CHAPTER 10

Between the turbines: soft substrate epibenthos and fish

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With the construction of wind farms, new hard substrates are introduced in the marine environment. The sediment between the turbine rows and around the wind farms, however, remains soft. Still, the inhabiting fauna can be influenced by the presence of the turbines (reef effect) in the wind farm and the absence of fisheries (refugium effect). These effects were investigated for epibenthos, demersal fish and benthopelagic fish in the Thorntonbank and Bligh Bank wind farms. The analyses revealed some wind farm effects, but they were not consistent between wind farms. Fringe effects could not be shown.

INTRODUCTION

Since the start of offshore wind farm construction in Europe, a number of studies have described the reef effects of the new hard substrates on epibenthic fauna and on demersal and benthopelagic fish in their close vicinity (e.g. Wilhelmsson et al., 2006; Andersson et al., 2009; Reubens et al., 2011; Bergström et al., 2013; Reubens et al., 2013a). The sediment of the space between the turbines and their scour protection layers, however, remains soft. Still, the inhabiting fauna can be influenced by the presence of the turbines in the wind farm and the absence of fisheries (fisheries exclusion is in force in most European wind farms).

Wind farm effects include (1) depletion of phytoplankton by high densities of filtrating organisms on and around the turbine, which can negatively affect growth of filter feeders on the seabed (2) input of organic material from organisms associated with the turbines, as well as entrapment of material by the turbines, which could enrich the seabed and enhance abundances of deposit-feeding organisms, and in turn benefit predators on these, (3) predation by fish and crabs associated with the turbines, which could negatively affect abundances of prey species and (4) a reef effect enhancing abundances of pelagic fish species, and attracting flatfishes to the reef (Wilhelmsson et al., 2006; Andersson et al., 2009; Wilhelmsson et al., 2009). Additionally, underwater noise, vibrations and electromagnetic fields can cause disturbance and can influence the resident fauna (Wahlberg and Westerberg, 2005; Petersen and Malm, 2006; see also chapter 6).

The exclusion of fisheries activities from wind farms and their safety buffers may have positive effects within the closed areas (e.g. Jaworski et al., 2006), but also negative effects outside the wind farm borders due to a local reallocation of fishing effort (Berkenhagen et al., 2010). The effects of such reallocations on fauna inhabiting soft substrates are known as edge or fringe effects (see chapter 8).

The most detailed studies on soft substrate epibenthos and/or fish in wind farms have been carried out in Denmark, in the UK and in The Netherlands, but at different time scales and with different designs and sampling techniques. In Denmark, gill nets were combined with dredges and hydro-acoustics between turbines at distances up to 230m (Leonhard et al., 2011). The results showed changes in the fish abundances and community and in species diversity. Seven years after construction, small scale effects of single turbines were obvious, but impact effects on the wind farm scale could not be discerned from large scale population impacts. Van Deurs et al. (2013) focused on sandeels, for which negative effects on juveniles were observed. In the Netherlands (Lindeboom et al., 2011), short-term (2 years) monitoring results indicated no effects on the benthos in the sandy area between the OWEZ turbines, and only minor effects upon fish assemblages, especially near the turbines. At distances about 200 m from the turbines, there was an increase of sole, whiting and striped red mullet and a decrease of lesser weever in the wind farm in comparison to the reference areas. At the North Hoyle wind farm in the UK (Anonymous, 2005), there was no evidence of any major changes to invertebrate or fish numbers and distribution, based on trawl samples taken during the construction phase.

As in most European wind farms, the already constructed wind farms at the Thorntonbank and the Bligh Bank constitute patches of hard substrate on a seafloor dominated by sandy sediments. In the present study, we investigated whether the soft substrate epibenthos, demersal fish and benthopelagic fish living between the turbines and at the edges of the Thorntonbank and Bligh Bank wind farms have changed due to wind farm and fringe effects.

MONITORING DESIGN

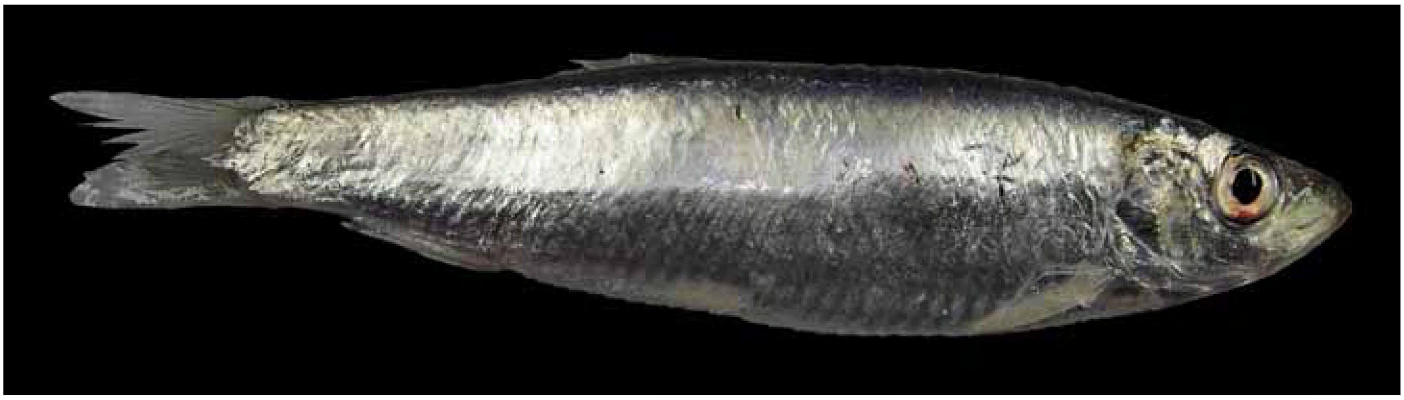
To study wind farm effects and fringe effects on the soft substrate fauna, trawl samples were taken within the wind farms, and more precisely between the turbine rows (at least 180m from the nearest turbine), just outside the edges of the concessions (fringe stations), and at reference stations well away of the concessions (Figure 1). On these track locations, fish fauna and epibenthos were sampled with an 8-meter shrimp 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. 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 were positioned following depth contours that run parallel to the coastline, thereby minimizing the depth variation within a single track. These sampling activities were repeated every six months (February-March and September-October) from 2005 to 2012 at the Thorntonbank (for construction periods, see chapter 2), and from 2008 to 2012 at the Bligh Bank (for construction periods, see chapter 2). From these samples, epifauna, demersal fish and benthopelagic fish were analysed in detail (see box 1). From 2005 onwards, the sampling design was adapted based on monitoring results and wind farm accessibility.

