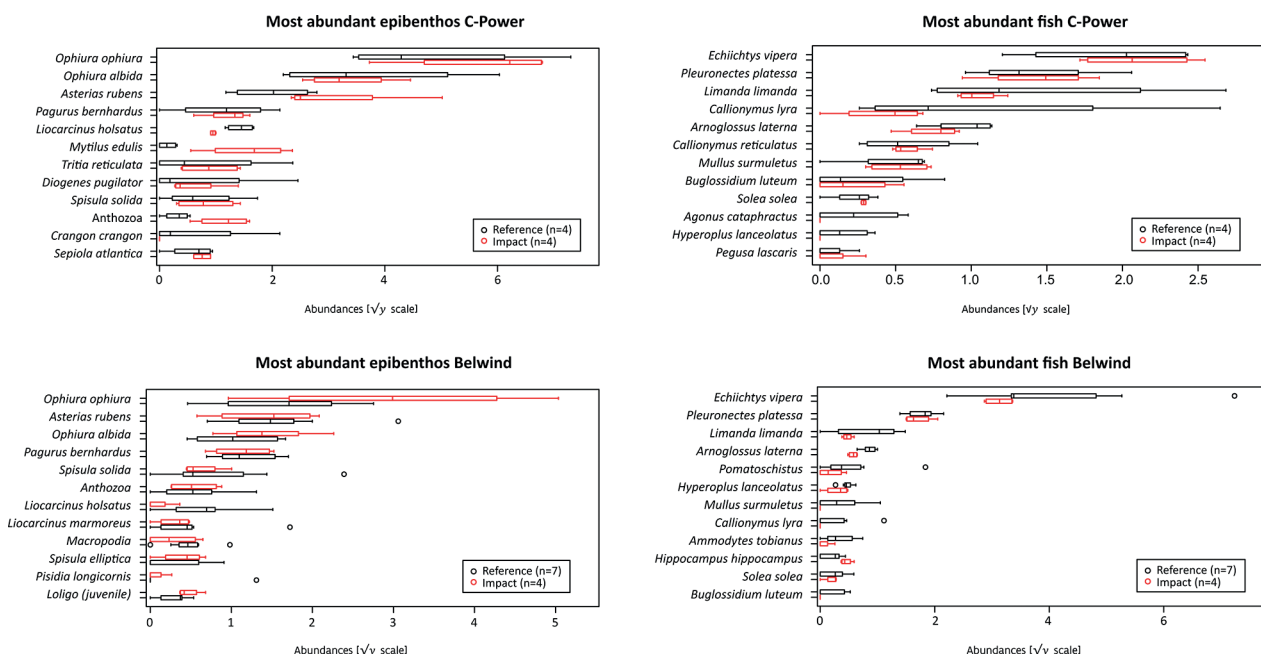


Figure 2. Box-and-whisker-plots showing minimum, maximum, 0.25 percentile, 0.75 percentile and median sqrt densities for most abundant epibenthos and demersal fish species in reference (black) and impact (red) samples for C-Power and Belwind offshore wind farms, sampled in September-October 2020. Outliers are visualized as circles.

Table 1. Average and standard deviation (SD) for epibenthos and fish species richness (S), overall density (N) and biomass (W) for the reference and impact samples gathered in 2020 in C-Power and Belwind offshore wind farms.

Ecosystem component	OWF	Impact	Avg. S \pm SD	Avg. N \pm SD (ind.1000 m ⁻²)	Avg. W \pm SD (g WW.1000 m ⁻²)
Epibenthos	C-Power	Reference	18 \pm 1	60 \pm 26	1957 \pm 553
		Impact	20 \pm 3	69 \pm 19	2825 \pm 562
	Belwind	Reference	14 \pm 4	14 \pm 10	870 \pm 695
		Impact	14 \pm 2	20 \pm 12	730 \pm 290
Fish	C-Power	Reference	12 \pm 2	13 \pm 7	–
		Impact	9 \pm 1	10 \pm 2	–
	Belwind	Reference	12 \pm 5	27 \pm 12	–
		Impact	8 \pm 1	14 \pm 2	–

in both OWFs (Impact, $p=0.05$) (Table 1). This corroborates our earlier findings that the soft sediment epibenthos and fish assemblage in between the turbines underwent no drastic changes due to the presence of OWFs (De Backer & Hostens 2017; De Backer *et al.* 2020).

