CHAPTER 7

A DECADE OF SOFT SEDIMENT EPIBENTHOS AND FISH MONITORING AT THE BELGIAN OFFSHORE WIND FARM AREA

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Abstract

Since 2005, an environmental beam trawl survey has been set-up in the Belgian part of the North Sea, designed to investigate the effect of offshore wind farms (OWFs) on epibenthos and demersal fish that reside on the soft sediments in between the turbines. The survey follows a Before/After – Control/Impact design and focusses on the two oldest concession areas: C-Power located on the Thornton Bank (54 turbines, 325 MW) and Belwind (55 turbines, 165 MW) located on the Bligh Bank. This contribution presents the results of resp. 8 and 9-year post-construction beam trawl monitoring. We specifically aimed at (1) investigating more in depth long-lasting changes both at the assemblage and the species level using a combination of multivariate and univariate techniques, and (2) exploring which environmental variables affect species assemblages associated with wind farms at a larger scale to better include natural variability.

Results showed that soft sediment epibenthos and fish assemblages in between the turbines underwent no drastic changes due to the presence of the OWFs at mid/longer term. The assemblages were mainly structured by temporal variability due to changes in temperature and climate indices NAO and AMO, and this degree of change is proportionally much larger than the local effect of the present OWF areas. Nevertheless, some significant secondary effects could be clearly related to the presence of the OWFs pointing to an expansion of the OWF effect beyond the immediate vicinity of the turbine on two fronts: (1) an expansion of the reef effect, and (2) signals of a refugium effect.

Expansion of the reef effect is suggested through the appearance of an increased number of hard substrate-associated species like long-clawed porcelain crab *Pisidia longicornis*, edible crab *Cancer pagurus* and seabass *Dicentrarchus labrax* in the soft sediment trawls. Also increased densities of common squid *Loligo vulgaris* were observed in C-Power, probably an indication for the use of the jacket foundations as substrates for egg deposition. However, the clearest indication for reef expansion was the significantly increased abundances of blue mussel *Mytilus edulis* and anemones *Anthozoa* sp., two species dominating the epifouling communities on the turbines. Although, densities were still low, they could increase heterogeneity in the soft-bottom sediments in between foundations in the future. Slightly, but significantly, increased fish densities of

some common soft sediment-associated fish species (common dragonet *Callionymus lyra*, solenette *Buglossidium luteum*, lesser weever *Echiichthys vipera* and plaice *Pleuronectes platessa*) inside the C-Power wind farm compared to the outside reference area seem to be the first signs of a refugium effect, probably related to a combination of fisheries exclusion and increased food availability. More pronounced effects were found for C-Power than for the more offshore Belwind OWF, stressing that effects might be site-specific and that extrapolation of these findings to other OWFs should be done with care.

1. Introduction

To meet with renewable energy targets, the European Commission advises that Europe needs to generate between 230 and 450 GW of offshore wind energy by 2050, with the centre of gravity for production located in the North Sea region. It is estimated that, by that time, 450 GW could provide almost a third of Europe's entire electricity demand (EWEA 2019). Since 2009, Belgium has been producing offshore wind energy and by the end of 2020, the totally installed capacity, organised within 9 different offshore wind farms (OWFs), will climb to 2262 MW produced by almost 400 turbines, which addresses 10% of the total Belgian need for electricity and meets half of its renewable energy targets (Rumes & Brabant 2019). Due to an additional area of 284 km^2 for the development of wind energy that is foreseen in the new marine spatial plan of 2020-2026, this capacity can even further increase up to 4000 MW (Rumes & Brabant 2019).

This rapid development of renewable wind energy at sea raises questions about its effects on the marine environment, and more importantly on the biota that live in this environment. The most prominent effect of the construction of OWFs is the introduction of artificial hard substrates into typical soft bottom environments, which will inevitably lead to alterations of soft sediment habitats and communities at a variety of spatial scales (Ashley *et al.* 2014 and references therein). The introduction of hard substrates generates a new 'rocky' habitat which attracts hard substrate species (Lindeboom *et al.* 2011; Kerkhof *et al.* 2012; De Mesel *et al.* 2015; Coolen 2017), and creates a reef effect for epibenthic fauna and demersal and bentho-pelagic fish (Reubens *et al.* 2011, 2013; Stenberg *et al.* 2015). These are changes that particularly occur at smaller spatial scales (turbine scale), but may, of course, affect the broader spatial scale through ecological interactions such as trophic linkages and energy flow (Gill & Wilhelmsson 2019). Other effects are underwater sound originating from the operational turbines or electromagnetic radiation created by the infield cables that can affect organisms as well and might disturb communication between individuals (Gill & Wilhelmsson 2019). Additionally, fisheries are excluded from the OWF area, which is another potential effect at play to induce changes on the soft-bottom assemblages (Handley *et al.* 2014).

Within this chapter, the objective is to investigate the potential long-term effect of OWFs in the Belgian part of the North Sea (BPNS) on soft-bottom epibenthos and fish species and assemblages that reside on the sandy sediments in between the turbines. Therefore, ILVO performs beam trawl monitoring surveys since 2005 following a Before/After Control/Impact (BACI) design within two OWFs: C-Power located on the Thornton Bank (54 turbines, 325 MW) and Belwind (55 turbines, 165 MW) located on the Bligh Bank, the first OWFs in Belgian waters. Results presented here are resp. 8 and 9-year post-construction. In previous reports, a post-construction 'overshoot' of epibenthos density and biomass was observed caused by an increase in opportunistic, scavenging species (Derweduwen *et al.* 2016a; De Backer & Hostens 2017). This was, however, a temporary phenomenon lasting only two-year post-construction. After this 'overshoot', 6 to 7-year post-construction, no real significant long-term changes have been observed for the soft-bottom epibenthic and fish assemblages in between the turbines (at distances > 200 m) (De Backer and Hostens 2018). This could be because time after construction was probably still too short and the whole operational OWF area not yet large enough to signal effects of fisheries exclusion beyond the immediate vicinity of the turbine. Another reason can be that natural variation is too large to detect effects at the assemblage level (Dannheim *et al.* 2019) or that effects are restricted to certain species, and as such not easily picked up at the community level.

Therefore, in the current report, we specifically aimed at (1) investigating more in depth long-lasting changes both at the assemblage and the species level using a combination of multivariate and univariate techniques, and (2) exploring which environmental variables affect species assemblages associated with wind farms at a larger scale to better include natural variability. We were mainly interested in 'stable' communities and long-term effects, and therefore focused on the years after the post-construction 'overshoot', so excluding the 2 years after construction from most analyses. These 2 post-construction years also coincide with the pioneering stage of the fouling assemblage on the turbines (Kerkhof *et al.* 2019), indicating as well that these first post-construction years were rather 'unstable'.

2. Material and methods

2.1. Sampling

Since the previous report of De Backer and Hostens (2018), two extra sampling campaigns were performed in autumn 2018 and 2019 with RV Belgica. Beam 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 for 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 minimising 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) onboard. The samples that could not be fully processed onboard were frozen and further processed in the lab.

2.2. Data used

2.2.1. Biological data

The time series of trawl samples in both C-Power and Belwind dates back to respectively 2005 (some other samples were available for 2004) and 2008 (2004 for 1 reference sample). However, within the sampling period 2004-2019, 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 locations in autumn during the entire time period is given in table 1. For an overview map of all track locations, the reader is referred to Vandendriessche *et al.* (2015).

For C-Power, the construction of the second and third phases (48 jacket foundation turbines) took place in 2011. As such, trawls from 2004 up to 2010 were considered to represent baseline conditions (Baseline period) for both impact (Impact) and reference areas (Reference), while trawls after 2013 reflect conditions after which the first effects of the impact had already diminished (operational period; table 1). This way, the post-construction 'overshoot' effect (Derweduwen *et al.* 2016a; De Backer & Hostens 2017) is excluded as much as possible, and the long-term effects of the wind farm can be studied more reliably. Although wind farm construction of the first phase of C-Power (6 gravity-based turbines) started in 2008 and finished in 2009, it was decided to consider these years as baseline conditions, since our sampling locations were located away from these turbines and were as such not (are at least little) impacted by the first construction phase.

For Belwind, construction of the OWF took place in 2010 (55 monopile foundation turbines). The baseline for both impact and reference area was established in 2008 and 2009 (baseline period). Similarly, as for C-Power, the two post-construction years were excluded from statistical analyses to reliably study long-term effects. As such samples from 2013-2019 were used to represent the 'settled' operational wind farm conditions (operational period; table 1).

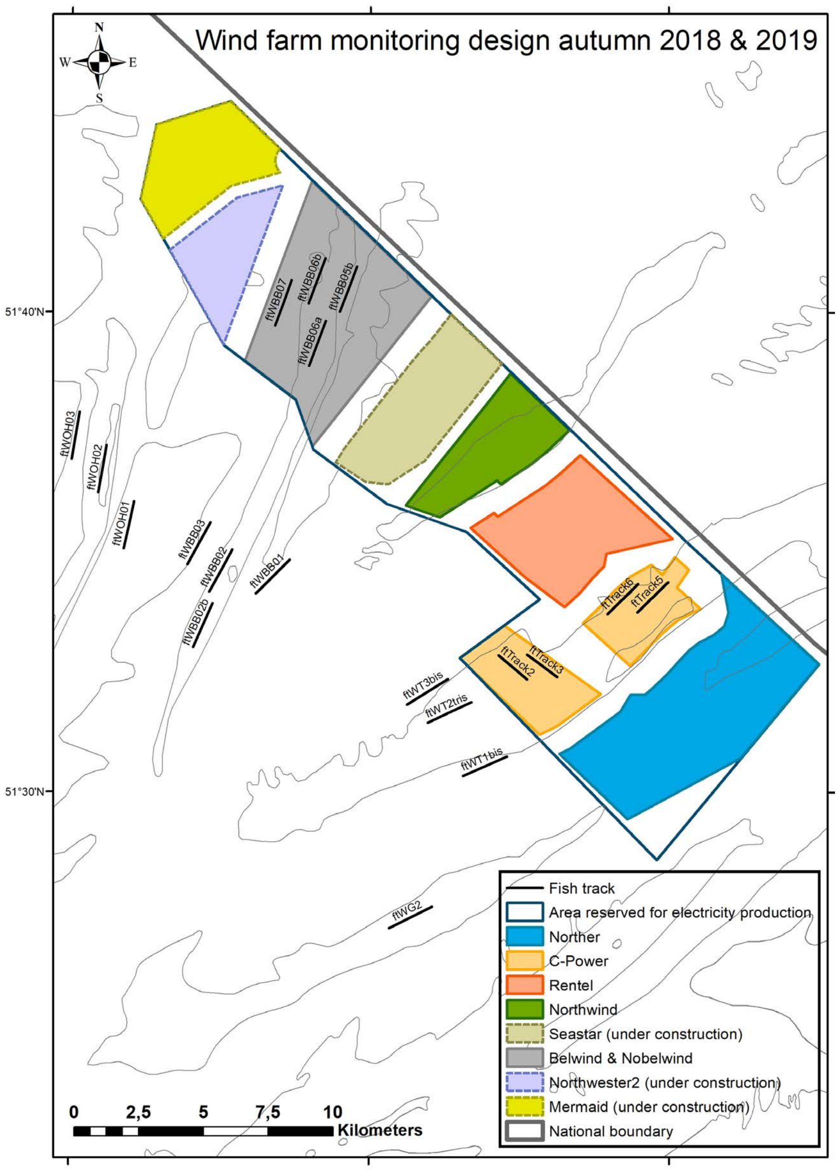

Figure 1: Overview map showing the 2018 and 2019 trawl locations at the C-Power and Belwind concession area and the respective reference locations.

Table 1. Overview table of the sampling design for the C-Power and Belwind wind farm within the time period 2004-2019 with indication of the different periods as used in the analyses. Construction periods are marked in light blue.

C-Power sampling design		Baseline								'Overshoot'		Operational					
Station	**Ref/Imp**	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015**	2016	2017	2018	2019
ftTB1	Ref	l															
ftTB2	Ref	l															
ftTB5	Imp	l															
ftTB8	Imp	l															
ftTrack1	Imp									s							
ftTrack2	Imp									s	s	s		s	s	s	s
ftTrack3	Imp									s	s			s	s	s	s
ftTrack4	Imp									s							
ftTrack5	Imp									s	s	s		s	s	s	s
ftTrack6	Imp									s	s	s		s	s	s	s
ftWG2	Ref		l	l	l	l		s		s	s	s		s	s	s	s
ftWT1	Ref		l			l		s (*)		s	s	s (*)		s (*)	s (*)	s (*)	s (*)
ftWT2	Ref		l			l	l & s	s (*)	s	s	s	s (*)		s (*)	s (*)	s (*)	s (*)
ftWT3	Ref		l			l	l & s	s		s	s	s		s (*)	s (*)	s (*)	s (*)
ftWT4	Imp		l			l		s									
ftWT5	Imp		l			l	l & s	s									
ftWT6	Imp		l			l		s									
ftWT8	Imp		l	l	l	l	l	s									

Belwind sampling design		Baseline							'Overshoot'		Operational						
Station	**Ref/Imp**	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015**	2016	2017	2018	2019
ftWBB01 (G)	Ref	l	l	l	l	l	l	l & s	s	s	s	s		s	s	s	s
ftWBB02 (T)	Ref					l	l	s	s	s	s			s	s	s	s
ftWBB02b (T)	Ref								s	s						s	s
ftWBB03 (G)	Ref					l	l	s	s	s	s	s		s	s	s	s
ftWBB05 (G)	Imp					l			s	s	s	s				s(*)	s(*)
ftWBB06 (T)	Imp					l	l										
ftWBB06a (T)	Imp								s	s				s	s	s	s
ftWBB06b (T)	Imp								s	s	s			s	s	s	s
ftWBB07 (G)	Imp					l	l		s	s	s				s	s	s
ftWOH01 (G)	Ref					l		s	s	s	s	s			s	s	s
ftWOH02 (T)	Ref					l	l	s	s	s	s				s	s	s
ftWOH03 (G)	Ref					l	l	s	s	S	s				s	s	s

Long (l) and short (s) refer to the duration of the trawl (long = 30 minutes, short = 15 minutes). Asterisks (*) refer to stations that were relocated due to logistic considerations. For Belwind, a distinction is made between top samples (T) and gully samples (G). Ref: reference tracks outside concession; Imp: impact tracks in specific wind farm. **: no sampling due to unavailability of sampling vessel.