BOX 1: ecosystem components

Epifauna: fauna that live on a surface, such as the sea floor, other organisms, or objects. Epifauna of soft substrates are animals that live on the surface of sandy and muddy sediments, and include bivalves, snails, starfish, ophiuroids, shrimps and crabs.

Demersal fish: fish that live and feed on or near the bottom. These include flatfish such as sole and plaice, and small non-commercial species such as lesser weever and the reticulated dragonet.

Benthopelagic fish: fish that inhabit the water just above the bottom, feeding on benthos and zooplankton. These include whiting, pouting, herring, sprat and horse mackerel.



Pictures in Box1:
Common sea star *(Asterias rubens)*
Sole *(Solea solea)*
Sprat *(Sprattus sprattus)*

Figure 1. BACI sampling design showing trawl locations before construction and after construction (2012)

We tested wind farm and fringe effects for three ecosystem components (demersal fish, benthopelagic fish, epibenthos), for two seasons (autumn and spring), for two sandbank habitats (Thorntonbank and Bligh Bank) and for two subhabitats (sandbanks and gullies). Test were done on density, biomass and diversity data per ecosystem component, on community structure per ecosystem component, and on densities and size-frequencies of a selection of species.

The statistical analyses were based on the "Before After Control Impact" (BACI) design (Smith et al., 1993, see BOX 2), similar to the studies of van Deurs et al. (2013) and Leonhard et al. (2011). Since the number of years in the "after" group (i.e. years after construction) is still limited for parts of the wind farms (the jacket foundations of the Thorntonbank wind farm were constructed between 2011 and 2013) and since the BACI design does not easily pick up temporary effects, we also checked for differences between control and impact samples within particular years. The number of trawl samples included in the BACI design tests is given in table 1. Differences between treatment groups over the years were visualized using time evolution graphs. Non-parallelism in the trend lines (control versus impact) were interpreted as a possible sign of environmental impact.

				BC	BI	AC	AI
Thorntonbank	spring	wind farm effect	top	5	7	7	8
			gully	7	2	10	2
		fringe effect	gully	7	4	10	8
	autumn	wind farm effect	top	4	5	9	15
			gully	4	1	2	13
		fringe effect	gully	4	2	13	11
Bligh Bank	spring	wind farm effect	top	2	2	6	2
			gully	8	2	12	4
		fringe effect	gully	8	4	12	4
	autumn	wind farm effect	top	2	1	8	5
			gully	7	2	16	5
		fringe effect	gully	7	2	16	8

Table 1. Indication of the number of trawl samples included in each BACI test per treatment (BC: Before-Control; BI: Before-Impact; AC: After-Control; AI: After-Impact)

BOX 2: before after control impact – BACI

The BACI design describes an experimental approach and analytical method to trace environmental effects from substantial man-made changes to the environment. The aim of the method is to estimate the state of the environment before and after (BA) any change and further to compare changes at reference sites (or control sites) with the actual area of impact (wind farm area) (CI). In this approach, an impact, if it exists, can be detected as a statistical interaction in the difference between the impacted and control locations from before to after the disturbance. Graphically, evidence of an environmental impact is the non-parallelism of the response between the control and the treatment sites. In the figure to the right (Schwarz, 1998), the results in the first row above both show no environmental impact; the results in the bottom row all show evidence of an environmental impact.

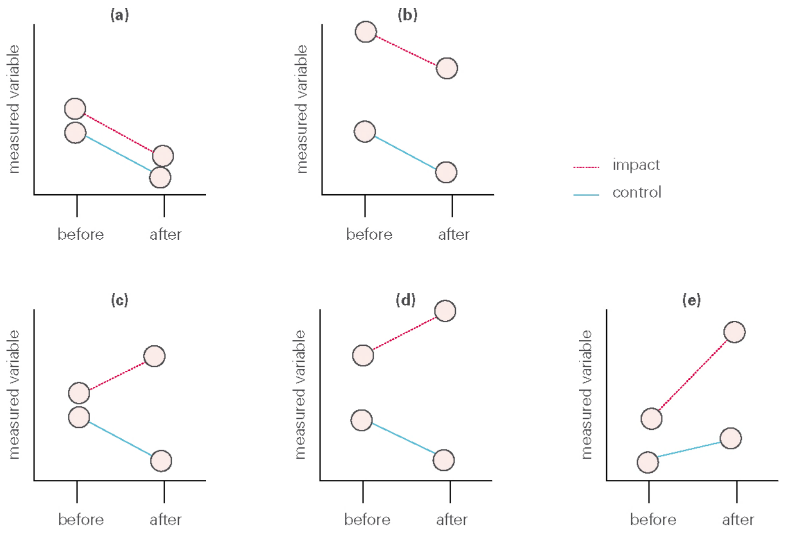


Figure 2. Summary of the results of the statistical analyses. Red text indicates significant effects (p<0.05) of the BACI interaction term. Blue text indicates significant CI effects within specific years (BACI effect not significant). Arrows indicate increase or decrease.