On the other hand, the overall epibenthos density (N) and biomass (W) were significantly affected by the presence of the OWFs (Table 1), with significantly higher densities in between the turbines for both OWFs (Impact, $p=0.001$), and significantly higher overall epibenthos biomass within C-Power (pairwise $p=0.02$). This overall higher density is mainly attributed to increased abundances (although not significant) of some dominant epibenthic species in the impact samples compared to the reference samples (Fig. 2). Especially, densities of common starfish *Asterias rubens* were higher in between the turbines of C-Power compared to the reference samples (average 10.8 ± 8.3 and 4.4 ± 2.6 ind. 1000 m⁻², respectively). We also observed increased densities of blue mussel *Mytilus edulis* within C-Power (avg. 2.9 ± 1.96 and 0.08 ± 0.02 ind. 1000 m⁻², respectively for impact and reference), and anemones *Anthozoa* spp. (most probably *Metridium* spp.) also displayed higher values in the impact samples (avg. 1.5 ± 0.9 and 0.2 ± 0.1 ind. 1000 m⁻² respectively). Blue mussel and anemones (most probably *Metridium* spp.) are likely drop-offs from the turbines

since they are known to foul on the turbine foundations (De Mesel *et al.* 2015; Krone *et al.* 2013; Kerckhof *et al.* 2019). Starfish are known to predate on mussels (Kautsky *et al.* 1990; Norberg & Tedengren 1995; Reimer & Tedengren 1996), so higher starfish densities are probably the result of an attraction to the increased presence of blue mussel.

Higher epibenthos densities in Belwind OWF were only recorded for the brittle star *Ophiura albida* (avg. 11.2 ± 9.1 and 3.2 ± 2.5 ind. 1000 m⁻², respectively, for impact and reference) (Fig. 2). This species is typically associated with soft sediments, showing stationary burrowing behaviour and predominantly feeding on infaunal organisms (Boos *et al.* 2010). It remains unclear whether the higher densities in Belwind can be attributed to an OWF effect, related to changed food availability (e.g. changes in macrobenthos species) or changed predation pressure (e.g. changes in fish abundances). Up till now, no clear indications of such changes were recorded in Belwind (Lefaible *et al.* 2019; De Backer *et al.* 2020), so we assume that the increased density mainly reflects natural variation.

In contrast to epibenthos, the overall fish density was significantly lower in the impact samples compared to the reference samples for both OWFs (Impact, $p=0.02$) (Table 1), although at the individual species level no such differences could be discerned for the 2020 data (Fig. 2). These observations may

partly negate the first sign of a refugium effect that was noted for C-Power based on the longer time series analysis (De Backer *et al.* 2020). Of course, fish are mobile species, and the high standard deviations (especially in the reference samples), partly related to the low number of samples, suggest that the real refugium effect might have been obscured in 2020. This warrants further investigation and especially an extended time series is needed to assess the refugium effect.

The expansion of the artificial reef effect in the soft sediment habitat comprises several factors, such as the drop-off of hard substrate species, organic enrichment through faecal deposits of suspension feeders and changes in habitat structure (*e.g.* presence of empty mussel shells) (Degraer *et al.* 2020). For this study, we had a closer look into the presence of such drop-offs and other typical hard substrate-associated species (assignment

based on species-identification.org, www.sealifebase.ca and www.marlin.ac.uk). A significantly higher number of hard substrate-species (S) was observed in between the turbines compared to the reference samples for both OWFs (impact, $p=0.02$), where the response was again most pronounced in C-Power (Fig. 3). Also the hard substrate-species composition was significantly different in C-Power impact vs reference samples (manyglm, $p=0.013$) (Fig. 4).

Aside the number of species, also significantly higher densities ($p=0.0007$) and biomass values ($p=0.0034$), were recorded for C-Power impact vs reference samples (Fig. 3). At species level, all hard substrate-species, such as blue mussel, Anthozoa, sea-urchin *Psammechinus miliaris*, short-snouted seahorse *Hippocampus hippocampus*, brittle star *Ophiothrix fragilis*, hairy crab *Pilumnus hirtellus*, European seabass *Dicentrarchus*