For all analyses, count data were converted to densities based on the trawled surface area for standardisation to individuals/1000m². 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. So, for the ecosystem component fish, both demersal and bentho-pelagic fish were retained and these are throughout the chapter referred to as fish.

2.2.2. Environmental variables

A time series of the North-Atlantic Oscillation index (NAO), a measure of the pressure difference between Iceland and the Azores was downloaded from the NOAA Climate Prediction Centre website (https://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/nao.shtml). A similar data set containing values of the Atlantic Multidecadal Oscillation (AMO) was used from the NOAA Earth System Research Laboratory's Physical Sciences Division website (https://www.esrl.noaa.gov/psd/data/timeseries/AMO/). These two climate indices have already been used in several ecological studies, because it has been widely recognised that they can influence the distribution and abundance of marine species. Next to yearly values, winter indices were also calculated by averaging the values of the months December-March. Satellite-originating sea surface temperature (SST) values were obtained through the EU Copernicus Marine Environment Monitoring Service (http://marine.copernicus.eu/) as well as measurements of chlorofyll (chl), phucoxanthin silicon, nitrate (NO_3), ammonium (NH_4) and oxygen (O_2) values. These monthly datasets were averaged over 0.25° x 0.25° grid cells to obtain a standardised resolution and this was done for each year. Trawl locations were assigned to a grid cell and given the environmental values of this grid cell. Further, yearly SST winter values were calculated in the same way as for the climatic indices. Moreover, to consider lagged responses to changes in SST, lagged SST 1-3 years were incorporated as well in the analyses. Lastly, daily discharge values from the adjacent Scheldt estuary were obtained through the Flemish Hydrological Information Centre and mean values for each year were calculated (www.waterinfo.be).

2.3. Data analysis

2.3.1. Multivariate analyses

For this study, we tested multivariate wind farm effects on densities for two ecosystem components (epibenthos and fish) in a two-factorial PERMANOVA (type III sums of squares because of unbalanced design) with factors 'period' and 'impact' (with 'period' being a time factor being either baseline or operational, see section 2.2.1). This was done for both the C-Power and Belwind concession separately. The primary aim was to analyse interaction effects between 'period' 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 period' interaction term was found, pairwise tests were conducted to test for differences between impact groups (*i.e.* reference versus impact samples) within each period or between periods within each impact group. Similarity percentages (SIMPER) analysis was done to detect the species responsible for the observed changes between groups of samples. Principal coordinates analysis (PCO) was used to visualise the data with additional vector overlay that was based on Spearman correlations ($R > 0.75$).

Distance-based linear models (DistLM) based on BEST selection and AIC_c criterion were used to relate patterns in community structure to the environmental variables, and one extra categorical variable related to the impact with four binary categories: 'reference samples before construction', 'impact samples before construction', 'reference samples after construction' and 'impact samples after construction'. Environmental data were normalised and collinearity among variables was examined using Spearman rank correlation coefficients prior to the DistLM analyses. For linearly dependent variables ($|r| > 0.7$) only one variable was retained in the analysis. As such NO_3, NH_4, phucoxanthin and salinity were excluded from the analyses due to collinearity with chlorophyll. Si, O_2 and winter SST were excluded because of collinearity with average SST. For Belwind, SSTlag1 was also correlated with average SST and excluded from the models. We specified indicators to combine sets of predictor variables to be able to put related variables together in the model (Anderson *et al.* 2008). In total, two individual variables chlorophyll and discharge and four indicators (sets of variables) were included in the DistLM model: temperature including SST, SSTlag1 (not for Belwind), SSTlag2, SSTlag3; NAO including avg. NAO and winter NAO; AMO including avg. AMO and winter AMO; and impact including the four binary categories as mentioned above. We ran both BEST model and marginal tests showing how much each variable explains when taken alone, ignoring all other variables (Anderson *et al.* 2008).

For all these tests, rare species (occurring in < 5% of the samples over the entire time series regardless of their densities but these were usually very low as well) were excluded, density data were square root transformed and similarity among samples was quantified using Bray-Curtis similarity index.

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

2.3.2. Univariate and single species models

A wind farm effect was tested for univariate measures of epibenthic organisms and demersal fish: species number, total density and total biomass (only available for epibenthos). The OWF effect was also studied at species level, using the densities of the ten most abundant species for both epibenthos and fish of both OWFs. Lastly, two epibenthic species *Anthozoa sp*. and *Mytilus edulis*, known to be dominating the fouling community on the turbines (Kerkhof *et al.* 2019), were also included in the analysis since previous research suggested a wind farm effect for both species (De Backer & Hostens 2018).

For both the univariate measures and the single species densities, regression modelling in combination with a BACI (Before-After/Control-Impact)-approach was applied. Adding an impact factor (Reference/Impact; RI), a time factor (Baseline/Operational; BO) and their interaction to each model allowed for testing a wind farm effect (significant interaction), whilst also taking into account any natural variation in time. These analyses were conducted for both OWFs separately, as they differ in depth, foundation type, sediment characteristics and other environmental conditions.

Based on previous analyses of Belwind (*e.g.* Vandendriessche *et al.* 2015), it was decided to include a random effect of depth within the models as the random factor top/gully, resulting in the use of linear mixed modelling for Belwind. As the differences in depth between samples are much less pronounced in C-Power, it was deemed not necessary to include such random factor for the models of C-Power. The univariate measures and the densities of the different species of fish and epibenthos were modelled using generalised least squares (GLS) models for C-Power. A variance structure was included for both model groups. The use of such a variance structure allows for differences in variance between different sample groups and is widely used to control the heterogeneity within the data (Zuur *et al.* 2007). The

final models for both wind farms are given by:
For C-Power: gls(Y ~ RI + BO + RI:BO, weights = var. structure)
For Belwind: lme(Y ~ RI + BO + RI:BO + random [top/gully], weights = var. structure)
The different variance structures that were used are:

- vf = varIdent(form = ~ 1 | BO)
- vf1 = varIdent(form = ~ 1 | RI)
- vf2 = varComb(varIdent[form = ~ 1 | RI], varIdent[form = ~ 1 | BO])
- vf3 = varIdent(form = ~ 1 | IR*BO)

They were included in the weights argument of the model. Choosing the best model was done by testing four different variation structures against the simpler linear model, and selection was based on the Akaike Information Criterion (AIC) with a preference for the simplest model having the lowest AIC-value. The model selection for all models was performed using maximum likelihood (ML) estimation, while the final models were fit using restricted maximum likelihood (REML) estimation. This is mainly important for mixed models, because ML estimation can in this case produce biased estimates for variance and covariance parameters (Zuur *et al.* 2009). Significance tests were conducted only on the final model fitted with REML using a two-way ANOVA (type III, Chisq). The presence of outliers was assessed by using Cleveland dotplots and boxplots; and if present were removed to avoid any misfit of the model. Only data points that would possibly change the outcome of the model were considered as outliers, because a high variation is typical for ecological density data and has to be taken into account when estimating confidence intervals and standard errors. To deal with this high amount of variation, the removal of outliers was chosen over a transformation of the response variable, because the latter changes the entire relationship between the explanatory variables and the response variable for univariate techniques (Keele 2008).

Next to these statistical model results, visualisation of the time series was done in time series graphs based on average values to enable putting the model results in a wider perspective. All analyses, data exploration, data frame manipulations and visualisation were conducted in R using following packages: dplyr, tidyr, ggplot2, ggpubr, nlme and car (R Core Team 2020; version 3.6.1).

3. Results

3.1. Epibenthos

3.1.1. Species number, density and biomass

For C-Power, the time series plot for species number (S) showed a slight general increase over the years for the impact samples (fig. 2). When comparing baseline with operational period, a significant OWF effect for species number (interaction term $p = 0.0016$) was observed. Average species number increased within the OWF area (avg. S: 13 spp. vs 18 spp.), while average species number was stable for the reference area (avg. S: 16 spp.). Taking a closer look at the species list made clear that the increase in species number is mainly due to the appearance of species associated with hard substrates in the impact samples that were absent in these samples before the construction of the OWF. It concerns *Cancer pagurus*, *Mytilus edulis*, *Ophiothrix fragilis*, *Pilumnus hirtellus* and *Pisidia longicornis*. Epibenthos density and biomass within C-Power showed a very similar pattern over time, with immediately after construction an overshoot in density and biomass within the impact samples (fig. 2). However, no significant OWF effect was observed on the longer term, when modelling baseline versus operational period (resp. $p = 0.44$ and $p = 0.21$). For both impact and reference samples, there is a significant increase in both average density (resp. 22 *vs* 48 ind./1000 m² and 37 *vs* 52 ind./1000 m²) and biomass (resp. 59 *vs* 182 g WW/1000m² and 94 *vs* 166 GWW/1000 m²) towards the

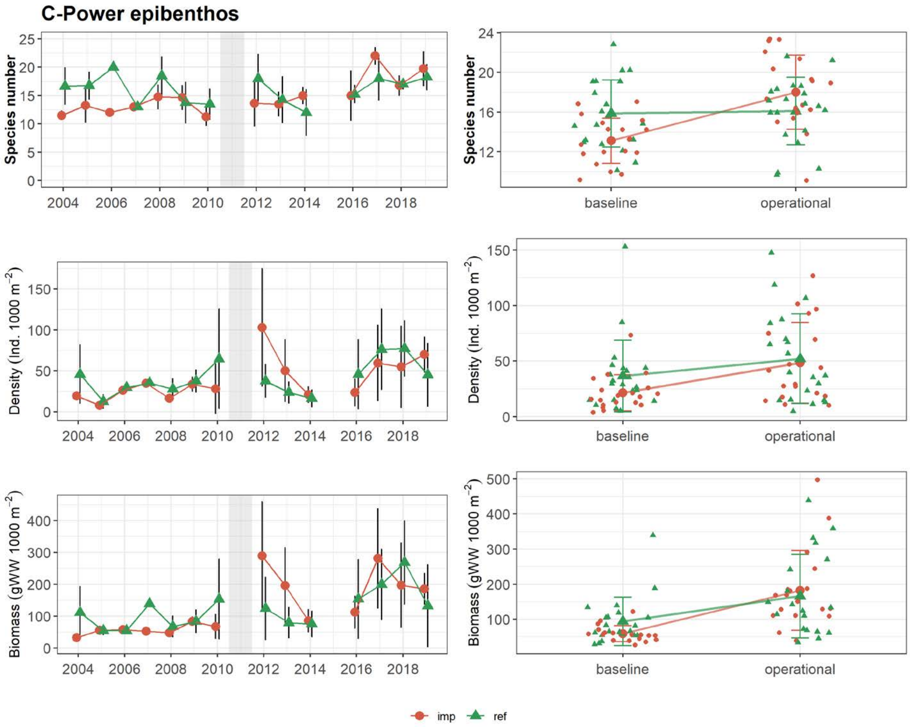

Figure 2. (Left) Time series plots of the univariate variables species number (S), density (N) and biomass for epibenthos at C-Power wind farm. (Right) Mean values (± SD) for baseline (2004-2010) and operational (2014-2019) period allowing to identify offshore wind farm effect. Construction of the second phase of C-Power was in 2011 indicated with a grey rectangle.

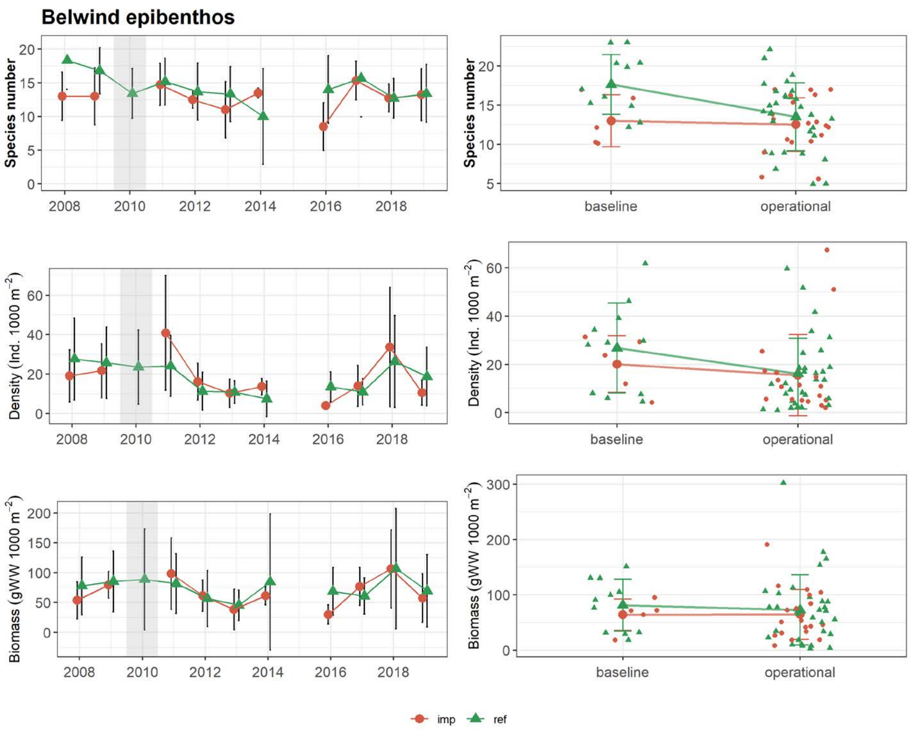

Figure 3. (Left) Time series plots of the univariate variables species number (S), density (N) and biomass for epibenthos at Belwind wind farm. (Right) Mean values (± SD) for baseline (2008-2009) and operational (2012-2019) period allowing to identify offshore wind farm effect. Construction of Belwind was in 2010 indicated with a grey rectangle.

operational period (resp. p = 0.012 and p < 0.001) (fig. 2).