		THORNTONBANK WIND FARM					
		Spring			Autumm		
		Wind farm effect		Fringe effect	Wind farm effect		Fringe effect
		top	gully	gully	top	gully	gully
COMMUNITY LEVEL	Density						
	Biomass			epibenthos (BACI) ↑	epibenthos (2009) ↑		
	Species number					demersal fish (2008) ↓	
	Species composition						
SPECIES LEVEL	Density						
	Mean lenghth			whiting (BACI) ↑	dab (2011) ↓		

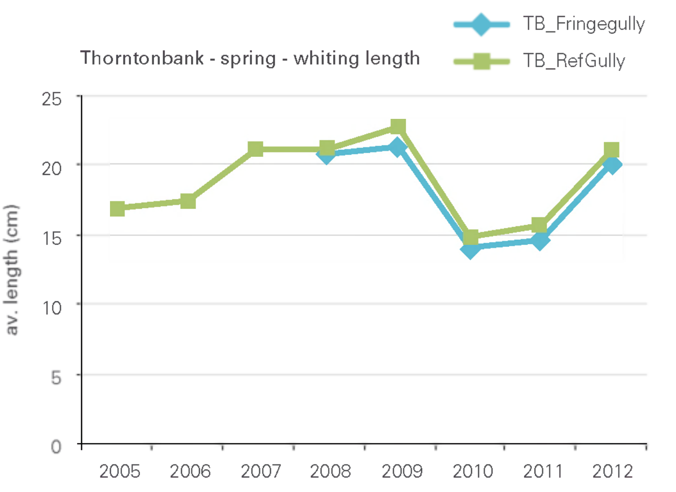
		BLIGH BANK WIND FARM					
		Spring			Autumm		
		Wind farm effect		Fringe effect	Wind farm effect		Fringe effect
		top	gully	gully	top	gully	gully
COMMUNITY LEVEL	Density						
	Biomass	epibenthos (BACI) ↑			epibenthos (BACI) ↑		
	Species number						
	Species composition					demersal fish (2012)	
SPECIES LEVEL	Density	Sea star, sole (BACI) ↑		sole (2012), dab (2012) ↑	sole (2012), dab (2012) ↑	sandeel (2012), ophiuroids (2009), urchin (2009) ↓	
	Mean lenghth						

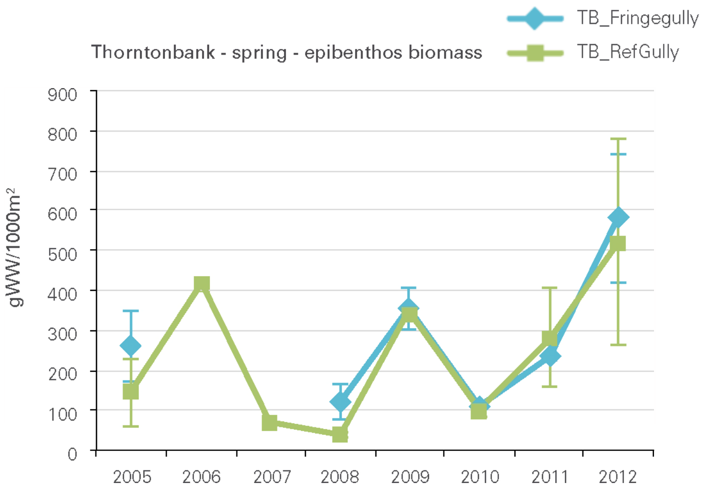
FRINGE EFFECTS

Thorntonbank

Two significant fringe effects were observed at the Thorntonbank: increase of epibenthos biomass and whiting length (Figure 2). However, analysis of these results together with time series graphs and length frequency results (not shown) suggests that the differences were minor.

Figure 3. Time series graphs of whiting length (average length in cm ± SE) and epibenthos biomass (average g wet weight per 1000m² of seafloor ± SE) at the Thorntonbank in spring

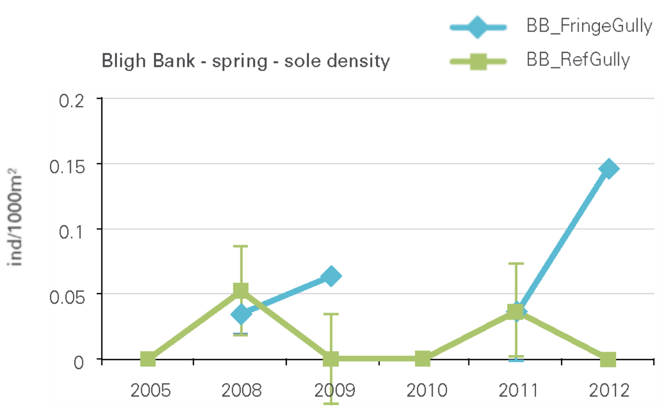


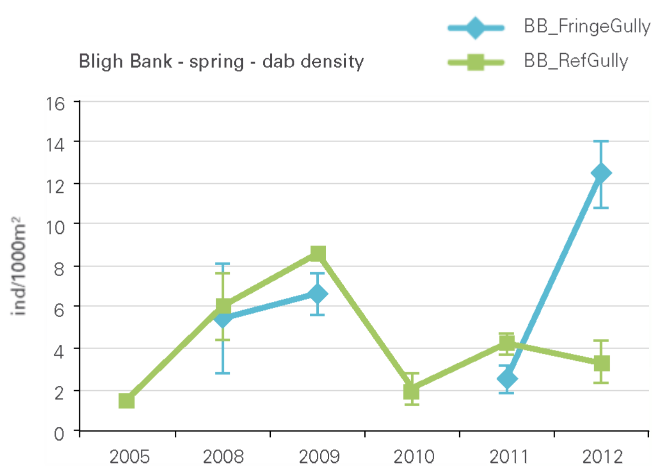


Bligh Bank

At the Bligh bank wind farm, effects between fringe and control stations were only seen for sole (*Solea solea*) and dab *(Limanda limanda)* densities in spring 2012 (Figure 2 and 4). In both cases, the non-parallelisms between fringe and reference stations were striking and higher densities were observed in the fringe stations. However, these differences did not result in a BACI effect, so they might be either temporary or the first signs of a persistent fringe effect. These results indicate that fringe effects just outside the wind farm concessions could not be shown at this time.