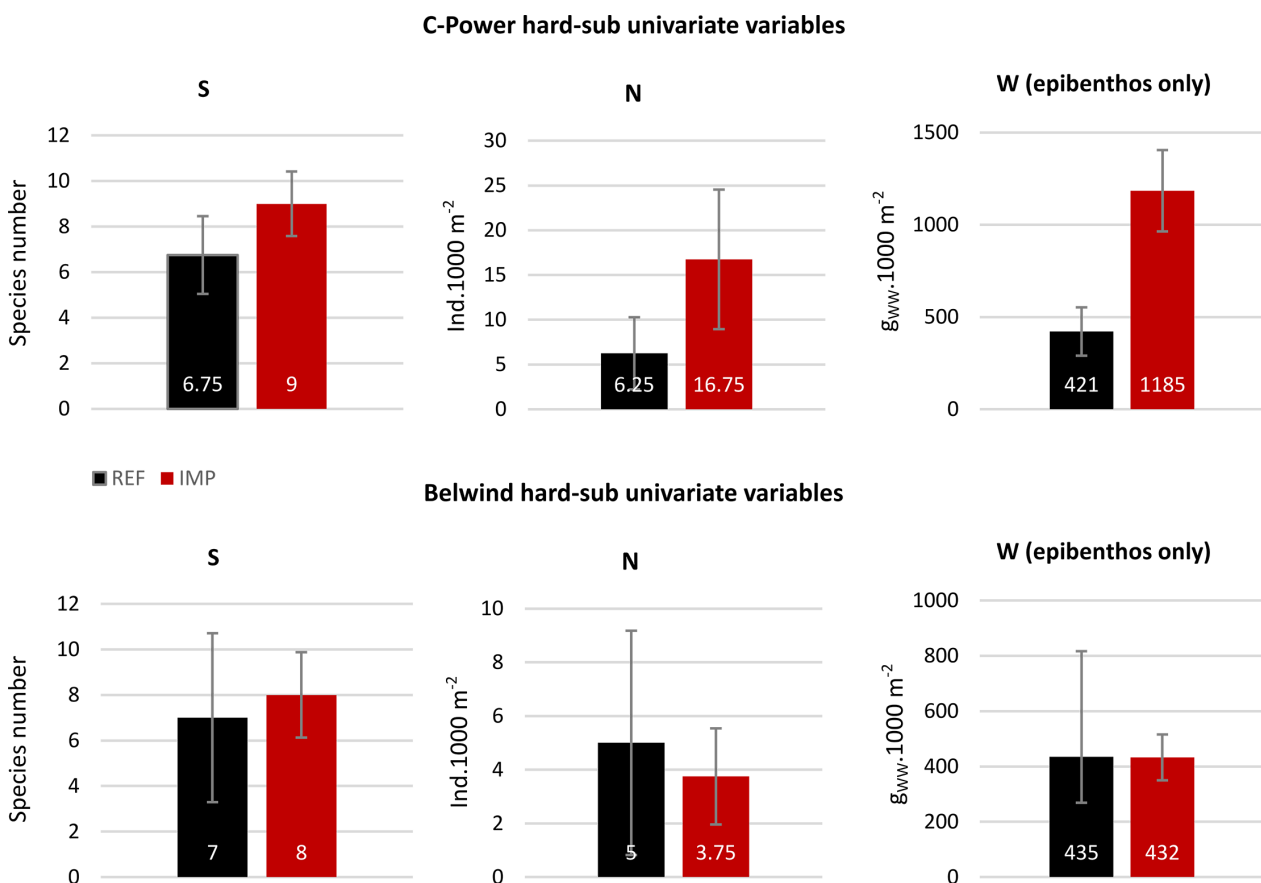


Figure 3. Average species richness (S), density (N) and biomass (W) (\pm standard deviation) for hard-sub associated species (fish, epibenthos and cephalopods), for impact and reference samples in C-Power and Belwind, gathered in September-October 2020. Numbers within each barplot are the respective average values.