For Belwind, a small significant interaction effect (p = 0.033) was detected for epibenthic species number. Average species number declined within the reference samples from 17 to 13 spp., while for the impact samples it remained stable (around 13 species; fig. 3). Investigating the species list, we as well observed the appearance of some hard substrate-associated species in the impact samples after construction of the OWF namely *M. edulis* and *Necora puber*. Also *Inachus dorsettensis* and *C. pagurus* appeared in the impact samples after construction but this applied as well to the reference samples. For density and biomass, no OWF effect was detected (resp. p = 0.23 and p = 0.5), average density and biomass were very similar in impact and reference samples and in both periods. Nevertheless, similarly as for C-Power, a small overshoot in density was observed right after construction in the impact samples (fig. 3).

3.1.2. Community structure linked to predictor variables

For C-Power, a significant interaction effect (impact x period, $p_{perm} = 0.01$) was observed. Pairwise tests showed that both in the baseline and in the operational period, impact and reference samples significantly differed from each other (resp. $p_{perm} = 0.001$ and $p_{perm} = 0.04$), and even higher significant differences occurred between both periods within each impact group (p < 0.001). SIMPER analyses showed that much lower average densities of brown shrimp *Crangon crangon* (REF: 9 *vs* 0.2 ind./1000m²; IMP: 6 *vs* 0.2 ind./1000 m²) and much higher average densities of *Ophiura ophiura* (REF: 2.5 *vs* 14.5 ind./1000m²; IMP: 12.2 *vs* 1.4 ind./1000m²) occurred in the operational period for both impact groups. Difference between reference and impact group within the baseline period was mainly because of higher average densities of *C. crangon* and much higher average densities of *Ophiura albida* (resp. 8.5 *vs* 2.6 ind./1000m²) in reference samples compared to impact samples but overall species composition was very similar. In the operational period, differences in average densities of dominant species also occurred but less pronounced, hence the smaller significant difference and more overlap in the PCO plot (fig. 4). More remarkable was the increased average densities of hard substrate-associated species

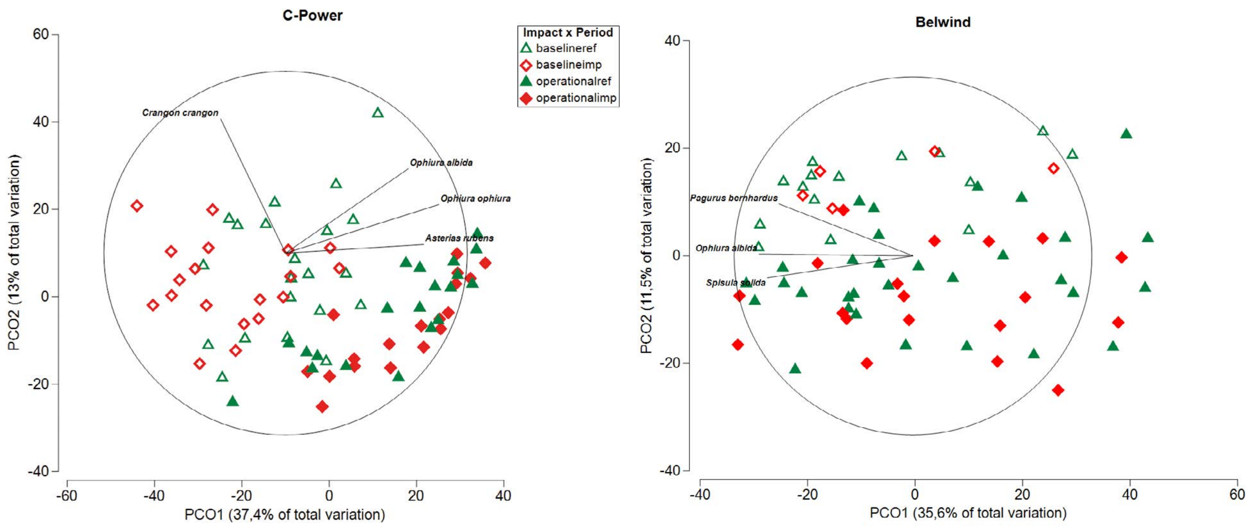

Figure 4. PCO plots based on Bray-Curtis resemblance matrix of square root transformed epibenthic density data for C-Power and Belwind with indication of impact group and sampling period. Vector overlay shows species best correlated with the observed multivariate pattern and is based on Pearson correlation (> 0.75).

Table 2. Proportion of epibenthic community variation that is explained by each individual predictor variable based on marginal DistLM tests for C-Power and Belwind

Variable	Pseudo-F	p-value	Proportion explained (%)
C-Power			
Chlorophyll	1.891	NS (0.07)	2.4
Temperature	7.601	0.0001	29.4
AMO	2.464	0.0097	6.2
NAO	8.721	0.0001	18.9
Discharge	6.636	0.0001	8
Impact	10.070	0.0001	29
Belwind			
Chlorophyll	2.860	0.0158	4
Temperature	2.377	0.0022	9.8
AMO	1.888	0.0372	5.3
NAO	2.641	0.0045	7.3
Discharge	3.241	0.008	4.5
Impact	2.539	0.0013	10.3

M. edulis (resp. 1 *vs* 0.002 ind./1000 m^2) and *Anthozoa* sp. (resp. 1.1 *vs* 0.1 ind./1000m^2) in impact samples compared to reference samples. A DISTLM analysis investigated the relationship between predictor variables (both climate, environmental and impact) and the observed multivariate pattern. Marginal tests showed that all predictor variables, except for chl, had individually a significant relationship with the multivariate data cloud (table 2). Temperature and impact individually explained most of the variation, both 29% (table 2). Together, these five predictor variables explained 55% of the total variation in the epibenthic community structure of C-Power based on BEST model with AIC_c criterion.

For Belwind, no significant interaction effect (impact x period, $p_{perm} = 0.7$) was observed, indicating that the epibenthic community structure on the soft sediments between the turbines was not affected by the presence of the OWF (fig. 4). The only significant difference was found between baseline and operational period ($p_{perm} < 0.001$) and SIMPER indicated that this was mainly because of a decrease in average densities of *O. albida* (5.1 *vs* 2.4 ind./1000 m^2) and *Pagurus bernhardus* (7 *vs* 3.3 ind./1000 m^2). DistLM marginal tests showed that all predictor variables individually explained a smaller or larger part of the observed multivariate variation. Temperature and impact individually explained the highest proportion of the variation, resp. 9.8 and 10.3% (table 2). The BEST model based on AIC_c criterion selected a combination of chl, NAO, discharge and impact which explained 23.4% of the total variation in the epibenthic community structure.

3.1.3. Single species models

Top 10 most common species

In C-Power, *P. bernhardus*, *O. albida* and *Asterias rubens* were the top 3 most abundant epibenthic species. For none of them a wind farm effect was observed, nor for the rest of the top 10 except for *Loligo vulgaris* (p = 0.03) (table 3 and figures in annex 1). This species showed a doubling in density for impacted samples in the operational years compared to the baseline (0.23 *vs* 0.46 ind./1000 m^2), while an

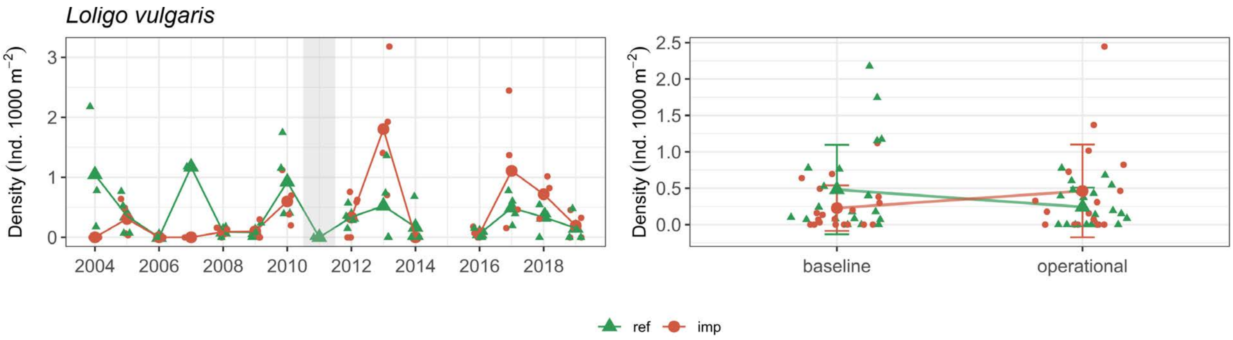

Figure 5. (Left) Time series plots of *Loligo vulgaris* densities in C-Power. (Right) Mean density values (± SD) for *L. vulgaris* in the baseline (2004-2010) and operational years (2014-2019) in C-Power. Construction of the second phase of C-Power was in 2011 indicated with a grey rectangle.

opposite effect could be discerned for the reference samples (0.48 *vs* 0.24 ind./1000 m^2), with low densities overall (fig. 5). When inspecting the time series plot for *L. vulgaris*, very variable densities can be observed with peaks in some years and near-zero density values in other years. However, peaks are mostly occurring simultaneously in both impact and reference areas, except in 2004 and 2007 (only 1 sample) where densities in reference samples were much higher (fig. 5). In operational phase years, a higher density during peaks can be observed for impacted samples compared to reference samples, while the opposite is visible in the baseline years which thus explains why a significant interaction effect was found (fig. 5). A significant time effect was also found for 6 out of the 10 most abundant species, while the impact effect was only significant for *O. albida* (table 3 and figures in annex 1). This impact effect can be explained by a difference in density between reference and impact samples during the baseline years (9.9 *vs* 3.1 ind./1000 m^2), with higher densities found in reference areas in general.

Pagurus bernhardus, *A. rubens* and *O. ophiura* were the three most abundant epibenthic species that were found in Belwind. None of the top 10 epibenthic species showed a significant interaction effect, but for *Sepiola atlantica* a near significant p-value was obtained for the interaction term ($p = 0.05$). This effect is probably detected because of a large peak in density in 2014 in the impact samples, while densities in other years are similar in both impact and reference areas (table 4 and figures in annex 2). For half of the most abundant epibenthic species, a significant time effect was found, while only one species *S. atlantica* showed a significant impact effect.

Focus on two dominant fouling species

For both hard substrate species *Anthozoa* sp. ($p = 0.01$) and *Mytilus edulis* ($p < 0.001$), a wind farm effect was obtained for C-Power (table 3). No or very low densities of these species were found in both reference and impact trawls in the baseline period, while a clear increase in density was observed only in impact samples in the operational period (*Anthozoa* sp.: 0.02 *vs* 4.48 ind./1000 m^2; *M. edulis*: 0.00 *vs* 1.70 ind./1000m^2; fig. 6). In 2017, both species reached a peak in density with a lot of variation between trawls, after which densities declined again. After this decline, *M. edulis* densities in impact samples were only found to be marginally higher than in reference samples. For *Anthozoa* sp., densities in impact samples remained higher than for reference samples during the last two years.

For Belwind, a significant interaction effect could only be detected for *M. edulis* ($p = 0.04$; table 4). For *Anthozoa* sp., the interaction was not significant ($p = 0.19$) as densities also increased in reference samples and are only higher in impact samples in 2018. For both species, the observed wind farm effect seems to appear only after a couple of years after construction (fig. 6).

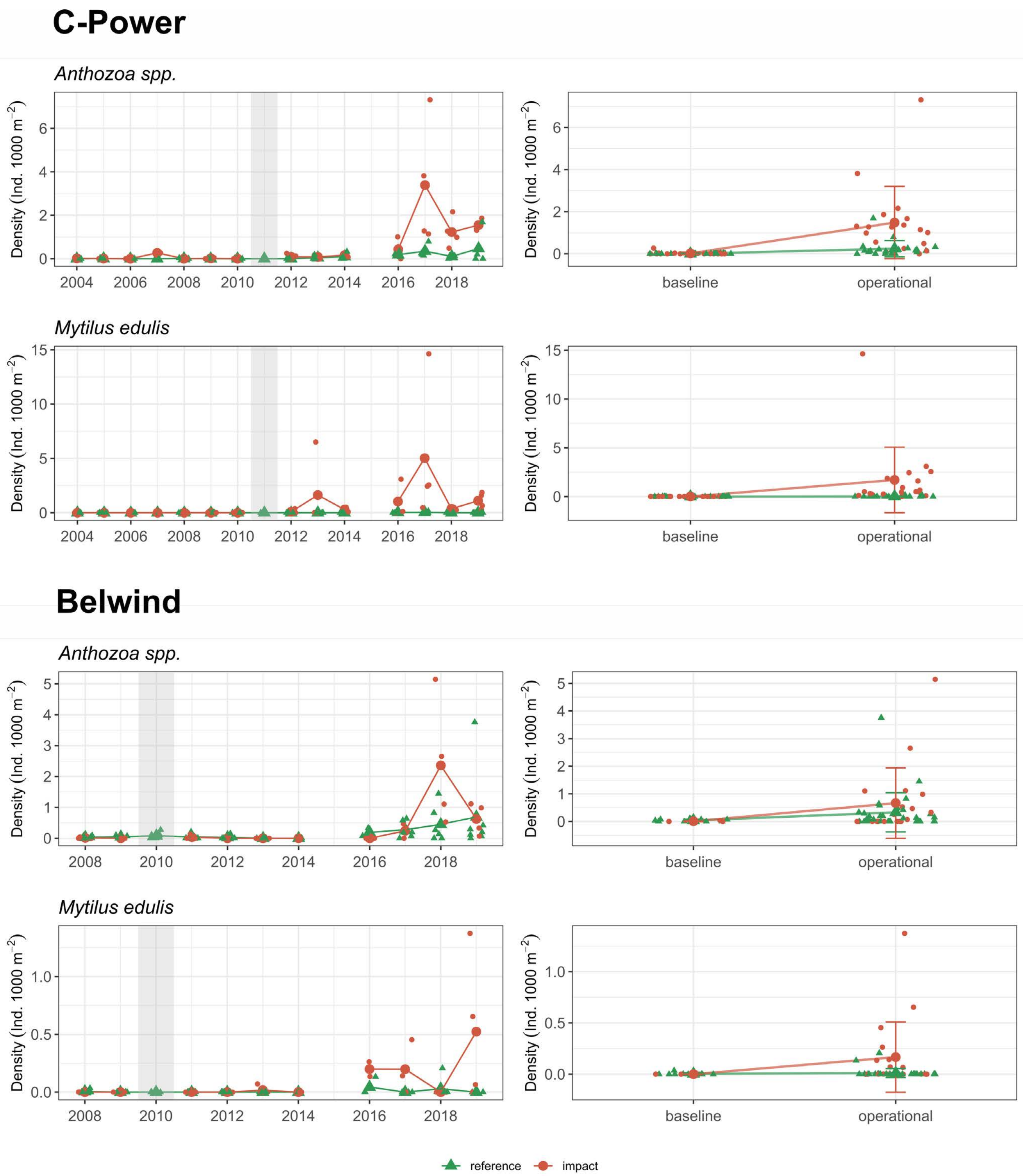

Figure 6. (Left) Time series plots for *Anthozoa* sp. and *M. edulis* densities in both C-Power and Belwind. (Right) Mean density values (± SD) for *Anthozoa* sp. and *Mytilus edulis* in the baseline (C-Power: 2004-2010; Belwind: 2008-2009) and operational years (C-Power: 2014-2019; Belwind: 2013-2019). Grey rectangles indicate construction periods.