Figure 4. Time series graphs of sole density (average number of individuals per 1000m² ± SE) and dab density at the Bligh Bank in spring



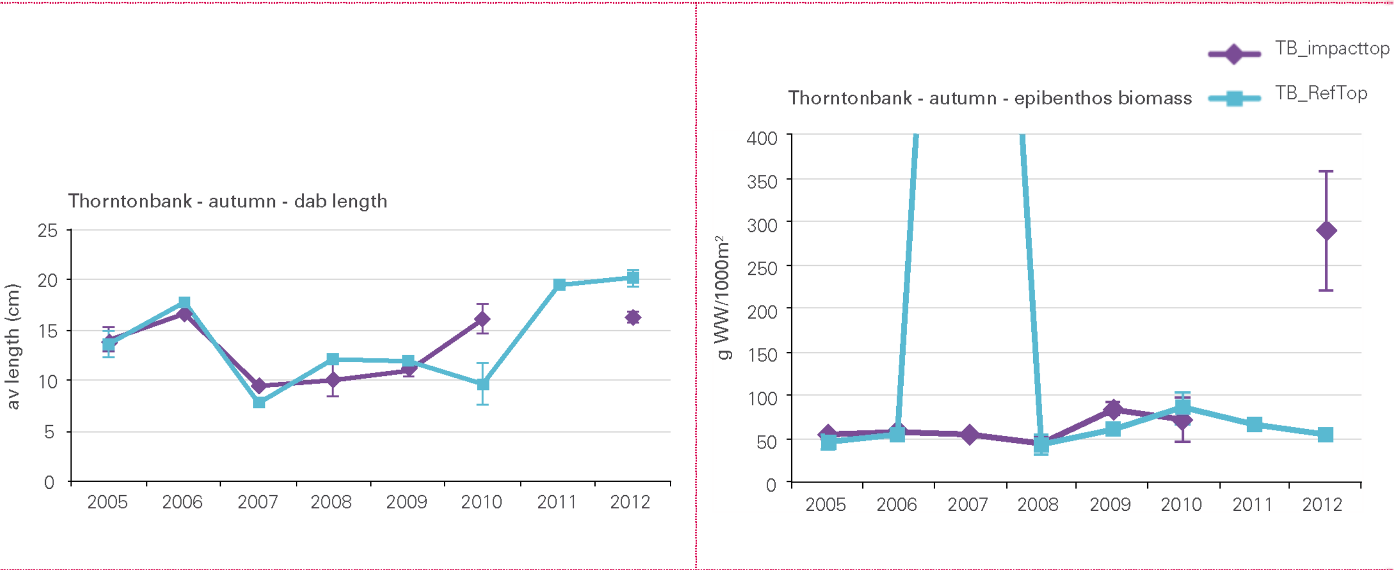


WIND FARM EFFECTS

Thorntonbank

At the Thorntonbank, no significant wind farm effects were observed with BACI analyses. However, significant differences between wind farm control and impacts stations were observed within particular years for dab mean length (2012), epibenthos biomass (2009), and species number of demersal fish (2009) (Figure 5). Epibenthos biomass was higher at the wind farm top stations in 2009 and 2012, but only the difference in 2009 turned out to be significant. In autumn 2008, the number of species within the demersal fish was lower at the impact gully station than at the reference stations, but this result was based on only 3 fish tracks.

Figure 5. Time series graphs dab length (average length in cm ± SE) and epibenthos biomass (average g wet weight per 1000m² ± SE)

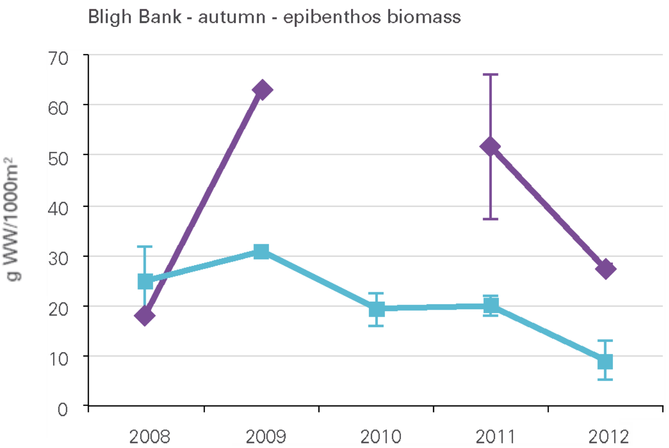


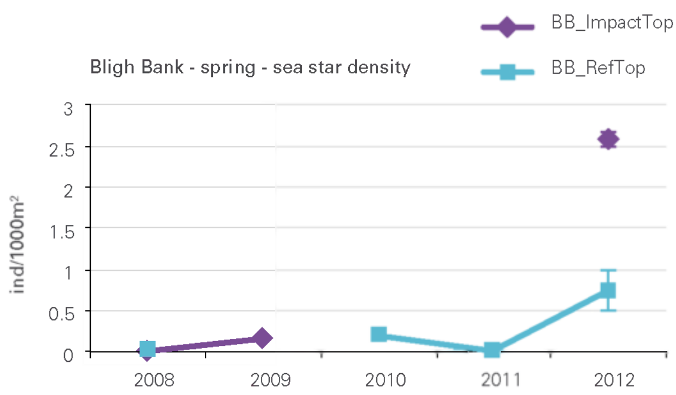
Bligh Bank

Within the Bligh Bank data, a large number of non-parallelisms were observed within the time series of ecosystem and species parameters. Only a few of these turned out to be significant within the BACI framework:

- An increase in epibenthos biomass at the sandbank top stations within the wind farm, both in autumn and spring (Figure 6)
- Increases in the spring densities of the common sea star (*Asterias rubens*) at the sandbank top stations within the wind farm (Figure 6). Strongly increased numbers of sea stars were also observed at the gully stations, both at the Bligh Bank and the Thorntonbank (not significant). Densities were highest in 2011 at the Bligh Bank, and in 2012 at the Thorntonbank, i.e. 2 years after construction (not taking into account the gravity based foundations built in 2008). Comparison of density data and biomass data for this species, indicated that the increases seen in the gullies were mainly due to a recruitment of small individuals. At the sandbank tops, trends in density and biomass were similar.
- Increases in the densities of sole at the sandbank top stations within the wind farm, caused by the presence of some young individuals (16 – 22 cm) at the impact stations in 2012 and the total absence of sole at the reference stations.