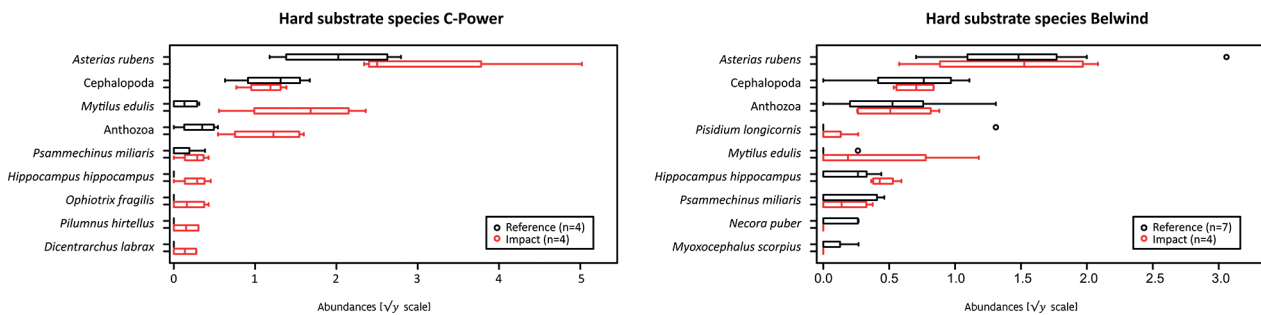


Figure 4. Box-and-whisker-plots showing minimum, maximum, 0.25 percentile, 0.75 percentile and median sqrt densities for all hard substrate species (fish, epibenthos, and cephalopods) in reference (black) and impact (red) samples for C-Power and Belwind taken during autumn 2020. Outliers are visualized as circles.

labrax, displayed higher densities in the C-Power impact samples (Fig. 4). However, this was only significant for blue mussel ($p=0.022$) and nearly significant for *Anthozoa* spp. ($p=0.07$). For Belwind, the patterns for hard substrate-associated species were again more subtle, with slightly higher densities for only a few species (blue mussel, sea horse and long-clawed porcelain crab *Pisidia longicornis*) in the OWF samples (Fig. 4).

For this part of the study, we also included the cephalopods (*Alloteuthis subulata*, *Loligo vulgaris*, juvenile *Loligo* sp., *Sepia officinalis* and *Sepiola atlantica*) as hard substrate-associated species. These species are known to attach their eggs to hard substrates (Mapes & Nuetzel 2009), which might influence their presence on the soft sediments in between the turbines. However, no obvious differences were noted for this group of benthopelagic organisms in 2020 (Fig. 4).

Overall, the results for 2020 corroborate our earlier findings of an artificial reef effect expansion in the OWFs towards the soft sediments in between the turbines (> 200 m distance), which started about seven years after construction (De Backer & Hostens 2017; De Backer *et al.* 2020). Epibenthic organisms like Anthozoa and blue mussel, which are known to foul on the turbines (Kerckhof *et al.* 2019), other epibenthic organisms (*e.g.* *Ophiotrix fragilis*, *Pilumnus hirtellus*) that appear in higher densities on the scour protection layer surrounding the turbines, and fish species that are attracted to the ‘reef’ structures

(*e.g.* seahorse and seabass), all seem to be expanding into the soft sediments, albeit in relatively low densities. This proves that changes induced by OWFs are not restricted to the turbines and scour protection layer, but may also extend in four dimensions (Degraer *et al.* 2020).

Introducing artificial structures into a soft-sediment ecosystem will alter diverse cause-effect pathways that operate over different spatial and temporal scales (Dannheim *et al.* 2020). On the long term, local turbine-scale effects may cascade into further environmental responses. Furthermore, the observed effects were most pronounced in C-Power compared to Belwind OWF, suggesting that the environmental responses in epibenthic and demersal benthopelagic fish assemblages to the installation of OWFs is likely to be site-specific. Therefore, extrapolation of the results to other OWFs should be done with care, while monitoring need to be continued to grasp any further spatial distribution of the artificial reef and refugium effects.

Acknowledgements

The authors would like to thank RBINS OD Nature/Belspo for granting shiptime on the RV Belgica and its crew for help during sampling in autumn 2020. We also thank several ILVO colleagues for their help during sampling and in the lab. This study contributes to the Belgian environmental monitoring programme, WinMon.BE.