Table 3. Overview and results of the GLS models for the ten most abundant epibenthos and fish species together with the two included hard-substrate epibenthic species (light blue) within the C-Power wind farm. The percentage of zero's indicates in how many % of the trawls the species was absent. The different variance structures referred to in the table can be found in the material and methods section. The fourth column indicates if any outliers were removed before fitting the model and how many. The last three columns indicate p-values for all fixed terms of the model obtained from a type III ANOVA test (Chisq). Significant values are indicated in bold ($p < 0.05$).

Species	% zero's	Variance structure	Outliers removed	P(Baseline/ Operational)	P(Reference/ Impact)	P(Interaction)
C-Power epibenthos						
Pagurus bernhardus	0.00	/	yes (1)	**0.009**	0.330	0.320
Ophiura albida	2.56	vf3	no	**0.007**	**0.001**	0.309
Asterias rubens	2.56	vf3	no	**0.002**	0.845	0.614
Ophiura ophiura	1.28	vf3	no	**0.001**	0.378	0.944
Liocarcinus holsatus	6.58	vf1	yes (2)	0.169	0.159	0.566
Sepiola atlantica	19.23	vf3	no	0.432	0.093	0.161
Crangon crangon	21.79	vf3	no	**0.010**	0.262	0.260
Macropodia spp.	32.05	vf3	no	**0.000**	0.407	0.620
Loligo vulgaris	32.05	vf3	no	0.156	0.094	**0.032**
Loligo juv.	43.59	vf3	no	0.124	0.360	0.315
Anthozoa sp.	51.282	vf2	no	**0.003**	0.210	**0.006**
Mytilus edulis	75.641	vf2	no	0.137	**0.033**	**0.028**
C-Power fish						
Species	% zero's	Variance structure	Outliers removed	P(Baseline/ Operational)	P(Reference/ Impact)	P(Interaction)
Arnoglossus laterna	1.30	vf3	yes (1)	**0.007**	0.097	0.395
Limanda limanda	1.32	vf3	yes (2)	**0.034**	**0.015**	0.051
Pleuronectes platessa	1.28	vf3	no	0.376	0.262	**0.010**
Echiichthys vipera	0.00	vf3	no	0.106	0.078	**0.027**
Pomatoschistus	3.85	vf3	no	0.118	0.193	0.183
Callionymus lyra	6.41	vf3	no	**0.005**	**0.003**	**0.002**
Buglossidium luteum	11.54	vf3	no	**0.004**	**0.001**	**0.010**
Mullus surmuletus	14.10	vf3	no	**0.039**	0.192	0.163
Callionymus reticulatus	20.51	vf3	no	**0.003**	0.077	0.072
Hyperoplus lanceolatus	28.21	vf3	no	0.148	0.153	0.146

Table 4. Overview and results of the LMER models for the ten most abundant epibenthos and fish species together with the two included hard substrate epibenthic species (light blue) within the Belwind wind farm. The percentage of zero's indicates in how many % of the trawls the species was absent. The different variance structures referred to in the table can be found in the material and methods section. The fourth column indicates if any outliers were removed before fitting the model and how many. The last three columns indicate p-values for all fixed terms of the model obtained from a type III ANOVA test (Chisq). Significant values are indicated in bold (p < 0.05).

Belwind epibenthos						
Species	% zero's	Variance structure	Outliers removed	P(Baseline/ Operational)	P(Reference/ Impact)	P(Interaction)
Pagurus bernhardus	0.00	/	no	**0.000**	0.612	0.901
Asterias rubens	4.55	vf3	no	**0.004**	0.439	0.419
Ophiura ophiura	7.58	vf2	no	0.296	0.387	0.236
Ophiura albida	10.61	vf3	no	**0.005**	0.191	0.105
Liocarcinus marmoreus	24.62	vf3	yes (1)	0.453	0.961	0.576
Liocarcinus holsatus	27.27	/	no	**0.000**	0.247	0.515
Macropodia	13.64	vf3	no	0.864	0.384	0.724
Spisula solida	15.15	vf3	no	0.833	0.251	0.213
Sepiola atlantica	34.85	vf3	no	0.975	**0.013**	0.053
Loligo juv.	34.85	/	no	**0.001**	0.390	0.330
Anthozoa	45.455	vf	no	0.093	0.101	0.189
Mytilus edulis	83.333	vf	no	0.378	0.898	**0.037**
Belwind fish						
Species	% zero's	Variance structure	Outliers removed	P(Baseline/ Operational)	P(Reference/ Impact)	P(Interaction)
Echiichthys vipera	0.00	vf	no	0.086	0.522	0.252
Pleuronectes platessa	3.03	vf2	no	0.072	0.203	0.170
Arnoglossus laterna	4.55	/	no	0.369	0.525	0.440
Hyperoplus lanceolatus	7.58	vf	no	**0.016**	0.269	0.239
Limanda limanda	16.67	vf2	no	**0.041**	0.965	0.870
Pomatoschistus	16.67	vf3	no	**0.034**	0.994	0.794
Callionymus reticulatus	34.85	vf3	no	**0.000**	0.119	0.089
Ammodytes tobianus	30.77	vf3	yes (1)	**0.006**	0.280	0.677
Mullus surmuletus	27.27	vf2	no	**0.025**	0.061	0.170
Buglossidium luteum	46.97	vf2	no	**0.033**	0.415	0.571

3.2. Fish

3.2.1. Species number, density and biomass

Species number and fish density are very similar over time for impact and reference samples in C-Power (fig. 7). This evidently resulted in an insignificant wind farm effect for both species number ($p = 0.35$) and density ($p = 0.11$; fig. 7).

For Belwind, just as for C-Power, no significant interaction effect was found for species number ($p = 0.14$), nor for fish density ($p = 0.06$). For both variables, a significant time effect was observed with a decrease in both average species number and fish density towards the operational period (fig. 8). When looking at the species list, there was one species for which the appearance seemed an indication of an OWF effect *i.e. Dicentrarchus labrax*, which was absent before construction and now occurred in 20% of the impact samples.

3.2.2. Community structure linked to predictor variables

For C-Power, a significant interaction effect (impact x period, $p_{perm} = 0.004$) was detected. Pairwise tests showed that in the baseline period impact and reference samples differed significantly ($p_{perm} = 0.006$). SIMPER analyses indicated that this was mainly because of density differences in the most common species. For most species, lower average densities were found in the impact samples compared to the reference samples *e.g.* for top 3 contributors to dissimilarity *Callionymus reticulatus* (5.1 *vs* 2.2 ind./1000 m²), *Callionymus lyra* (3.5 *vs* 0.6 ind./1000 m²) and *Limanda limanda* (5.5 *vs* 1.3 ind./1000 m²). In the operational period, reference and impact samples no longer differed significantly ($p_{perm} = 0.2$), which is also clear in the PCO plot where they cluster closer together (fig. 9). Pairwise tests also showed significant differences between periods within impact groups ($p_{perm} < 0.0001$ for both). For the reference group, mainly

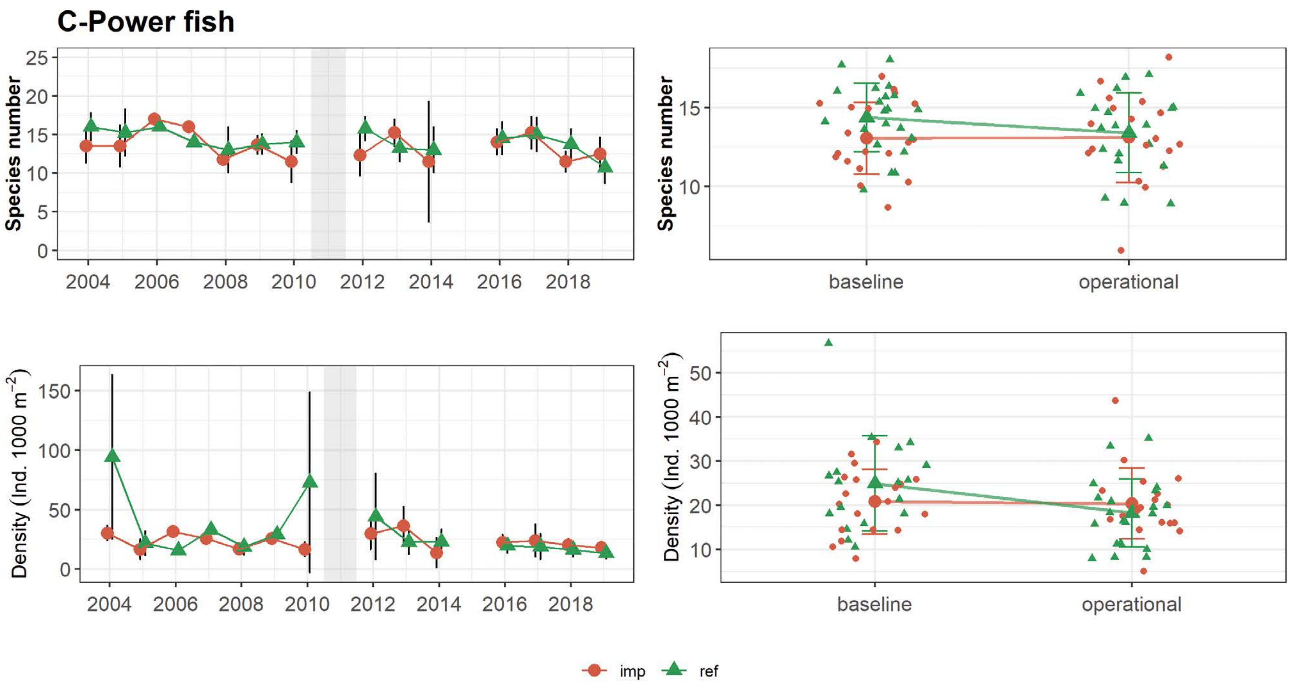

Figure 7. (Left) Time series plots of the univariate variables species number (S), density (N) and biomass for fish at C-Power wind farm. (Right) Mean values (± SD) for baseline (2004-2010) and operational (2014-2019) period allowing to identify offshore wind farm effect. Construction of the second phase of C-Power was in 2011 indicated with a grey rectangle.

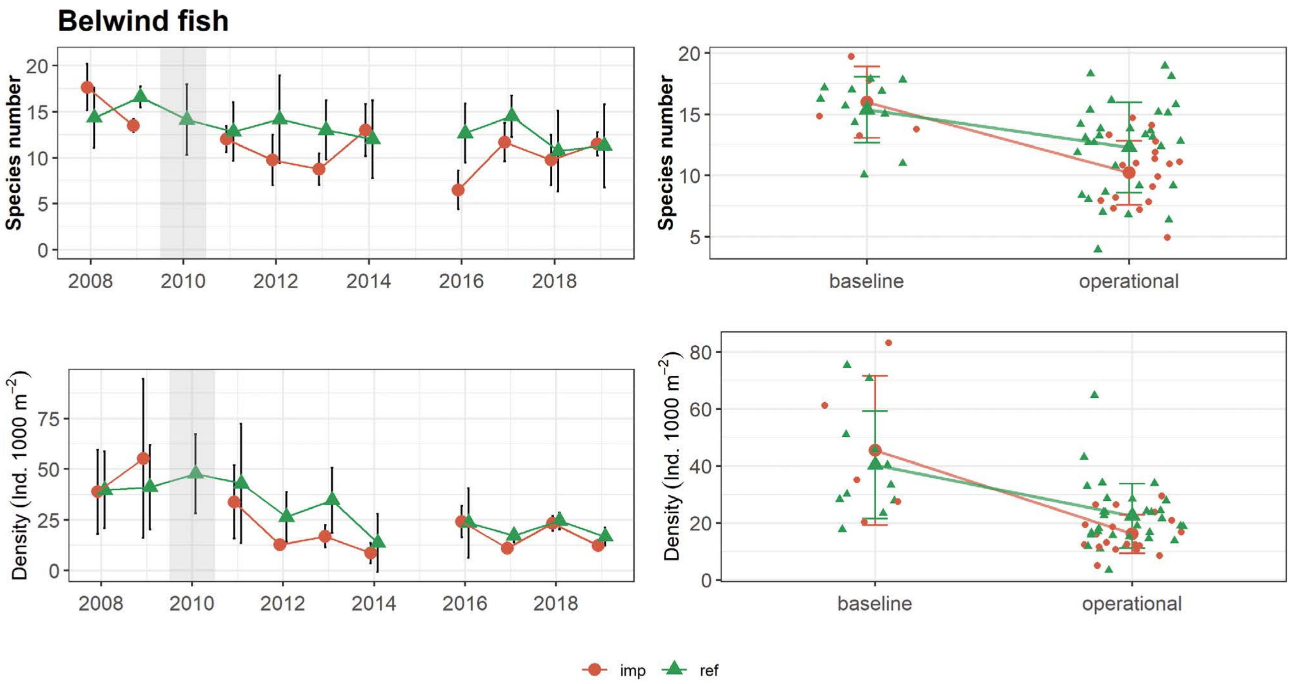

Figure 8. (Left) Time series plots of the univariate variables species number (S), density (N) and biomass for fish at Belwind wind farm. (Right) Mean values (± SD) for baseline (2008-2009) and operational (2012-2019) period allowing to identify offshore wind farm effect. Construction of Belwind was in 2010 indicated with a grey rectangle.