Figure 6. Time series graphs of epibenthos biomass (average g wet weight per 1000m² ± SE) and sea star sole densities (average number of individuals per 1000m² ± SE) at the Bligh Bank

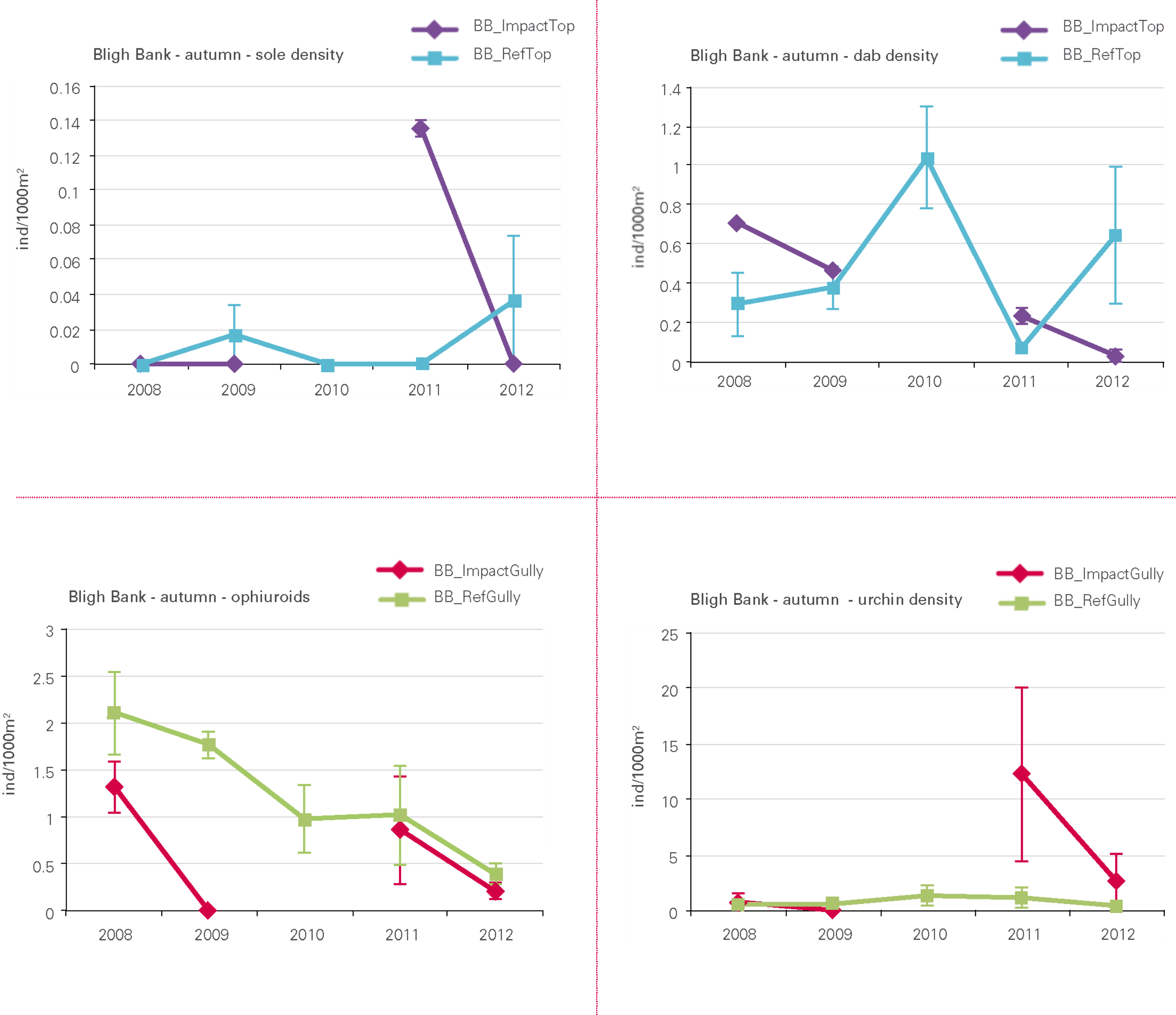




Non-significant BACI-effects, but effects within specific years were observed for a number of factors (Figure 7):

- Dab and sole densities in autumn 2011 were relatively high at the impact top stations, but were again lower in 2012.
- The demersal fish species composition within the gullies of the Bligh Bank was significantly different from the one found at the reference stations in autumn 2012, which was mainly due to different proportions of solenette (*Buglossidium luteum*), sandeel (*Ammodytes tobianus*) and dragonet (*Callionymus lyra*). Only the differences in sandeel were significant.
- In 2009, densities of ophiuroids (*Ophiura ophiura*) and urchins (*Psammechinus miliaris*) were lower at impact stations compared to reference stations. Such a decrease in autumn 2009 (during piling activities) was also seen for squid (*Allotheutis subulata*), dragonet and dab, although not significant. For urchins, densities then spectacularly increased in 2011 – 2012 both in autumn and spring. A similar trend, although less strong was seen for ophiuroids and hermit crabs (*Pagurus bernhardus*). High numbers of young ophiuroids and sea stars, and clusters of urchins have also been observed on and near the turbines (F. Kerckhof, pers. comm.), so the observations from the surrounding soft substrates are probably the direct result of the presence of hard substrates. Especially for the urchins, which feeds predominantly on seaweed, hydroids, bryozoans and barnacles, the presence of hard substrates is of great importance. The increased densities, especially in the gullies, may result from dislodgment from the turbines and from the presence of coarse sediments around the wind turbines, which is the preferred habitat for green sea urchins. Additionally, urchins are prone to physical damage by trawling (Lokkeborg, 2005), so this species profits from the absence of beam trawl fisheries within the wind farm.
- Sandeel densities (*Ammodytes tobianus*) were lower at the impact gully stations in autumn 2012. Trends in sandeel are discussed in more detail in the next paragraph.