References

- Boos, K., Gutow, L., Mundry, R. & Franke, H.-D. 2010. Sediment preference and burrowing behaviour in the sympatric brittlestars *Ophiura albida* Forbes, 1839 and *Ophiura ophiura* (Linnaeus, 1758)(Ophiuroidea, Echinodermata). *Journal of Experimental Marine Biology and Ecology* 393 (1-2): 176-181. <https://doi.org/10.1016/j.jembe.2010.07.021>
- Coolen, J.W., Van Der Weide, B., Cuperus, J., Blomberg, M., Van Moorsel, G.W., Faasse, M.A., Bos, O.G., Degraer, S. & Lindeboom, H.J. 2020. Benthic biodiversity on old platforms, young wind farms, and rocky reefs. *ICES Journal of Marine Science* 77 (3): 1250-1265. <https://doi.org/10.1093/icesjms/fsy092>
- Dannheim, J., Degraer, S., Elliot, M., Smyth, K. & Wilson, J.C. 2019. Seabed communities. In: Perrow, M.R. (ed.) *Wildlife and Wind Farms, Conflicts and Solutions. Volume 3 Offshore: Potential Effects*. Pelagic Publishing, Exeter, pp. 64-85.
- Dannheim, J., Bergström, L., Birchenough, S.N., Brzana, R., Boon, A.R., Coolen, J.W., Dauvin, J.-C., De Mesel, I., Derweduwen, J. & Gill, A.B. 2020. Benthic effects of offshore renewables: identification of knowledge gaps and urgently needed research. *ICES Journal of marine Science* 77 (3): 1092-1108. <https://doi.org/10.1093/icesjms/fsz018>
- De Backer, A. & Hostens, K. 2017. Effects of Belgian offshore windfarms on soft sediment epibenthos and fish: an updated time series. In: Degraer, S. et al. *Environmental Impacts of offshore Wind Farms in the Belgian Part of the North Sea: A continued Move towards Integration and Quantification*. pp. 59-71.
- 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. *Environmental Impacts of offshore Wind Farms in the Belgian Part of the North Sea: Empirical Evidence inspiring Priority Monitoring*. pp. 79-113.
- Degraer, S., Carey, D.A., Coolen, J.W., Hutchison, Z.L., Kerckhof, F., Rumes, B. & Vanaverbeke, J. 2020. Offshore wind farm artificial reefs affect ecosystem structure and functioning: A synthesis. *Oceanography* 33 (4): 48-57. <https://doi.org/10.5670/oceanog.2020.405>
- 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: 1-14. <https://doi.org/10.1007/s10750-014-2157-1>
- 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. <https://doi.org/10.1016/j.seares.2013.11.005>
- Kautsky, N., Johannesson, K. & Tedengren, M. 1990. Genotypic and phenotypic differences between Baltic and North Sea populations of *Mytilus edulis* evaluated through reciprocal transplantations. I. Growth and morphology. *Marine Ecology Progress Series*: 203-210. <https://doi.org/10.3354/meps059203>
- Kerckhof, F., Rumes, B. & Degraer, S. 2019. About “mytilisation” and “slimeification”: A decade of succession of the fouling assemblages on wind turbines off the Belgian coast. In: Degraer et al. *Environmental Impacts of offshore Wind Farms in the Belgian Part of the North Sea: marking a Decade of Monitoring, Research and Innovation*. pp. 73-84.

- 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. <https://doi.org/10.1016/j.marenvres.2012.12.004>
- Lefaible, N., Colson, L., Braeckman, U. & Moens, T. 2019. Evaluation of turbine-related impacts on macrobenthic communities within two offshore wind farms during the operational phase. In: Degraer, S. et al. *Environmental Impacts of offshore Wind Farms in the Belgian Part of the North Sea: marking a Decade of Monitoring, Research and Innovation. Memoirs on the Marine Environment*. pp. 47-63.
- Mapes, R.H. & Nuetzel, A. 2009. Late Palaeozoic mollusc reproduction: cephalopod egg-laying behavior and gastropod larval palaeobiology. *Lethaia* 42 (3): 341-356. <https://doi.org/10.1111/j.1502-3931.2008.00141.x>
- Norberg, J. & Tedengren, M. 1995. Attack behaviour and predatory success of *Asterias rubens* L. related to differences in size and morphology of the prey mussel *Mytilus edulis* L. *Journal of Experimental Marine Biology and Ecology* 186 (2): 207-220. [https://doi.org/10.1016/0022-0981\(94\)00158-A](https://doi.org/10.1016/0022-0981(94)00158-A)
- Reimer, O. & Tedengren, M. 1996. Phenotypical improvement of morphological defences in the mussel *Mytilus edulis* induced by exposure to the predator *Asterias rubens*. *Oikos*: 383-390. <https://doi.org/10.2307/3545878>
- Wang, Y., Naumann, U., Wright, S.T. & Warton, D.I. 2012. Mvabund – an R package for model-based analysis of multivariate abundance data. *Methods in Ecology and Evolution* 3 (3): 471-474. <https://doi.org/10.1111/j.2041-210X.2012.00190.x>