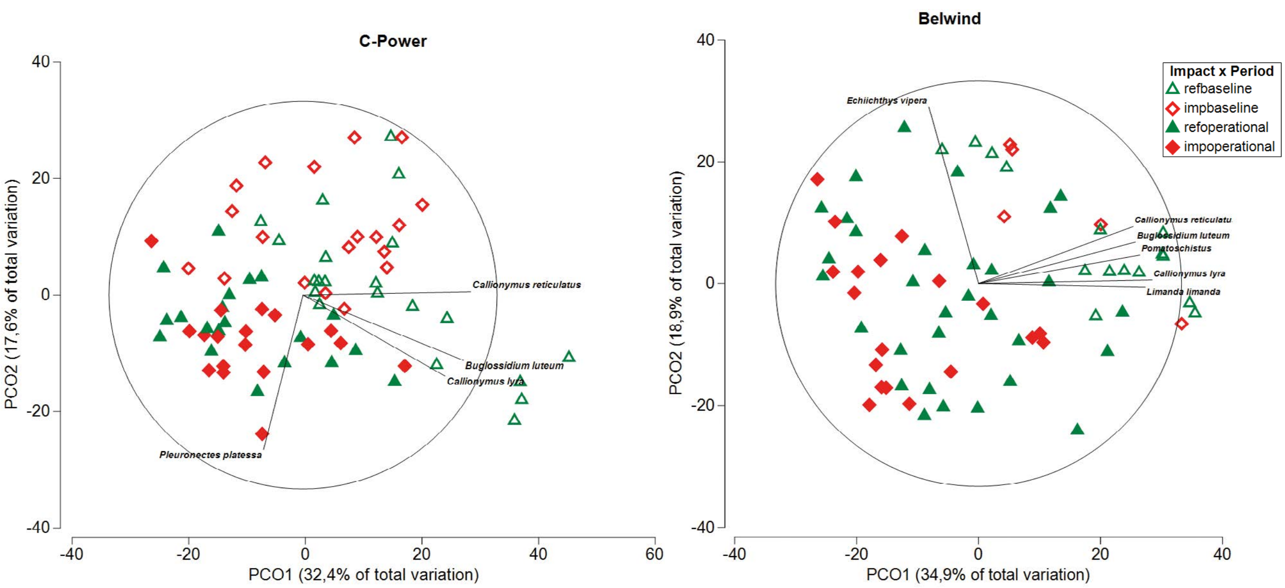

Figure 9. PCO plots based on Bray-Curtis resemblance matrix of square root transformed fish density data for C-Power and Belwind with indication of impact group and sampling period. Vector overlay shows species best correlated with the observed multivariate pattern and is based on Pearson correlation (> 0.75).

Table 5. Proportion of demersal fish community variation that is explained by each individual predictor variable based on marginal DistLM tests for C-Power and Belwind.

Variable	Pseudo-F	p-value	Proportion explained (%)
C-Power			
Chlorophyll	1.121	NS (0.32)	1.5
Temperature	4.855	0.0001	21
AMO	1.459	NS (0.1)	3.7
NAO	3.427	0.0003	8.4
Discharge	3.998	0.0018	5
Impact	7.210	0.0001	22.6
Belwind			
Chlorophyll	6.739	0.0001	9
Temperature	5.570	0.0001	20.2
AMO	2.331	0.0144	6.5
NAO	5.529	0.0001	14.2
Discharge	9.092	0.0001	11.8
Impact	7.289	0.0001	24.9

decreases in common species were observed towards the operational period *e.g.* *C. reticulatus* (5.1 *vs* 0.1 ind./1000 m²), *C. lyra* (3.5 *vs* 0.6 ind./1000m²) and *L. limanda* (5.5 *vs* 1 ind./1000 m²). While for the impact group, a different pattern is observed with as well a decrease for *C. reticulatus* towards the operational period (2.2 *vs* 0.2 ind./1000 m²), but for most other common species an increase or *status quo* was detected for the operational period with the clearest increase for *Pleuronectes platessa* (0.6 *vs* 2.7 ind./1000 m²). A DistLM analysis investigated the relationship between predictor variables and the observed multivariate pattern. Marginal tests showed that temperature (21%), NAO (8.4%), discharge (5%) and the categorical impact variable (22.6%) individually explained a significant proportion of the total variation in the multivariate data cloud (table 5). The BEST model based on AIC_c criterion included all predictor variables and explained 47.5% of the total variation in the demersal fish community structure.

For Belwind, no significant interaction effect (impact x period, $p_{perm} = 0.7$) was observed, indicating that an effect on the fish community structure on the soft sediments between the turbines by the presence of the OWF could not be demonstrated (fig. 9). The only significant effect was found between baseline and operational period ($p_{perm} < 0.001$). SIMPER indicated this was due to a decrease in densities of the common species in the operational period compared to the baseline period *e.g.* for top 3 contributors to dissimilarity between periods *Echiichthys vipera* (22.1 *vs* 13.7 ind./1000m²), *C. lyra* (1.8 *vs* 0.06 ind./1000 m²) and *Buglossidium luteum* (1.8 *vs* 0.04 ind./1000 m²). Marginal DistLM tests showed that all individual predictor variables explained a significant part of the variation of the observed multivariate pattern (table 5). The individual variables explaining most of the individual variation were temperature (20.2%) and impact (24.9%; table 5). The BEST model based on AIC_c criterion selected temperature, NAO and impact to be included and explained 46.1% of the total variation observed in the fish community structure.

3.2.3. Single species models

For C-Power, the three fish species with the highest presence in the samples were *Arnoglossus laterna, L. limanda* and *P. platessa*. For *B. luteum* ($p = 0.01$), *P. platessa* ($p = 0.01$), *E. vipera* ($p = 0.03$) and *C. lyra* ($p = 0.002$), a significant interaction could be found between the impact factor (RI) and the time factor (BO). Density models of *L. limanda* ($p = 0.05$) and *C. reticulatus* ($p = 0.07$) also showed a near-significant interaction term. For solenette *B. luteum*, a wind farm effect was detected, but this was mainly due to a decrease in density in reference samples over time (3.3 *vs* 0.99 ind./1000 m^2), while the densities in impacted samples remained stable (fig. 10). For common dragonet *C. lyra*, of

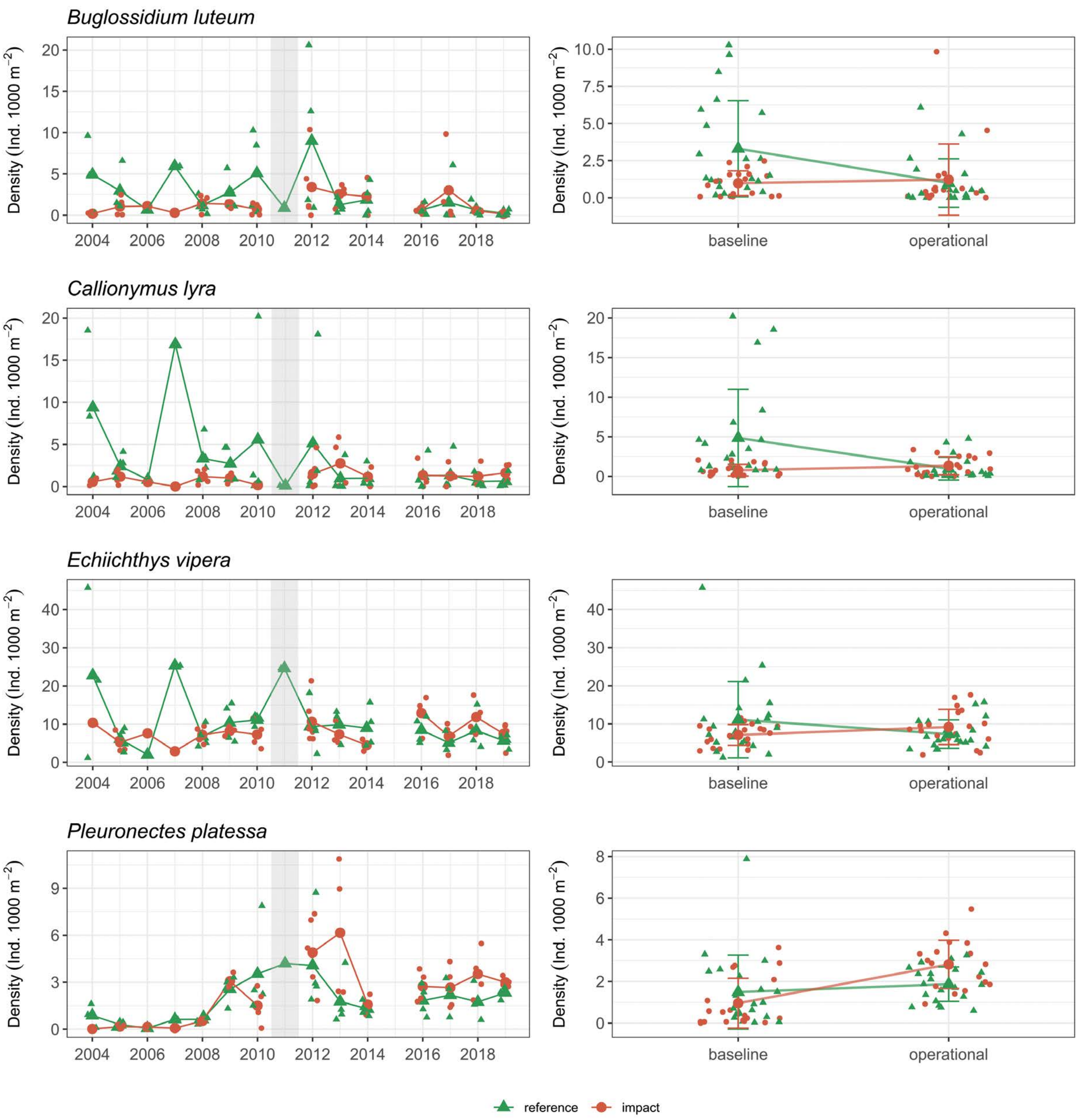

Figure 10. (Left) Time series plots of densities (individuals per 1000 m^2). (Right) Mean density values (± SD) for fish species in C-Power for which a wind farm effect was detected in the baseline (2004-2010) and operational years (2014-2019). Construction of the second phase of C-Power was in 2011 indicated with a grey rectangle.

which its densities also showed a wind farm effect, a similar pattern over time could be discerned. Peaks in densities were similar for both species in 2004, 2007, 2010 and 2012 in reference samples, after which densities stabilised and equalled densities in the impacted areas (fig. 10). A small significant interaction effect ($p = 0.03$) was found for lesser weever *E. vipera* densities in the C-Power wind farm. Densities of this species declined slightly in reference samples, while the opposite trend was observed for impacted samples (fig. 10). The time series plot showed very variable density values from year to year for reference samples, mainly during baseline years and construction, while impact samples showed a steadier course over time. During the last four years of the sampling, density of lesser weever in the impacted areas remained consistent, but marginally, higher than in reference areas (fig. 10). A wind farm effect was also found for plaice *P. platessa* ($p = 0.01$), with higher average densities during operational years in impacted sites compared to the baseline conditions (0.96 *vs* 2.82 ind./1000 m^2). Average densities in reference areas maximised during the construction years of the wind farm, but stabilised again from 2013 onwards. This trend is also visible for impacted areas, but is less clear due to the data gap in 2010. During operational years, densities found in trawls of impacted areas are consistently higher than those found in reference areas, while this was not the case in the baseline period (fig. 10).

Belwind samples had the highest abundances of *E. vipera*, *P. platessa* and *A. laterna*. None of the fish species in Belwind showed a significant wind farm effect. A near significant interaction, however, was obtained for *C. reticulatus* ($p = 0.09$), which can be explained by a steeper decline of densities over time in reference samples compared to impact samples (table 4 and figures in annex 4). For all but three of the 10 most abundant species, a significant time effect was found, which was negative for six out of the seven species (positive for *Mullus surmuletus*). Overall, fish densities seem to have declined over time within this wind farm, but this both for reference and impact area simultaneously (table 4 and figures in annex 4).

4. Discussion

This chapter presents the results of 8 and 9-year post-construction beam trawl monitoring at C-Power (jacket foundations, located 30 km offshore) and Belwind (monopile foundations located 46 km offshore). We specifically focused on the longer-term effects of an established operational OWF on the soft sediment epibenthos and demersal and bentho-pelagic fish in between the turbines (at distance > 200 m), both at assemblage and species level. Therefore, we excluded the first two post-construction years from our analyses in order to exclude the previously observed post-construction ‘overshoot’ effect for some epibenthic species in both wind farms (more pronounced in C-Power), especially visible for *Asterias rubens* and *Pagurus bernhardus* (Derweduwen *et al.* 2016a; De Backer & Hostens 2017; time series graphs in this report).