Figure 7. Time series graphs of sole, dab, ophiuroid and urchin densities (average number of individuals per 1000m² ± SE) at the Bligh Bank



Urchin *Psammechinus miliaris* at the Bligh Bank wind farm

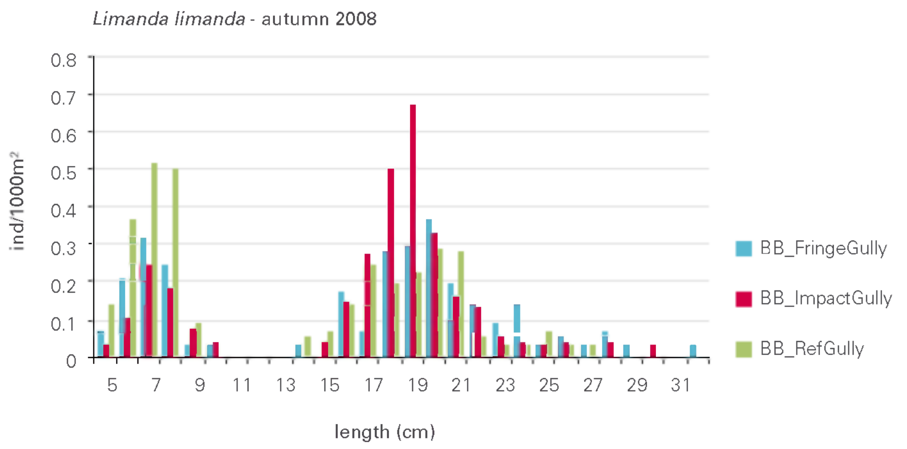
We also made some observations that were not picked up by the statistical analyses but that are worth mentioning in the context of wind farm effects:

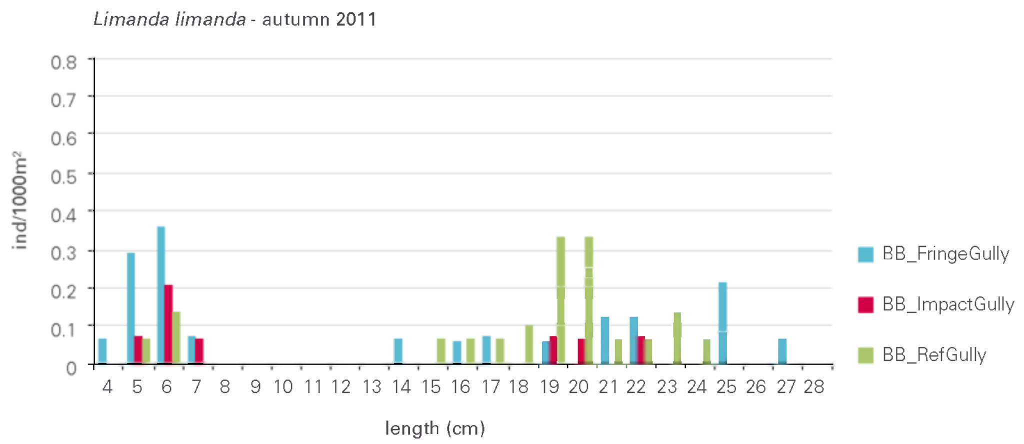
- For plaice (*Pleuronectes platessa*) density, there was a general increase in numbers over the years (Figure 8). In 2011, this trend was broken at the fringe stations, but again restored in 2012. In 2012, numbers had decreased in the impact gully stations, while numbers at other gully stations had increased. Plaice also seemed to be slightly bigger at the impact stations of the Bligh Bank in 2011 – 2012. No dramatic shifts in population structure were observed based on length-frequency analyses, but we did observe a small number of quite large animals (30-43cm), which had an important influence on the average length calculations. The presence of large plaice was also noted during diving operations in the Bligh Bank wind farm (J. Reubens, pers. comm.), and indicate a refugium effect for flatfish. This refuge hypothesis is also applicable to turbot (*Psetta maxima*). Although the time series analysis for this flatfish species was based on very few specimens, comparisons with catches elsewhere in the Belgian part of the North Sea suggest that wind farms might influence the density and size of this species: 4 out of 13 specimens caught in the Belgian part of the North Sea in 2011, for example, originated from inside the wind farm. These four turbots had an average length of 34 cm, while the average length of all other specimens was 23 cm.

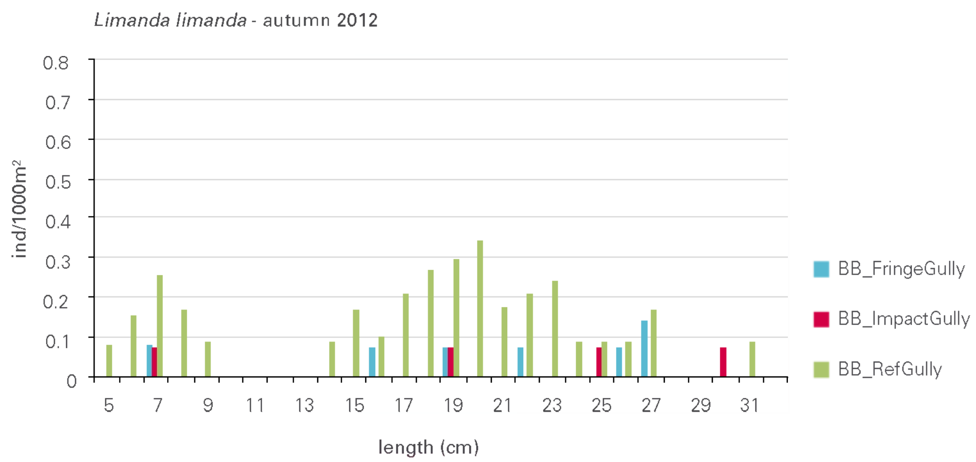
Figure 8. Time series graph of plaice density (individuals per 1000 m²) at the Bligh Bank

- The average length of dab was quite small in the impact gully stations in autumn 2011. When taking a closer look at the length-frequency distributions (Figure 9), we saw that, throughout the years, two size classes could be distinguished in dab for the reference stations. In autumn 2011, the number of fish from the larger size class was strongly reduced in fringe and impact stations. In autumn 2012, numbers were reduced in both size classes. It appears that dab is moving away from the fringe and impact stations, initially only larger fish, but recently also the smallest fish have mostly gone. This was confirmed by the density evolution graphs, that show decreasing densities at the impact stations, but also at the fringe stations. In spring 2012, it seemed to be the other way round: densities at reference stations remained similar, but the ones at impact and fringe stations increased.

Figure 9. Length distributions of dab (average number of individuals per 1000m² per cm size class) at the Bligh Bank gully stations in autumn 2008 – 2011 - 2012

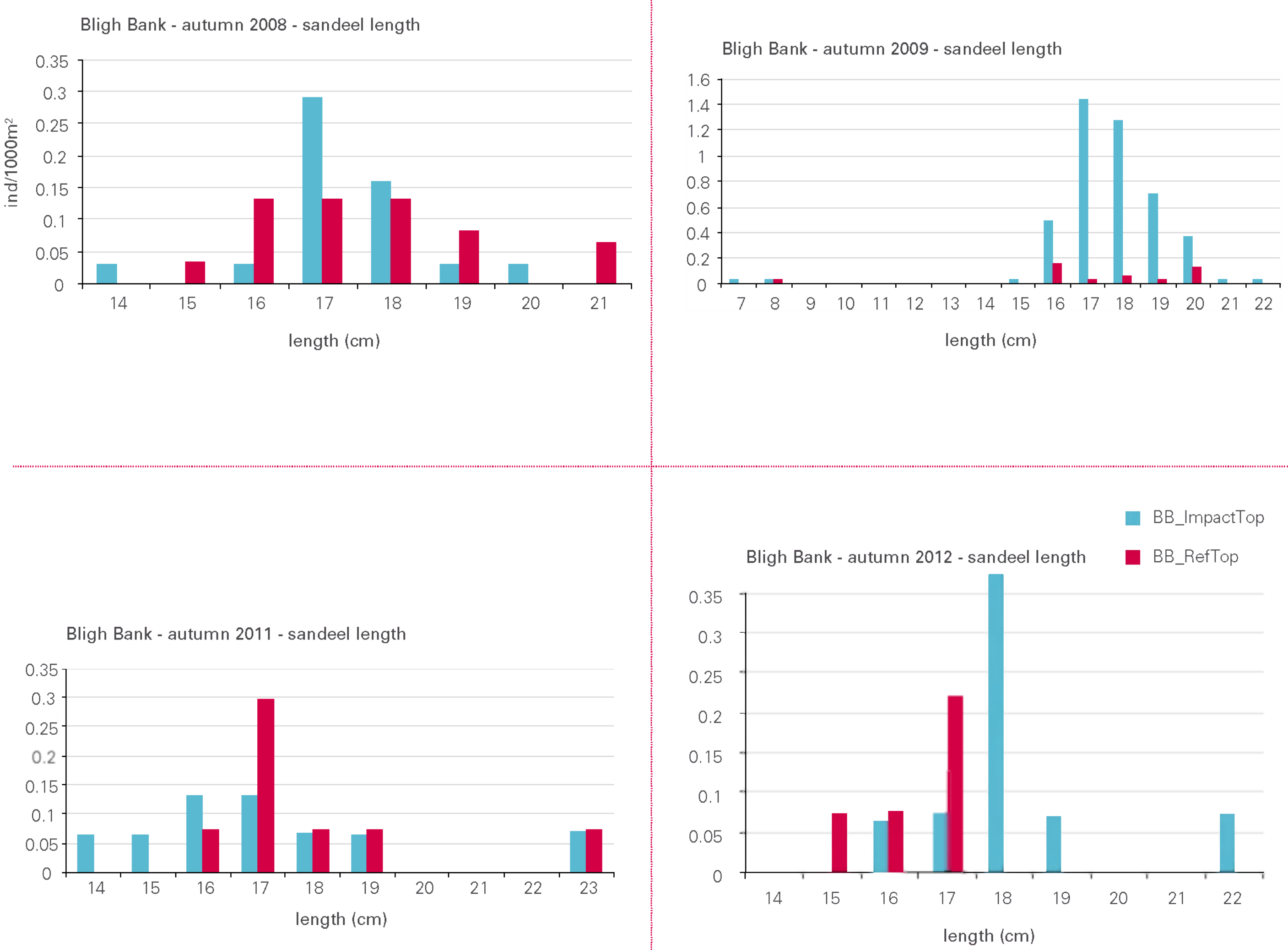






- The changes in sandeel (*Ammodytes tobianus*) size and density were not significant in the BACI design (except for impact gully stations in 2012, see above), but a few striking non-parallelism were seen in the density and size evolution graphs of the sandbank top stations. In 2008, the length frequency distribution was similar for all stations groups. In 2009 (during piling activities), the average length was similar, but we observed much higher densities of adults (>10cm) at the impact stations on the sandbank top. In 2010, no samples could be taken. In 2011, we observed more relatively small adult sandeels at the impact stations, while they were larger in 2012 (Figure 10).

Figure 10. Length distributions of sandeel (average number of individuals per 1000m² per cm size class) at the Bligh Bank top stations in autumn 2008-2009-2011-2012



Other than changes in size distribution over the years, we observed episodic increases of sandeel at both wind farms in both seasons at the sandbank top impact stations (Figure 11). This may be due to changes in the recruitment and pelagic activity of these fish (Van Deurs et al., 2012), but since effects on sandeel have been registered at the Horns Rev I wind farm in Denmark, density and size should be followed closely. At Horns Rev, increases during and shortly after construction were attributed to changes in grain size and in predator abundance (Leonhard et al., 2011; Van Deurs et al., 2012). Lindeboom et al. (2011) found no indications of wind farm avoidance by sandeels. Future development in the sandeel populations may be influenced by the development of the biological community at the hard substrate, resulting in an increasing number of predators attracted to the area (Anonymous, 2006). Consequently, a future focus on sandeels in the monitoring program is advised, including a sampling strategy that is more suitable for quantitative estimations of this species' densities.