4.1. Temporal variability, dominant structuring effect for epibenthos and demersal fish

The soft sediment epibenthos and fish assemblages in between the turbines underwent no drastic changes due to the presence of the OWFs at mid/longer term. The species originally inhabiting the sandy bottom are still present and remain dominant in both OWFs. This is in line with other studies *(e.g.* Bergström *et al.* 2013; Stenberg *et al.* 2015), which was to be expected, since changes may take place at different spatial scales and effects are diminishing with distance from the turbine (Dannheim *et al.* 2019, 2020). As such, changes further away from the turbines (> 200 m from the piles) can be presumed to be more subtle. The main observed temporal differences, both at the assemblage and the species level, were often observed in both the impact and reference zones. This showed that the epibenthos and fish assemblages of soft sediments are in first place structured by temporal variability at larger spatial scales, and that this degree of variation is proportionally much larger than the local effect of the presence of hard sub foundations in the OWF areas. For instance, the brown shrimp *C. crangon* was a dominant species in autumn samples at the Thornton Bank before 2011 in both impact and reference locations, but it almost disappeared afterwards. This may be linked to a change in the migration pattern or reproduction cycle in relation to temperature changes (Boddeke 1975; Beukema 1992). Another example is given by reticulated dragonet, *C. reticulatus*, which showed a remarkable decrease over time both at the Bligh Bank and the Thornthon Bank, *i.e.* at a larger spatial scale.

We have introduced environmental predictor variables in our multivariate analyses to explain the observed variation. Generally, around 50% of the variation (except for epibenthos at Bligh Bank) could be explained, which is surprisingly high. Temperature (combination of SST and 1-3 year lagged SST) was one of the important individual variables explaining a large part of the variation, but also the climate indices NAO or AMO were often selected by the models to explain part of the variation. Many studies have shown these variables to be important in structuring biological communities (Harris *et al.* 2014; Ottersen *et al.* 2001). Chlorophyll and daily discharge from the Scheldt contributed much less to the explained variation. These results indicate that temporal variation based on SST and other climate variables are important drivers of the temporal structure in soft sediment epibenthos and fish assemblages.

We also included the categorical variable 'impact' in our analyses, which appeared to be an important explanatory variable as it was selected by all our models. This suggests that the OWF effect might actually be as important as the time aspect. However, due to the binary nature of this categorical variable, also a time factor and a spatial factor (related to the specific location of the beam trawl samples) are encapsulated within this predictor variable, which means that it is actually a combination of time, space and OWF effect. Hence, our primary conclusion remains that the epibenthos and demersal fish assemblages were mainly structured by temporal variability (comparable over larger spatial scales), and that this degree of change is proportionally much larger than the local effect of the present OWFs. Nevertheless, some significant secondary effects could be clearly related to the presence of the OWFs.

4.2. Further expansion of the reef effect?

For C-Power, some obvious OWF effects were discerned in the epibenthic species assemblage, suggesting a further expansion of the reef effect. The number of epibenthic species significantly increased in the impact area (*i.e.* the soft sediments in between the OWF-foundations), mainly due to the appearance of hard-bottom associated species like *Ophiothrix fragilis*, *Pilumnus hirtellus*, *Pisidia longicornis*, *Mytilus edulis* and *Cancer pagurus*. These are all species that were not present in the area before construction of the OWF and now known to occur on the scour protection layer of the turbines (De Mesel *et al.* 2015; Krone *et al.* 2016; Kerkhof *et al.* 2019). For Belwind, some of these hard substrate epibenthic species popped-up as well on the soft sediments, although this was less pronounced. Here, one fish species seabass, *Dicentrarchus labrax*, appeared in the impact samples after construction, while it was absent in the baseline period. This species is known to be attracted to hard substrates (Fabi *et al.* 2004) and has been spotted in schools around the turbines of Belwind (pers. comm. Jan Reubens and own observation).

We found significant density increases of *Mytilus edulis* (in both OWFs) and *Anthozoa* sp. (in C-Power only) in the soft sediments, both species that are fouling on the turbines (De Mesel *et al.* 2013; Kerkhof *et al.* 2019). This was observed for the first time in 2017, where living mussel clumps were found in the beam trawl samples (De Backer & Hostens 2018), and it seems that this pattern continues. Increased densities of both anemones and blue mussels started to appear 5 to 6-year post-construction, coinciding with the *M. edulis-Metridium senile* 'climax' succession stage 6-year post-construction, as described for the hard substrate assemblage on the monopiles in Belwind (Kerkhof *et al.* 2019). For C-Power, only scrape samples from the gravity-based foundations were studied and a climax *Metridium senile* stage was found (Kerkhof *et al.* 2019). No study on the epifouling of the jacket foundations in C-Power is done, but based on the increased *M. edulis* densities in the soft-sediment in this OWF, we can expect that this will be similar to what is described for Belwind. Also other studies showed that jacket-like foundations (oil rigs, gas platforms) exhibit a favourable substrate for blue mussels (Maar *et al.* 2009; Krone *et al.* 2013). These mussel clumps and Anthozoa found in the soft sediments are probably 'knocked off' from the turbines and transported with the currents. Survival chances of *M. edulis* on mobile soft-bottoms at depths of 20 m, with high risk of burial, are probably low (Hutchison *et al.* 2016). Nevertheless, in some macrobenthic soft sediment samples close to the turbines in C-Power (< 50 m), mussel-bed associated communities have been described (Lefaible *et al.* 2019), showing that these species are able to survive (at least for some time) in or on soft sediments. Further, this observation is in line with the so-called 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. Up until now, densities of mussels at 200 m distance from the turbine are still low and soft-bottom epibenthic species remain dominant, but it is a clear indication that the reef effect is expanding beyond the turbine scale and could thus increase heterogeneity in the soft-bottom sediments at wind farm scale in the (near) future.

Another significant reef effect detected at the species level is the increased density of common squid *Loligo vulgaris* within the C-Power wind farm. *Loligo vulgaris* is a benthic spawner and attaches egg clusters to hard substrata (Hastie *et al.* 2009). Although, densities of *L. vulgaris* greatly varied from year-to-year in the OWF operational period, patterns between reference and impact samples were quite similar over time, but higher densities were observed within the C-Power OWF area. This might be a first indication that *L. vulgaris* uses the jacket foundations for egg deposition. Egg deposition in the North Sea of *L. vulgaris* mainly peaks in late spring/summer depending on water temperature (FAO 2010). Our sampling campaign is late summer/early autumn and mainly juvenile squid are caught, which could originate from the spawning in summer. In an earlier study on squid larvae in C-Power, we did not find an effect (yet) of the OWF (Vandendriessche *et al.* 2016), but as that study was performed in the first years after construction it was probably too early to detect any effects. Partial attraction to gas platforms has been observed previously (Fabi *et al.* 2004). A visual census for egg clusters during the spawning season (*i.e.* late spring/summer) on the jacket foundations would be the best follow-up to confirm or refute this hypothesis.

The above results clearly suggest that with longer time after construction, the reef effect is expanding further into the soft sediments between the turbines, not (yet) replacing the original soft-sediment assemblages but adding slight changes to these communities.

4.3. First signs of fisheries exclusion or increased food availability?

We observed a few significant effects within the soft sediment demersal fish assemblages. These results are in line with Methratta & Dardick (2019), who in a recent review on finfish, observed limited significantly positive effects mainly for species associated with hard bottoms, rather than for soft-bottom-associated species, and larger effects in direct vicinity of the turbines (< 40 m). As our beam trawl samples are located > 200 m from the turbines, with focus on soft-bottom-associated species, it is not surprising that effects were rather limited.

Nonetheless, for C-Power we observed significant effects for four common soft sediment fish species: common dragonet *C. lyra*, lesser weever *E. vipera*, solenette *B. luteum* and plaice *P. platessa*. The first three are small, non-commercial, benthivore species, showing a similar trend: decreasing abundance in the reference area and a *status quo*/slight increase in abundance in the impact area, especially in the later years. This may be a first hint of a 'refugium' effect in between the turbines related to a positive effect of fisheries exclusion on bycatch species. A second explanation for the higher densities of these three fish species may be food availability. In an earlier study, right after construction (Derweduwen *et al.* 2012), fuller stomachs were discerned for these three species in the OWF, indicating that they benefit from the epifouling on the scour protection layer. In a follow-up study, an increased occurrence of *Pisidia longicornis*, a dominant species on the scour protection, was found in the stomachs of lesser weever in the wind farm, indicating a diet change in the OWF (Derweduwen *et al.* 2016b). Most probably, a combination of both increased food availability and fisheries exclusion explains the observed patterns.

The fourth species, for which a significant positive effect with increased abundance in C-Power was observed, is plaice *P. platessa*, a commercial flatfish species. This is a confirmation of earlier indications that plaice was present in higher abundance within the OWF (Vandendriessche *et al.* 2015; De Backer & Hostens 2017). In another study, looking at fishing activities around OWFs in the Belgian North Sea, we found an indication of increased catch rates of plaice around the C-Power wind farm (De Backer & Hostens 2019). All these results are consistent over the years, signalling a 'refugium' effect for plaice between the turbines in the C-Power OWF, that might be an effect of fisheries exclusion. Whether or not in combination with increased food availability requires further research.

For Belwind, no such refugium effect on the demersal fish assemblage has been observed. In general, effects were more pronounced for C-Power than for Belwind. The unbalanced design (with only two years of baseline samples in Belwind) might mask some effects. On the other hand, the long-time series post-construction give a better estimate of the mean population, and time series graphs from both impact and reference areas normally allow to signal potential effects, which was not the case for Belwind. Moreover, the difference for both OWFs is not only found for epibenthos and demersal fish assemblages; also for the soft sediment macrobenthos assemblage the effects are more pronounced in C-Power (Lefaible *et al.* 2019). It remains unclear why this difference between both OWFs exist. It may be related to differences in foundation type, site-specific differences such as distance to shore, depth, hydrographic conditions, sediment or community type. However, differences in surrounding fishing pressure have been noted as well (De Backer & Hostens 2019). The fishing exclusion zone surrounding C-Power has been larger for a longer time period both northwest and southeast, related to the construction of Rentel and Norther. Belwind is surrounded by the Nobelwind concession, but the construction of other neighbouring OWFs only started in 2019. This might lead to a higher fishing effort surrounding Belwind, partially nullifying the refugium effect. The differences do highlight the fact that extrapolation from site-specific OWF effects should be done with care. It also highlights the importance of performing OWF monitoring in different types of wind farms, each with their own specificity.

5. Conclusion

Temporal variation, related to changes in temperature and climate indices, is the main driver structuring epibenthos and demersal fish assemblages, partially masking the potential effect of the presence of OWFs. Nonetheless, we found some clear effects in the soft sediment epibenthic and demersal fish assemblages, which point to an expansion of the OWF effect beyond the immediate vicinity of the turbine, around 8-year post-construction. Effects were subtle but apparent at two levels: (1) an expansion of the reef effect in the soft sediment assemblages, through an increased number of hard substrate-associated species like *Pisidia longicornis*, *Cancer pagurus* and *Dicentrarchus labrax*, and significantly increased abundances of *Mytilus edulis* and *Anthozoa* sp., two species dominating the epifouling communities on the turbines; (2) signals of a refugium effect in C-Power for some common soft sediment-associated fish species (common dragonet *C. lyra*, solenette *B. luteum*, lesser weever *E. vipera* and plaice *P. platessa*) showing higher densities inside the wind farm compared to the reference area, probably related to a combination of fisheries exclusion and increased food availability. More pronounced effects were found for C-Power than for the more offshore Belwind OWF, stressing that effects might be site-specific and that extrapolation of these findings to other OWFs should be done with care.