Figure 11. Time series graph of sandeel densities (average number of individuals per 1000m² ± SE) at the Bligh Bank and Thorntonbank top stations

- Lobsters (*Homarus gammarus*) visit rocky habitats in search for shelter and food, thereby performing extensive migrations and using artificial hard substrata as stepping stones within extensive soft bottom areas (Krone et al.., 2013b). They have occasionally been observed by divers in a Swedish wave farm (Langhamer et al.., 2009) and at the scour protections of the gravity based foundations in Belgium (J. Reubens and A. Norro, pers. comm.). They were however not caught on Belgian soft substrates during monitoring campaigns in the last decade. In autumn 2012, a lobster strayed from the wind farm hard substrates into the sandy area between the turbine rows of the Thorntonbank wind farm. Such observations suggest that the reef effects caused by each turbine are expanding into the soft substrates between the turbine rows.

Thorntonbank trawl catch containing a lobster

CONCLUSIONS

All considered, some remarkable differences between wind farm impact and control stations were observed. The analyses revealed some wind farm effects in autumn 2009 at the Bligh Bank (e.g. decreases in dab, ophiuroids, squid and dragonet and increase in sandeel). At that time, the stations were sampled only weeks after the start of piling activities, so the observed changes were probably short lived construction effects. As for post-construction effects, we saw changes in demersal fish composition, a decrease in demersal fish species number, and an increase in epibenthos biomass. The changes in demersal fish may have resulted from the absence of fisheries in the area or local changes in sedimentology and infaunal communities. For commercially important flatfish, we observed higher densities (sole) and/or changes in length-frequency distribution (dab, plaice). This may signal a refugium effect, but bearing in mind that large flatfish such as sole do not stay within a wind farm for longer periods (Lindeboom et al., 2011), this effect will be limited. Dab on the other hand seemed to move away from the wind farms. The increase in epibenthos (e.g. sea stars, urchins, hermit crabs) probably resulted from the presence of hard substrates and their fouling communities and from the absence of fisheries. The increase, however, was mainly seen for dominant, scavenging species such as echinoderms and hermit crabs. Signs of recovery of populations of long living species vulnerable to trawling, as was seen for *Ostrea edulis* and *Sertularia cupressina* at Horns Rev (Anonymous, 2006), have not yet been observed at the soft substrates of Belgian wind farms.

Importantly, the observed effects were not consistent between wind farms. This weakens the BACI results, but is not surprising, given the differences in communities (De Backer et al., 2010), in sandbank topography (see chapter 2 and 4), in (historic) fisheries pressure (see chapter 8), differences in age of the wind farms and types of foundations used (see chapter 2). This inconsistency stresses the importance to replicate the monitoring activities across wind farms along the identified gradients.

Fringe effects could not be shown, both at the Thorntonbank and Bligh Bank wind farm. So, based on biological data on epibenthos and fish, we did not observe effects of changing fisheries activities in the area or overflow effects from the closed area constituted by the wind farms.

Even though the used design is appropriate for this type of impact studies, we still want to point out some considerations that were taken into account during the interpretation of the results. First, there is the risk of false positives in multiple testing. We tested two effects, three ecosystem components, two seasons, two sandbank habitats, and two subhabitats. Test were done on density, biomass and diversity data per ecosystem component, on community structure per ecosystem component, and on densities and size-frequencies of a selection of species. As more attributes are compared, it becomes more likely that the impact and control groups will appear to differ on at least one attribute by random chance alone (e.g. Benjamini & Hochberg, 1995; Verhoeven et al., 2005). Since this is an exploratory study, we did not correct for that at this time. Even then, the observed differences and trends were seldom statistically significant within the BACI framework. This is probably due to a number of factors. First, there is the limited number of post-construction observations (1 year for the Thorntonbank wind farm Phase 2, 2 years for the Bligh Bank wind farm), which strongly limits the power of the analyses. Additionally, it takes around three to five years before stable faunal communities are established after deployment of artificial hard structures (Jensen, 2002; Gray, 2006; Petersen & Malm, 2006), so the effects are likely to become more pronounced in the coming years. Secondly, the sampling distance relative to the turbines (>180m) is large as tracks are situated between turbine rows. The studies of Bergström et al. (2012, 2013) and of Wilhemsson et al. (2006) indicated that increased densities were limited to a radius of 20-160m from swedish turbines, depending on species and that smaller scale studies may be needed to document increases. For the Belgian case study, this may mean that increases between the turbine rows will remain very limited or that it will take a lot of time for the reef effects to expand into the space between turbine rows. Finally, the BACI design does not easily pick up small and gradual changes, so temporary effects or effects with a time lag relative to the actual impact can only be traced by careful and detailed analyses of the available data, taking into account the limitations of the design and the methodology.

FUTURE MONITORING

The results of the analyses indicate that it is essential to further extend the time series within the same design, and to replicate across wind farms along identified gradients. This will increase the power of the tests and shed light on the maturation of the new wind farm system. With time, wind farm effects are expected to extend increasingly into the soft substrates surrounding each turbine and each concession zone. The analyses also indicate that we should closely follow-up on wind farm effects concerning epibenthos, demersal flatfish and sandeel, and especially on species-specific information on length and density.
Based on the presented results, fringe effects could not be shown. Such effects may still occur in the following years and can be traced by an integrated analysis of biological data (as in the present study) and vessel monitoring system data (VMS) of Belgian and foreign vessels fishing in the eastern section of the Belgian part of the North Sea (Vandendriessche et al., 2011).