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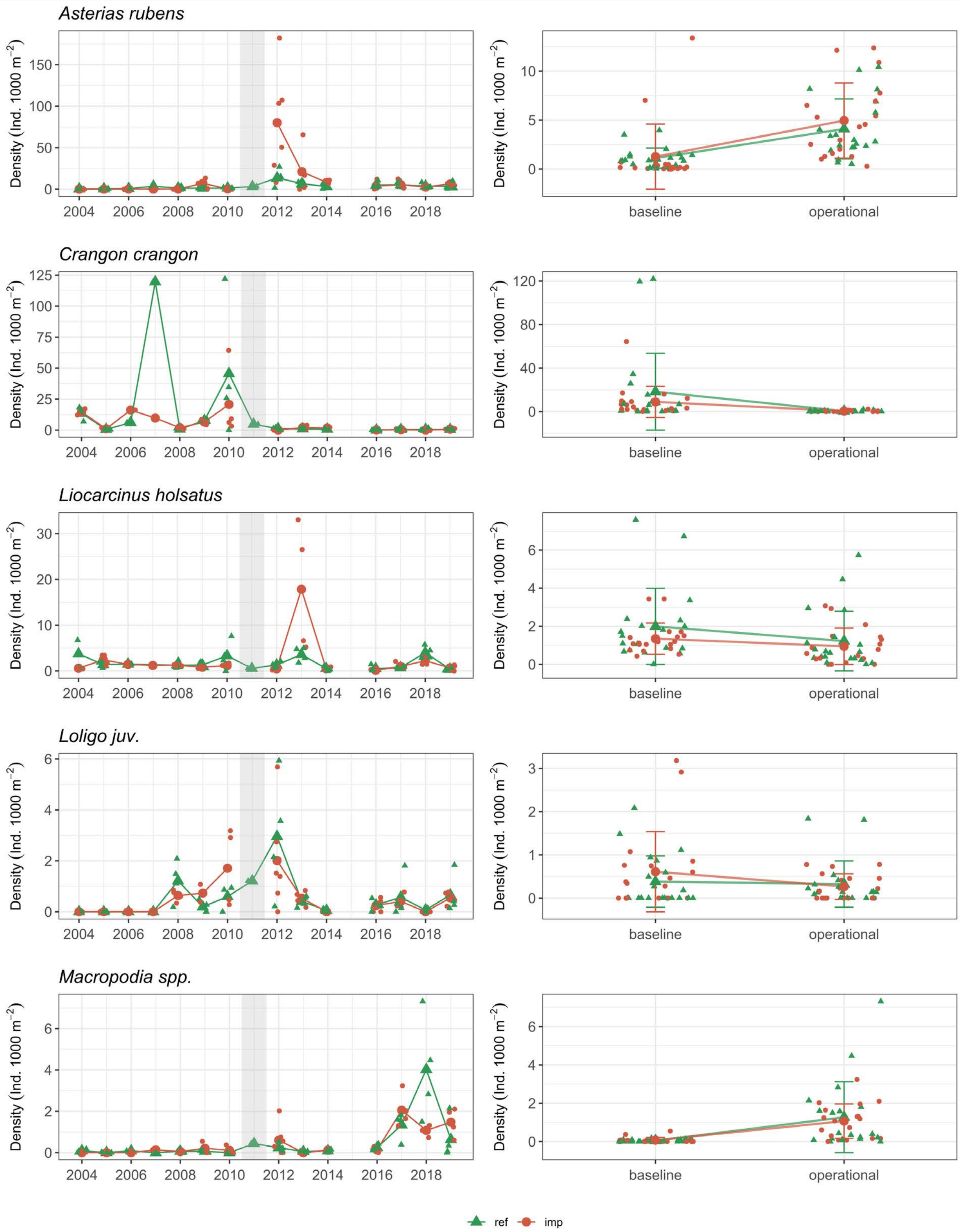
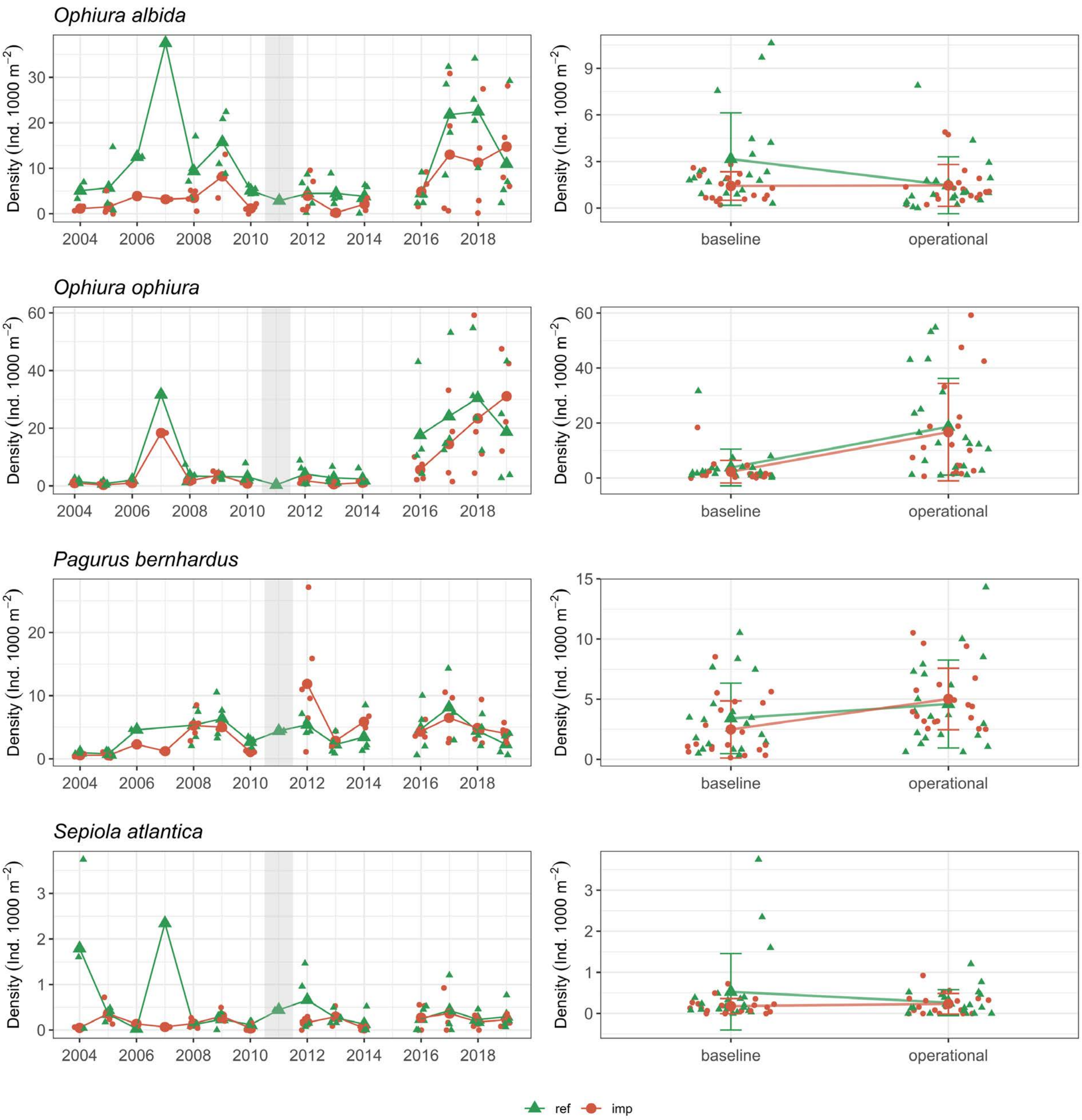
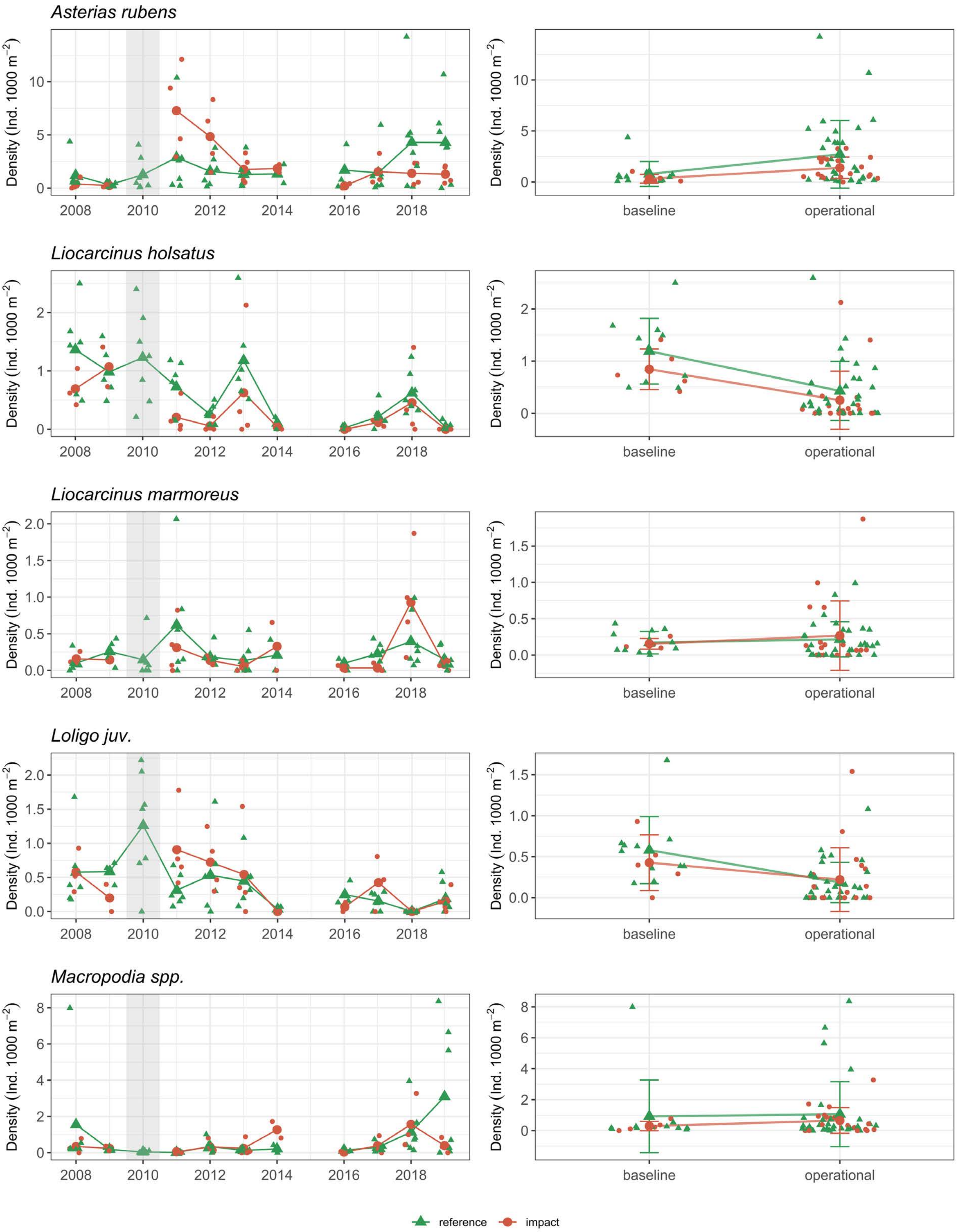
Annex

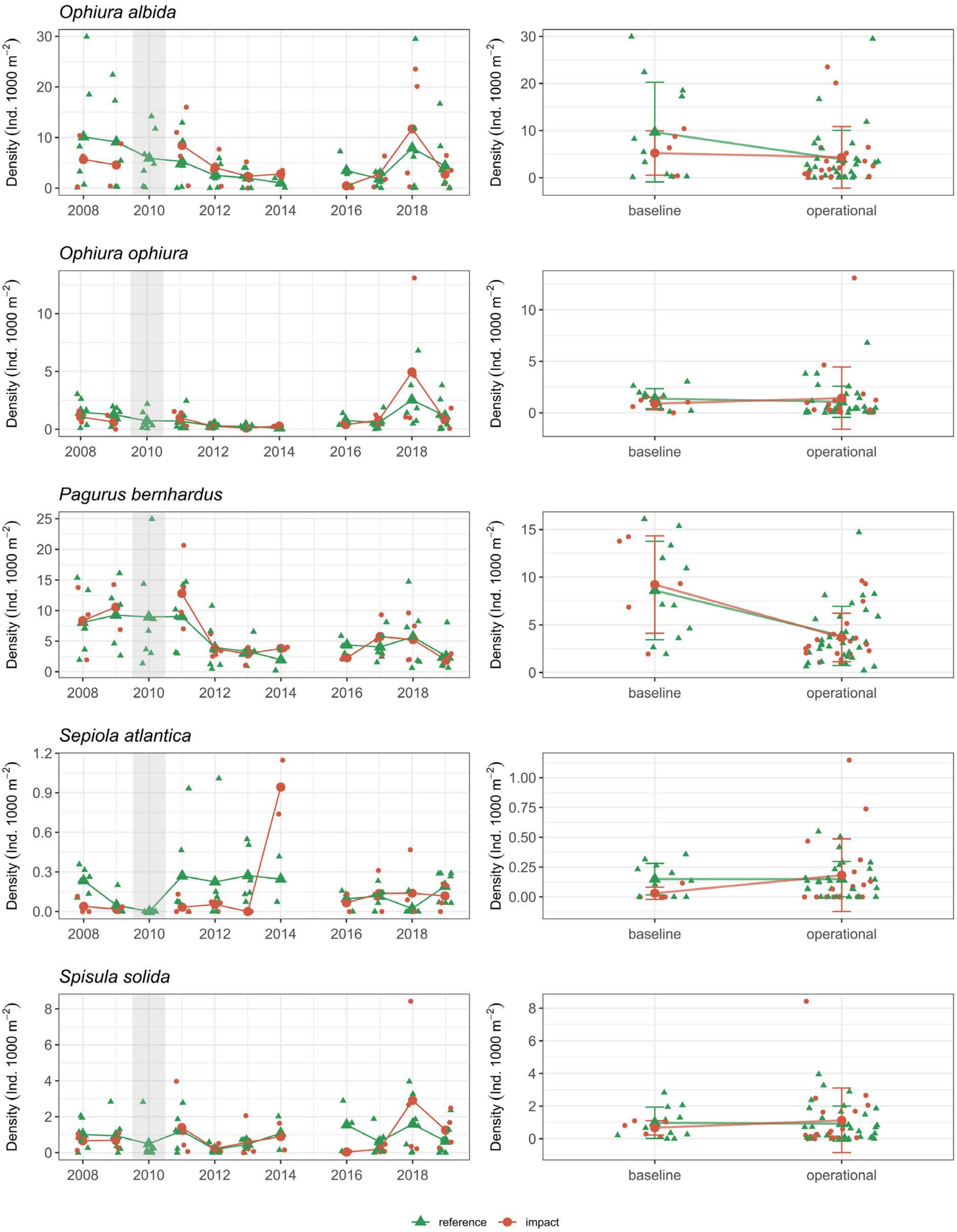
1. Epibenthos C-Power



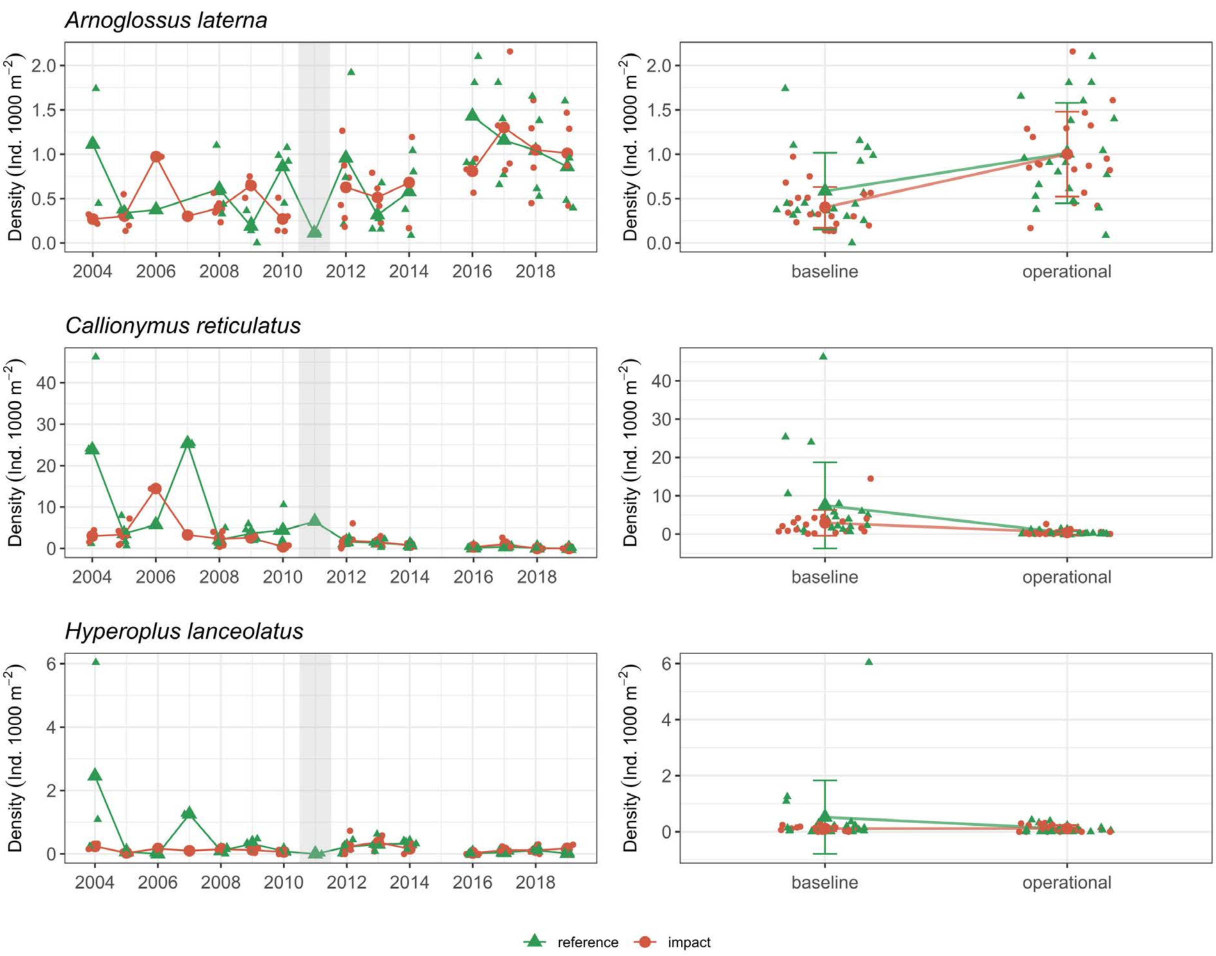

Ophiura albida
Density (Ind. 1000 m^-2)
baseline
operational
Ophiura ophiura
Pagurus bernhardus
Sepiola atlantica
2004
2006
2008
2010
2012
2014
2016
2018
ref
imp

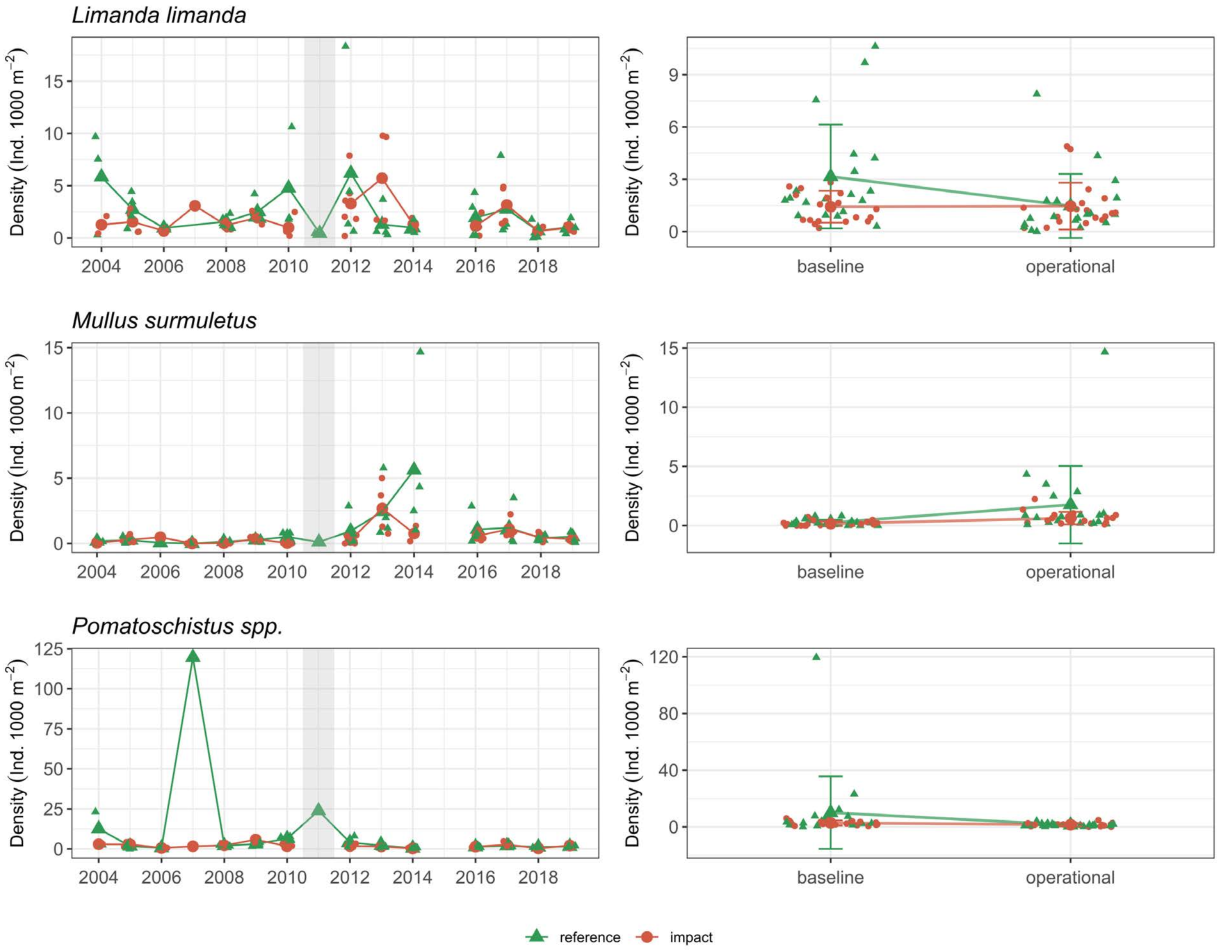
2. Epibenthos Belwind




Ophiura albida
Ophiura ophiura
Pagurus bernhardus
Sepiola atlantica
Spisula solida
Density (Ind. 1000 m⁻²)
2008
2010
2012
2014
2016
2018
baseline
operational
reference
impact

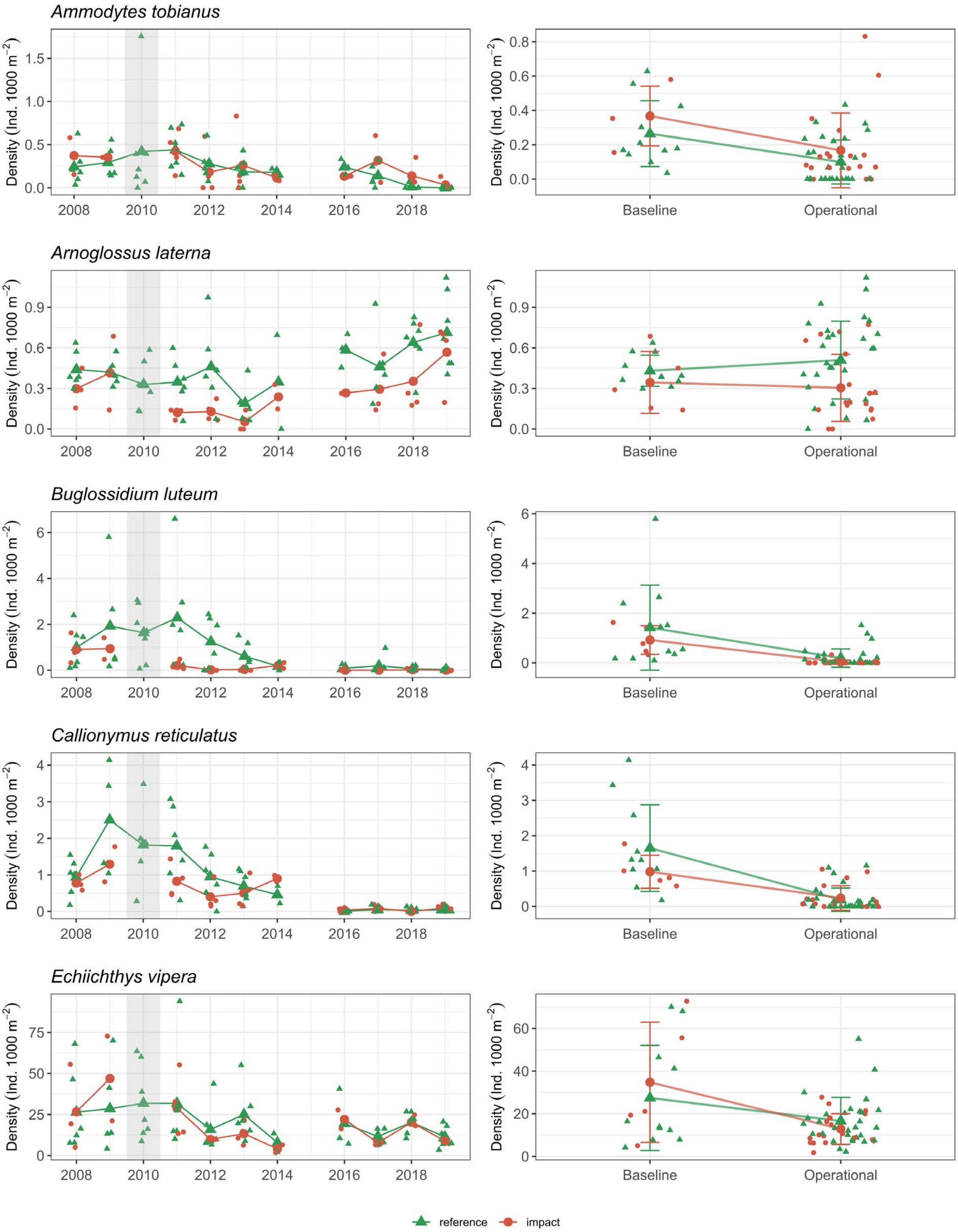
3. Fish C-Power

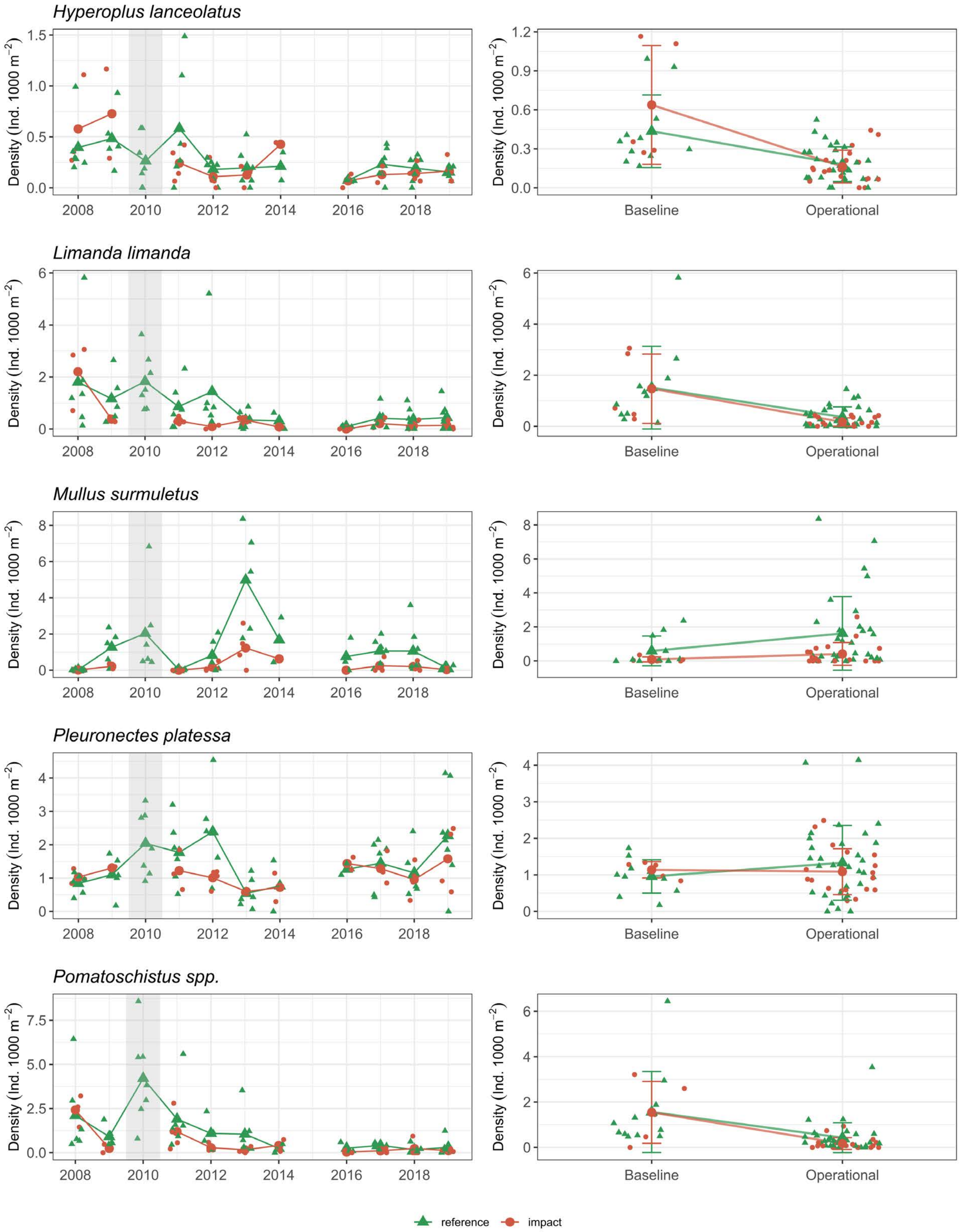




Limanda limanda
Mullus surmuletus
Pomatoschistus spp.
Density (Ind. 1000 m^{-2})
2004
2006
2008
2010
2012
2014
2016
2018
baseline
operational
reference
impact

4. Fish Belwind





Hyperoplus lanceolatus
Limanda limanda
Mullus surmuletus
Pleuronectes platessa
Pomatoschistus spp.
Density (Ind. 1000 m^{-2})
2008
2010
2012
2014
2016
2018
Baseline
Operational
reference
impact